Radio Regulations

ITU-R Recommendations
incorporated by reference

Radio Regulations

ITU-R Recommendations incorporated by reference

Edition of 2012

Note by the Secretariat

This revision of the Radio Regulations, complementing the Constitution and the Convention of the International Telecommunication Union, incorporates the decisions of the World Radio-communication Conferences of 1995 (WRC-95), 1997 (WRC-97), 2000 (WRC-2000), 2003 (WRC-03), 2007 (WRC-07) and 2012 (WRC-12). The majority of the provisions of these Regulations shall enter into force as from 1 January 2013; the remaining provisions shall apply as from the special dates of application indicated in Article **59** of the revised Radio Regulations.

In preparing the Radio Regulations, Edition of 2012, the Secretariat corrected the typographical errors that were drawn to the attention of WRC-12 and which were approved by WRC-12.

This edition uses the same numbering scheme as the 2001 edition of the Radio Regulations, notably:

With respect to *Article numbers*, this edition follows the standard sequential numbering. The Article numbers are not followed by any abbreviation (such as "(WRC-97)", "(WRC-2000)", "(WRC-03)", "(WRC-07)" or "(WRC-12)"). Consequently, any reference to an Article, in any of the provisions of these Radio Regulations (e.g. in No. **13.1** of Article **13**), in the texts of the Appendices as contained in Volume 2 of this edition (e.g. in § 1 of Appendix **2**), in the texts of the Resolutions included in Volume 3 of this edition (e.g. in Resolution **1 (Rev.WRC-97)**), and in the texts of the Recommendations included in Volume 3 of this edition (e.g. in Recommendation **8**), is considered as a reference to the text of the concerned Article which appears in this edition, unless otherwise specified.

With respect to *provision numbers in Articles*, this edition continues to use composite numbers indicating the number of the Article and the provision number within that Article (e.g. No. 9.2B means provision No. 2B of Article **9**). The abbreviation "(WRC-12)", "(WRC-07)", "(WRC-03)", "(WRC-2000)" or "(WRC-97)" at the end of such a provision means that the relevant provision was modified or added by WRC-12, by WRC-07, by WRC-03, by WRC-2000 or by WRC-97, as applicable. The absence of an abbreviation at the end of the provision means that the provision is identical with the provision of the simplified Radio Regulations as approved by WRC-95, and whose complete text was contained in Document 2 of WRC-97.

With respect to *Appendix numbers*, this edition follows the standard sequential numbering, with the addition of the appropriate abbreviation after the Appendix number (such as "(WRC-97)", "(WRC-2000)", "(WRC-03)", "(WRC-07)" or "(WRC-12)"), where applicable. As a rule, any reference to an Appendix, in any of the provisions of these Radio Regulations, in the texts of the Appendices as contained in Volume 2 of this edition, in the texts of the Resolutions and of the Recommendations included in Volume 3 of this edition, is presented in the standard manner (e.g. "Appendix **30 (Rev.WRC-12)**") if not explicitly described in the text (e.g. Appendix **4** as modified by WRC-12). In the texts of Appendices that were partially modified by WRC-12, the provisions that were modified by WRC-12 are indicated with the abbreviation "(WRC-12)" at the end of the concerned text. If an Appendix is referenced without any abbreviation after the Appendix number, in the texts of this edition (e.g., in No. **13.1**), or without other description, such reference is considered as a reference to the text of the concerned Appendix which appears in this edition.

Within the text of the Radio Regulations, the symbol, ↑, has been used to represent quantities associated with an uplink. Similarly, the symbol, ↓, has been used to represent quantities associated with a downlink.

Abbreviations have generally been used for the names of world administrative radio conferences and world radiocommunication conferences. These abbreviations are shown below.

Abbreviation	Conference
WARC Mar	World Administrative Radio Conference to Deal with Matters Relating to the Maritime Mobile Service (Geneva, 1967)
WARC-71	World Administrative Radio Conference for Space Telecommunications (Geneva, 1971)
WMARC-74	World Maritime Administrative Radio Conference (Geneva, 1974)
WARC SAT-77	World Broadcasting-Satellite Administrative Radio Conference (Geneva, 1977)
WARC-Aer2	World Administrative Radio Conference on the Aeronautical Mobile (R) Service (Geneva, 1978)
WARC-79	World Administrative Radio Conference (Geneva, 1979)
WARC Mob-83	World Administrative Radio Conference for the Mobile Services (Geneva, 1983)
WARC HFBC-84	World Administrative Radio Conference for the Planning of the HF Bands Allocated to the Broadcasting Service (Geneva, 1984)
WARC Orb-85	World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilising It (First Session – Geneva, 1985)
WARC HFBC-87	World Administrative Radio Conference for the Planning of the HF Bands Allocated to the Broadcasting Service (Geneva, 1987)
WARC Mob-87	World Administrative Radio Conference for the Mobile Services (Geneva, 1987)
WARC Orb-88	World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilising It (Second Session – Geneva, 1988)
WARC-92	World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992)
WRC-95	World Radiocommunication Conference (Geneva, 1995)
WRC-97	World Radiocommunication Conference (Geneva, 1997)
WRC-2000	World Radiocommunication Conference (Istanbul, 2000)
WRC-03	World Radiocommunication Conference, (Geneva, 2003)
WRC-07	World Radiocommunication Conference, (Geneva, 2007)
WRC-12	World Radiocommunication Conference, (Geneva, 2012)
WRC-15	World Radiocommunication Conference, 2015[1]

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[1] The date of this conference has not been finalized.

VOLUME 4

ITU-R Recommendations incorporated by reference[*]

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[*] In some of these Recommendations, which were adopted prior to 1 January 2001, the prefix "S" before the references to RR is still maintained until the concerned Recommendation is modified according to the standard procedures.

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RECOMMENDATION ITU-R TF.460-6[*]

Standard-frequency and time-signal emissions

(Question ITU-R 102/7)

(1970-1974-1978-1982-1986-1997-2002)

The ITU Radiocommunication Assembly,

considering

a)   that the World Administrative Radio Conference, Geneva, 1979, allocated the frequencies 20 kHz ± 0.05 kHz, 2.5 MHz ± 5 kHz (2.5 MHz ± 2 kHz in Region 1), 5 MHz ± 5 kHz, 10 MHz ± 5 kHz, 15 MHz ± 10 kHz, 20 MHz ± 10 kHz and 25 MHz ± 10 kHz to the standard-frequency and time-signal service;

b)   that additional standard frequencies and time signals are emitted in other frequency bands;

c)   the provisions of Article 26 of the Radio Regulations;

d)   the continuing need for close cooperation between Radiocommunication Study Group 7 and the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the General Conference of Weights and Measures (CGPM), the Bureau International des Poids et Mesures (BIPM), the International Earth Rotation Service (IERS) and the concerned Unions of the International Council of Scientific Unions (ICSU);

e)   the desirability of maintaining worldwide coordination of standard-frequency and time-signal emissions;

f)   the need to disseminate standard frequencies and time signals in conformity with the second as defined by the 13th General Conference of Weights and Measures (1967);

g)   the continuing need to make universal time (UT) immediately available to an uncertainty of one-tenth of a second,

recommends

1   that all standard-frequency and time-signal emissions conform as closely as possible to coordinated universal time (UTC) (see Annex 1); that the time signals should not deviate from UTC by more than 1 ms; that the standard frequencies should not deviate by more than 1 part in 10^{10}, and that the time signals emitted from each transmitting station should bear a known relation to the phase of the carrier;

2   that standard-frequency and time-signal emissions, and other time-signal emissions intended for scientific applications (with the possible exception of those dedicated to special systems) should contain information on UT1 − UTC and TAI − UTC (see Annex 1).

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[*]   This Recommendation should be brought to the attention of the IMO, the ICAO, the CGPM, the BIPM, the IERS, the International Union of Geodesy and Geophysics (IUGG), the International Union of Radio Science (URSI) and the International Astronomical Union (IAU).

ANNEX 1

Time scales

A   Universal time (UT)

Universal time (UT) is the general designation of time scales based on the rotation of the Earth.

In applications in which an imprecision of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of UT which should be used:

UT0   is the mean solar time of the prime meridian obtained from direct astronomical observation;

UT1   is UT0 corrected for the effects of small movements of the Earth relative to the axis of rotation (polar variation);

UT2   is UT1 corrected for the effects of a small seasonal fluctuation in the rate of rotation of the Earth;

UT1   is used in this Recommendation, since it corresponds directly with the angular position of the Earth around its axis of diurnal rotation.

Concise definitions of the above terms and the concepts involved are available in the publications of the IERS (Paris, France).

B   International atomic time (TAI)

The international reference scale of atomic time (TAI), based on the second (SI), as realized on the rotating geoid, is formed by the BIPM on the basis of clock data supplied by cooperating establishments. It is in the form of a continuous scale, e.g. in days, hours, minutes and seconds from the origin 1 January 1958 (adopted by the CGPM 1971).

C   Coordinated universal time (UTC)

UTC is the time-scale maintained by the BIPM, with assistance from the IERS, which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with TAI but differs from it by an integer number of seconds.

The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap-seconds) to ensure approximate agreement with UT1.

D   DUT1

The value of the predicted difference UT1 – UTC, as disseminated with the time signals is denoted DUT1; thus DUT1 ≈ UT1 – UTC. DUT1 may be regarded as a correction to be added to UTC to obtain a better approximation to UT1.

The values of DUT1 are given by the IERS in multiples of 0.1 s.

The following operational rules apply:

1   Tolerances

1.1   The magnitude of DUT1 should not exceed 0.8 s.

1.2   The departure of UTC from UT1 should not exceed ±0.9 s (see Note 1).

1.3   The deviation of (UTC plus DUT1) should not exceed ±0.1 s.

NOTE 1 – The difference between the maximum value of DUT1 and the maximum departure of UTC from UT1 represents the allowable deviation of (UTC + DUT1) from UT1 and is a safeguard for the IERS against unpredictable changes in the rate of rotation of the Earth.

2   Leap-seconds

2.1   A positive or negative leap-second should be the last second of a UTC month, but first preference should be given to the end of December and June, and second preference to the end of March and September.

2.2   A positive leap-second begins at 23h 59m 60s and ends at 0h 0m 0s of the first day of the following month. In the case of a negative leap-second, 23h 59m 58s will be followed one second later by 0h 0m 0s of the first day of the following month (see Annex 3).

2.3   The IERS should decide upon and announce the introduction of a leap-second, such an announcement to be made at least eight weeks in advance.

3   Value of DUT1

3.1   The IERS is requested to decide upon the value of DUT1 and its date of introduction and to circulate this information one month in advance. In exceptional cases of sudden change in the rate of rotation of the Earth, the IERS may issue a correction not later than two weeks in advance of the date of its introduction.

3.2   Administrations and organizations should use the IERS value of DUT1 for standard-frequency and time-signal emissions, and are requested to circulate the information as widely as possible in periodicals, bulletins, etc.

3.3   Where DUT1 is disseminated by code, the code should be in accordance with the following principles (except § 3.4 below):

–   the magnitude of DUT1 is specified by the number of emphasized second markers and the sign of DUT1 is specified by the position of the emphasized second markers with respect to the minute marker. The absence of emphasized markers indicates DUT1 = 0;

–   the coded information should be emitted after each identified minute if this is compatible with the format of the emission. Alternatively the coded information should be emitted, as an absolute minimum, after each of the first five identified minutes in each hour.

Full details of the code are given in Annex 2.

3.4   DUT1 information primarily designed for, and used with, automatic decoding equipment may follow a different code but should be emitted after each identified minute if this is compatible with the format of the emission. Alternatively, the coded information should be emitted, as an absolute minimum, after each of the first five identified minutes in each hour.

3.5   Other information which may be emitted in that part of the time-signal emission designated in § 3.3 and 3.4 for coded information on DUT1 should be of a sufficiently different format that it will not be confused with DUT1.

3.6   In addition, UT1 – UTC may be given to the same or higher precision by other means, for example, by messages associated with maritime bulletins, weather forecasts, etc.; announcements of forthcoming leap-seconds may also be made by these methods.

3.7   The IERS is requested to continue to publish, in arrears, definitive values of the differences UT1 – UTC and UT2 – UTC.

E   DTAI

The value of the difference TAI – UTC, as disseminated with time signals, shall be denoted DTAI. DTAI = TAI – UTC may be regarded as a correction to be added to UTC to obtain TAI.

The TAI – UTC values are published in the BIPM Circular T. The IERS should announce the value of DTAI in integer multiples of one second in the same announcement as the introduction of a leap-second (see § D.2).

<div align="center">

ANNEX 2

Code for the transmission of DUT1

</div>

A positive value of DUT1 will be indicated by emphasizing a number, n, of consecutive second markers following the minute marker from second marker one to second marker, n, inclusive; n being an integer from 1 to 8 inclusive.

$$\text{DUT1} = (n \times 0.1) \text{ s}$$

A negative value of DUT1 will be indicated by emphasizing a number, m, of consecutive second markers following the minute marker from second marker nine to second marker $(8 + m)$ inclusive, m being an integer from 1 to 8 inclusive.

$$\text{DUT1} = - (m \times 0.1) \text{ s}$$

A zero value of DUT1 will be indicated by the absence of emphasized second markers.

The appropriate second markers may be emphasized, for example, by lengthening, doubling, splitting or tone modulation of the normal second markers.

Examples:

<div align="center">

FIGURE 1

DUT1 = + 0.5 s

</div>

FIGURE 2

DUT1 = − 0.2 s

Minute
marker

Emphasized
second markers

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Limit of coded sequence ⟶

0460-02
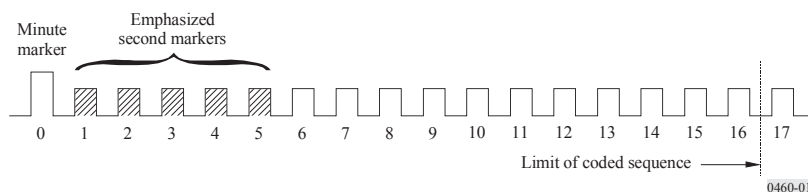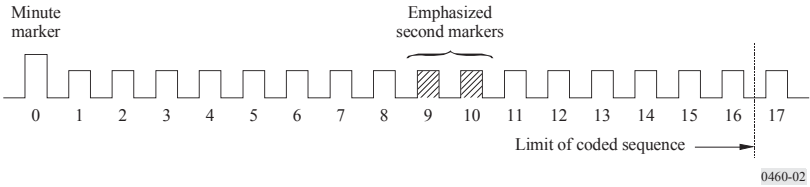
ANNEX 3

Dating of events in the vicinity of a leap-second

The dating of events in the vicinity of a leap-second shall be effected in the manner indicated in the following Figures:

FIGURE 3

Positive leap-second

event

leap-second

Designation of the date of the event

56 57 58 59 60 0 1 2 3 4

30 June, 23h 59m 60.6s UTC

30 June, 23h 59m ⟶ ⟵ 1 July, 0h 0m
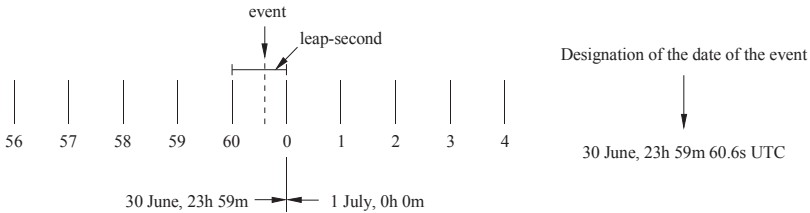
FIGURE 4

Negative leap-second

event

Designation of the date of the event

56 57 58 0 1 2 3 4 5 6

30 June, 23h 59m 58.9s UTC

30 June, 23h 59m ⟶ ⟵ 1 July, 0h 0m

0460-03
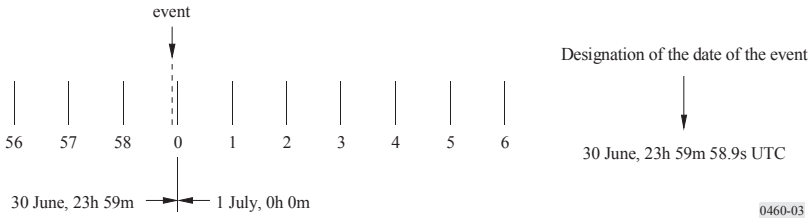
RECOMMENDATION ITU-R M.476-5*

DIRECT-PRINTING TELEGRAPH EQUIPMENT
IN THE MARITIME MOBILE SERVICE**

(Question ITU-R 5/8)

(1970-1974-1978-1982-1986-1995)

Summary

The Recommendation provides in Annex 1 characteristics for error detecting and correcting systems for existing direct-printing telegraph equipment. Annex 1 contains the technical characteristics of the transmission, the code and the modes of operation to be employed in the maritime-mobile service. New equipment should conform to Recommendation ITU-R M.625.

The ITU Radiocommunication Assembly,

considering

a)   that there is a requirement to interconnect mobile stations, or mobile stations and coast stations, equipped with start-stop apparatus employing the ITU-T International Telegraph Alphabet No. 2, by means of radiotelegraph circuits;

b)   that direct-printing telegraphy communications in the maritime mobile service can be listed in the following categories:

b.a   telegraph service between a ship and a coast station;

b.b   telegraph service between a ship and an extended station (ship's owner) via a coast station;

b.c   telex service between a ship and a subscriber of the (international) telex network;

b.d   broadcast telegraph service from a coast station to one or more ships;

b.e   telegraph service between two ships or between one ship and a number of other ships;

c)   that those categories are different in nature and that consequently different degrees of transmission quality may be required;

d)   that the categories given in b.a, b.b and b.c above may require a higher transmission quality than categories b.d and b.e for the reason that data could be handled through the services in the categories b.a, b.b and b.c, while the messages passed through the service of category b.d, and via the broadcast service of category b.e are normally plain language, allowing a lower transmission quality than that required for coded information;

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the Telecommunication Standardization Sector (ITU-T).

**   This Recommendation is retained in order to provide information concerning existing equipment, but will probably be deleted at a later date. New equipment should conform to Recommendation ITU-R M.625 which provides for the exchange of identification signals, for the use of 9 digit maritime mobile service identification signals and for compatibility with existing equipment built in accordance with this Recommendation.

Note by the Secretariat: The references made to the Radio Regulations (RR) in this Recommendation refer to the RR as revised by the World Radiocommunication Conference 1995. These elements of the RR will come into force on 1 June 1998. Where applicable, the equivalent references in the current RR are also provided in square brackets.

e)   that the service in category b.d and the broadcast service in category b.e cannot take advantage of an ARQ method, as there is in principle no return path;

f)   that for these categories of service which by their nature do not allow the use of ARQ, another mode, i.e. the forward error-correcting (FEC) mode should be used;

g)   that the period for synchronization and phasing should be as short as possible and should not exceed 5 s;

h)   that most of the ship stations do not readily permit simultaneous use of the radio transmitter and radio receiver;

j)   that the equipment on board ships should be neither unduly complex nor expensive,

recommends

1   that when an error-detecting and correcting system is used for direct-printing telegraphy in the maritime mobile service, a 7-unit ARQ system or a 7-unit forward acting, error-correcting and indicating time-diversity system, using the same code, should be employed;

2   that equipment designed in accordance with § 1 should meet the characteristics laid down in Annex 1.

ANNEX 1

1   General (Mode A, ARQ and Mode B, FEC)

1.1   The system in both Mode A (ARQ) and Mode B (FEC) is a single-channel synchronous system using the 7-unit error-detecting code as listed in § 2 of this Annex.

1.2   FSK modulation is used on the radio link at 100 Bd. The equipment clocks controlling the modulation rate should have an accuracy of better than 30 parts in 10^6.

NOTE 1 – Some existing equipments may not conform to this requirement.

1.3   The terminal input and output must be in accordance with the 5-unit start-stop ITU-T International Telegraph Alphabet No. 2 at a modulation rate of 50 Bd.

1.4   The class of emission is F1B or J2B with a frequency shift on the radio link of 170 Hz. When frequency shift is effected by applying audio signals to the input of a single-sideband transmitter, the centre frequency of the audio spectrum offered to the transmitter should be 1 700 Hz.

NOTE 1 – A number of equipments are presently in service, using a centre frequency of 1 500 Hz. These may require special measures to achieve compatibility.

1.5   The radio frequency tolerance of the transmitter and the receiver should be in accordance with Recommendation ITU-R SM.1137. It is desirable that the receiver employs the minimum practicable bandwidth (see also Report ITU-R M.585).

NOTE 1 – The receiver bandwidth should preferably be between 270 and 340 Hz.

2   Table of conversion

2.1   Traffic information signals

TABLE 1

Combi-nation No.	Letter case	Figure case	International Telegraph Alphabet No. 2 Code	Emitted 7-unit signal[1]
1	A	–	ZZAAA	BBBYYYB
2	B	?	ZAAZZ	YBYYBBB
3	C	:	AZZZA	BYBBBYY
4	D	⊠ [3]	ZAAZA	BBYYBYB
5	E	3	ZAAAA	YBBYBYB
6	F	[2]	ZAZZA	BBYBBYY
7	G	[2]	AZAZZ	BYBYBBY
8	H	[2]	AAZAZ	BYYBYBB
9	I	8	AZZAA	BYBBYYB
10	J	Audible signal	ZZAZA	BBBYBYY
11	K	(	ZZZZA	YBBBBYY
12	L	)	AZAAZ	BYBYYBB
13	M	.	AAZZZ	BYYBBBY
14	N	,	AAZZA	BYYBBYB
15	O	9	AAAZZ	BYYYBBB
16	P	0	AZZAZ	BYBBYBY
17	Q	1	ZZZAZ	YBBBYBY
18	R	4	AZAZA	BYBYBYB
19	S	'	ZAZAA	BBYBYYB
20	T	5	AAAAZ	YYBYBBB
21	U	7	ZZZAA	YBBBYYB
22	V	=	AZZZZ	YYBBBBY
23	W	2	ZZAAZ	BBBYYBY
24	X	/	ZAZZZ	YBYBBBY
25	Y	6	ZAZAZ	BBYBYBY
26	Z	+	ZAAAZ	BBYYYBB
27	← (Carriage return)		AAAZA	YYYBBBB
28	≡ (Line feed)		AZAAA	YYBBYBB
29	↓ (Letter shift)		ZZZZZ	YBYBBYB
30	↑ (Figure shift)		ZZAZZ	YBBYBBY
31	Space		AAZAA	YYBBBYB
32	Unperforated tape		AAAAA	YBYBYBB

[1]   B represents the higher emitted frequency and Y the lower.

[2]   At present unassigned (see ITU-T Recommendation F.1 C8). Reception of these signals, however, should not initiate a request for repetition.

[3]   The pictorial representation shown is a schematic of ✠ which may also be used when equipment allows (ITU-T Recommendation F.1).

2.2   Service information signals

TABLE 2

Mode A (ARQ)	Emitted signal	Mode B (FEC)
Control signal 1 (CS1)	BYBYYBB	
Control signal 2 (CS2)	YBYBYBB	
Control signal 3 (CS3)	BYYBBYB	
Idle signal β	BBYYBBY	
Idle signal α	BBBBYYY	Phasing signal 1
Signal repetition	YBBYYBB	Phasing signal 2

3   Characteristics

3.1   Mode A (ARQ) (see Figs. 1 and 2)

A synchronous system, transmitting blocks of three characters from an information sending station (ISS) towards an information receiving station (IRS), which stations can, controlled by the control signal 3 (see § 2.2), interchange their functions.

3.1.1   Master and slave arrangements

3.1.1.1   The station that initiates the establishment of the circuit (the calling station) becomes the "master" station, and the station that has been called will be the "slave" station;

this situation remains unchanged during the entire time in which the established circuit is maintained, regardless of which station, at any given time, is the information sending station (ISS) or information receiving station (IRS);

3.1.1.2   the clock in the master station controls the entire circuit (see circuit timing diagram, Fig. 1);

3.1.1.3   the basic timing cycle is 450 ms, and for each station consists of a transmission period followed by a transmission pause during which reception is effected;

3.1.1.4   the master station transmitting time distributor is controlled by the clock in the master station;

3.1.1.5   the slave station receiving time distributor is controlled by the received signal;

3.1.1.6   the slave station transmitting time distributor is phase-locked to the slave station receiving time distributor; i.e. the time interval between the end of the received signal and the start of the transmitted signal (t_E in Fig. 1) is constant;

3.1.1.7   the master station receiving time distributor is controlled by the received signal.

3.1.2   The information sending station (ISS)

3.1.2.1   Groups the information to be transmitted into blocks of three characters (3×7 signal elements), including, if necessary, "idle signals β" to complete or to fill blocks when no traffic information is available;

3.1.2.2   emits a "block" in 210 ms after which a transmission pause of 240 ms becomes effective, retaining the emitted block in memory until the appropriate control signal confirming correct reception by the information receiving station (IRS) has been received;

3.1.2.3   numbers successive blocks alternately "Block 1" and "Block 2" by means of a local numbering device. The first block should be numbered "Block 1" or "Block 2" dependent on whether the received control signal (see § 3.1.4.5) is a control signal 1 or a control signal 2. The numbering of successive blocks is interrupted at the reception of:

–   a request for repetition; or

–   a mutilated signal; or

–   a control signal 3 (see § 2.2);

3.1.2.4   emits the information of Block 1 on receipt of control signal 1 (see § 2.2);

3.1.2.5   emits the information of Block 2 on receipt of control signal 2 (see § 2.2);

3.1.2.6   emits a block of three "signal repetitions" on receipt of a mutilated signal (see § 2.2).

FIGURE 1

A-Mode operation

Selective call No. 32610 transmitted as $\boxed{\text{Q (RQ)C}}$ $\boxed{\text{XT (RQ)}}$

(see Recommendation ITU-R M.491 § 2, 3)

Basic timing cycle

a)   Start of communication
b)   Change of the direction of the traffic flow
c)   End of communication

CS: control signal
ISS: information sending station
IRS: information receiving station
RQ: signal repetition information signal

t: figure shift
t_p: (one way) propagation time
t_E: (fixed) equipment delay
*   The transmission of these signals may be omitted

D01

FIGURE 2

Mode A under error receiving conditions
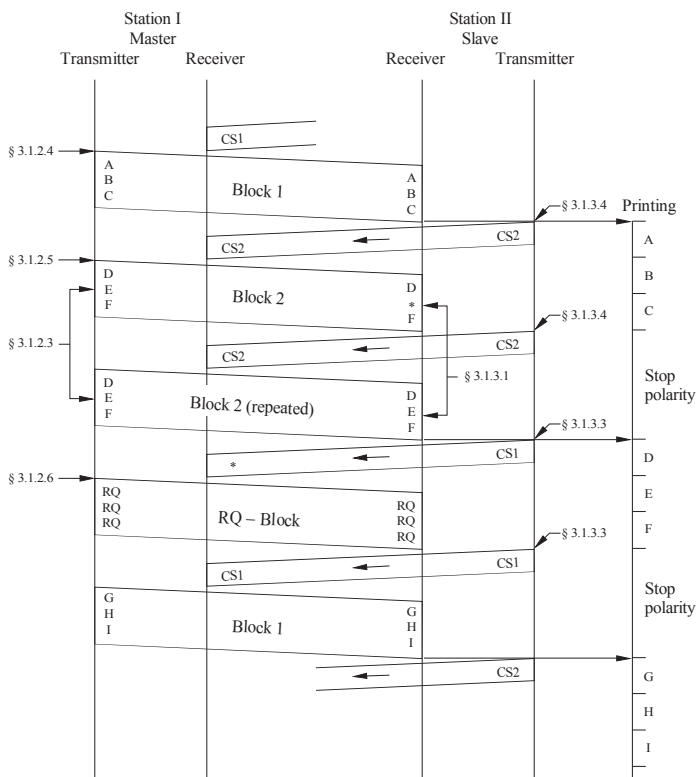
* Detected error symbol

D02

3.1.3   The information receiving station (IRS)

3.1.3.1   Numbers the received blocks of three characters alternately "Block 1" and "Block 2" by a local numbering device, the numbering being interrupted at the reception of:

–   a block in which one or more characters are mutilated; or

–   a block containing at least one "signal repetition"; (§ 3.1.2.6)

3.1.3.2   after the reception of each block, emits one of the control signals of 70 ms duration after which a transmission pause of 380 ms becomes effective;

3.1.3.3   emits the control signal 1 at the reception of:

–   an unmutilated "Block 2", or

–   a mutilated "Block 1", or

–   "Block 1" containing at least one "signal repetition";

3.1.3.4   emits the control signal 2 at reception of:

–   an unmutilated "Block 1", or

–   a mutilated "Block 2", or

–   a "Block 2" containing at least one "signal repetition".

3.1.4   Phasing

3.1.4.1   When no circuit is established, both stations are in the "stand-by" position. In this stand-by position no ISS or IRS and no master or slave position is assigned to either of the stations;

3.1.4.2   the station desiring to establish the circuit emits the "call" signal. This "call" signal is formed by two blocks of three signals (see Note 1);

3.1.4.3   the call signal contains:

–   in the first block: "signal repetition" in the second character place and any combination of information signals (see Note 2) in the first and third character place,

–   in the second block: "signal repetition" in the third character place preceded by any combination of the 32 information signals (see Note 2) in the first and second character place;

3.1.4.4   on receipt of the appropriate call signal the called station changes from stand-by to the IRS position and emits the control signal 1 or the control signal 2;

3.1.4.5   on receipt of two consecutive identical control signals, the calling station changes into ISS and operates in accordance with § 3.1.2.4 and 3.1.2.5.

NOTE 1 – A station using a two block call signal, shall be assigned a number in accordance with RR Nos. S19.37, S19.83 and S19.92 to S19.95 [Nos. 2088, 2134 and 2143 to 2146];

NOTE 2 – The composition of these signals and their assignment to individual ships require international agreement (see Recommendation ITU-R M.491).

3.1.5   Rephasing (Note 1)

3.1.5.1   When reception of information blocks or of control signals is continuously mutilated, the system reverts to the "stand-by" position after a predetermined time (a preferable predetermined time would be the duration of 32 cycles of 450 ms), to be decided by the user, of continuous repetition; the station that is master station at the time of interruption immediately initiates rephasing along the same lines as laid down in § 3.1.4;

3.1.5.2   if, at the time of interruption, the slave station was in the IRS position, the control signal to be returned after phasing should be the same as that last sent before the interruption to avoid the loss of an information block upon resumption of the communication. (Some existing equipments may not conform to this requirement);

3.1.5.3   however, if, at the time of interruption, the slave station was in the ISS position, it emits, after having received the appropriate call blocks, either:

–   the control signal 3; or

–   the control signal 1 or 2 in conformity with § 3.1.4.4, after which control signal 3 is emitted to initiate changeover to the ISS position;

3.1.5.4   if rephasing has not been accomplished within the time-out interval of § 3.1.9.1, the system reverts to the stand-by position and no further rephasing attempts are made.

NOTE 1 – Some coast stations do not provide rephasing (see also Recommendation ITU-R M.492).

3.1.6   Change-over

3.1.6.1   The information sending station (ISS)

–   Emits, to initiate a change in the direction of the traffic flow, the information signal sequence "Figure shift" – "Plus" ("figure case of Z") – "Question mark" ("figure case of B") (see Note 1) followed, if necessary, by one or more "idle signals β" to complete a block;

–   emits, on receipt of a control signal 3, a block containing the signals "idle signal β" – "idle signal α" – "idle signal β";

–   changes subsequently to IRS after the reception of a "signal repetition".

3.1.6.2   The information receiving station (IRS)

– Emits the control signal 3:

    a)   when the station wishes to change over to ISS,

    b)   on receipt of a block in which the signal information sequence "Figure shift" – "Plus" – (figure case of Z) – "Question mark" (figure case of B) terminates (see Note 1) or upon receipt of the following block. In the latter case, the IRS shall ignore whether or not one or more characters in the last block are mutilated:

– changes subsequently to ISS after reception of a block containing the signal sequence "idle signal β" – "idle signal α" – "idle signal β";

– emits one "signal repetition" as a master station, or a block of three "signal repetitions" as a slave station, after being changed into ISS.

NOTE 1 – In the Telex network, the signal sequence combination No. 26 – combination No. 2, sent whilst the teleprinters are in the figure case condition, is used to initiate a reversal of the flow of information. The IRS is, therefore, required to keep track of whether the traffic information flow is in the letter case or figure case mode to ensure proper end-to-end operation of the system.

3.1.7   Output to line

3.1.7.1   the signal offered to the line output terminal is a 5-unit start-stop signal at a modulation rate of 50 Bd.

3.1.8   Answerback

3.1.8.1   The WRU (Who are you?) sequence, which consists of combination Nos. 30 and 4 in the ITU-T International Telegraph Alphabet No. 2, is used to request terminal identification.

3.1.8.2   The information receiving station (IRS), on receipt of a block containing the WRU sequence, which will actuate the teleprinter answerback code generator:

– changes the direction of traffic flow in accordance with § 3.1.6.2;

– transmits the signal information characters derived from the teleprinter answerback code generator;

– after transmission of 2 blocks of "idle signals β" (after completion of the answerback code, or in the absence of an answerback code), changes the direction of traffic flow in accordance with § 3.1.6.1.

NOTE 1 – Some existing equipments may not conform to this requirement.

3.1.9   End of communication

3.1.9.1   When reception of information blocks or of control signals is continuously mutilated, the system reverts to the "stand-by" position after a predetermined time of continuous repetition, which causes the termination of the established circuit (a preferable predetermined time would be the duration of 64 cycles of 450 ms);

3.1.9.2   the station that wishes to terminate the established circuit transmits an "end of communication signal";

3.1.9.3   the "end of communication signal" consists of a block containing three "idle signal α":

3.1.9.4   the "end of communication signal" is transmitted by the ISS;

3.1.9.5   if an IRS wishes to terminate the established circuit it has to change over to ISS in accordance with § 3.1.6.2;

3.1.9.6   the IRS that receives an "end of communication signal" emits the appropriate control signal and reverts to the "stand-by" position;

3.1.9.7   on receipt of a control signal that confirms the unmutilated reception of the "end of communication signal", the ISS reverts to the "stand-by" position;

3.1.9.8   when after a predetermined number of transmissions (see Note 1) of the "end of communication signal" no control signal has been received confirming the unmutilated reception of the "end of communication signal", the ISS reverts to the stand-by position and the IRS times out in accordance with § 3.1.9.1.

NOTE 1 – A preferable predetermined number would be four transmissions of the "end of communication signal".

3.2 Mode B, forward error correction (FEC) (see Figs. 3 and 4)

A synchronous system, transmitting an uninterrupted stream of characters from a station sending in the collective B-mode (CBSS) to a number of stations receiving in the collective B-mode (CBRS), or from a station sending in the selective B-mode (SBSS) to one selected station receiving in the selective B-mode (SBRS).

3.2.1 The station sending in the collective or in the selective B-mode (CBSS or SBSS)

3.2.1.1 Emits each character twice: the first transmission (DX) of a specific character is followed by the transmission of four other characters, after which the retransmission (RX) of the first character takes place, allowing for time-diversity reception at 280 ms time space;

3.2.1.2 emits as a preamble to messages or to the call sign, alternately the phasing signal 1 (see § 2.2) and the phasing signal 2 (see § 2.2) whereby phasing signal 1 is transmitted in the RX, and phasing signal 2 in the DX position. At least four of these signal pairs (phasing signal 1 and phasing signal 2) should be transmitted.

3.2.2 The station sending in the collective B-mode (CBSS)

3.2.2.1 Emits during the breaks between two messages in the same transmission the phasing signals 1 and the phasing signals 2 in the RX and the DX position, respectively.

3.2.3 The station sending in the selective B-mode (SBSS)

3.2.3.1 Emits after the transmission of the required number of phasing signals (see § 3.2.1.2) the call sign of the station to be selected. This call sign is a sequence of four characters that represents the number code of the called station. The composition of this call sign should be in accordance with Recommendation ITU-R M.491. This transmission takes place in the time diversity mode according to § 3.2.1.1;

3.2.3.2 emits the call sign and all further signals in a 3B/4Y ratio, i.e. inverted with respect to the signals in Table 1 in the column "emitted 7-unit signal". Consequently, all signals, i.e. both traffic information signals and service information signals, following the phasing signals are transmitted in the 3B/4Y ratio;

3.2.3.3 emits the service information signal "idle signal β" during the idle time between the messages consisting of traffic information signals.

3.2.4 The station(s) receiving in the collective or in the selective B-mode (CBRS or SBRS)

3.2.4.1 Checks both characters (DX and RX), printing an unmutilated DX or RX character, or printing an error symbol or space, if both are mutilated.

3.2.5 Phasing

3.2.5.1 When no reception takes place, the system is in the "stand-by" position as laid down in § 3.1.4.1;

3.2.5.2 on receipt of the sequence *"phasing signal 1" – "phasing signal 2"*, or of the sequence *"phasing signal 2" – "phasing signal 1"*, in which phasing signal 2 determines the DX and phasing signal 1 determines the RX position, and at least one further phasing signal in the appropriate position, the system changes from "stand-by" to the CBRS position;

3.2.5.3 when started as CBRS the system changes to the SBRS (selectively called receiving station) position on receipt of the inverted characters representing its selective call number;

3.2.5.4 having been changed into the CBRS or into the SBRS position the system offers continuous stop-polarity to the line output terminal until either the signal "carriage return" or "line feed" is received;

3.2.5.5 when started as SBRS, the decoder re-inverts all the following signals received to the 3Y/4B ratio, so that these signals are offered to the SBRS in the correct ratio, but they remain inverted for all other stations;

3.2.5.6 both the CBRS and the SBRS revert to the stand-by position if, during a predetermined time, the percentage of mutilated signals received has reached a predetermined value.

FIGURE 3

B-mode operation

Collectively

1: phasing signal 1
2: phasing signal 2
<: carriage return (CR)
≡: line feed (LF)
∗ Detected error symbol
Overlined symbols (e.g. $\overline{M}$) are transmitted in the 3B/4Y ratio

Selectively

CBSS: B-mode - Sending collectively
CBRS: B-mode - Receiving collectively
SBSS: B-mode - Sending selectively
SBRS: B-mode - Receiving selectively

D04

FIGURE 4

Flow chart showing processes in B-mode operation

Emission
realized
manually

Emission
realized
automatically

Overlined symbols (e g $\overline{\alpha}$) are transmitted/detected
in the 3B/4Y ratio
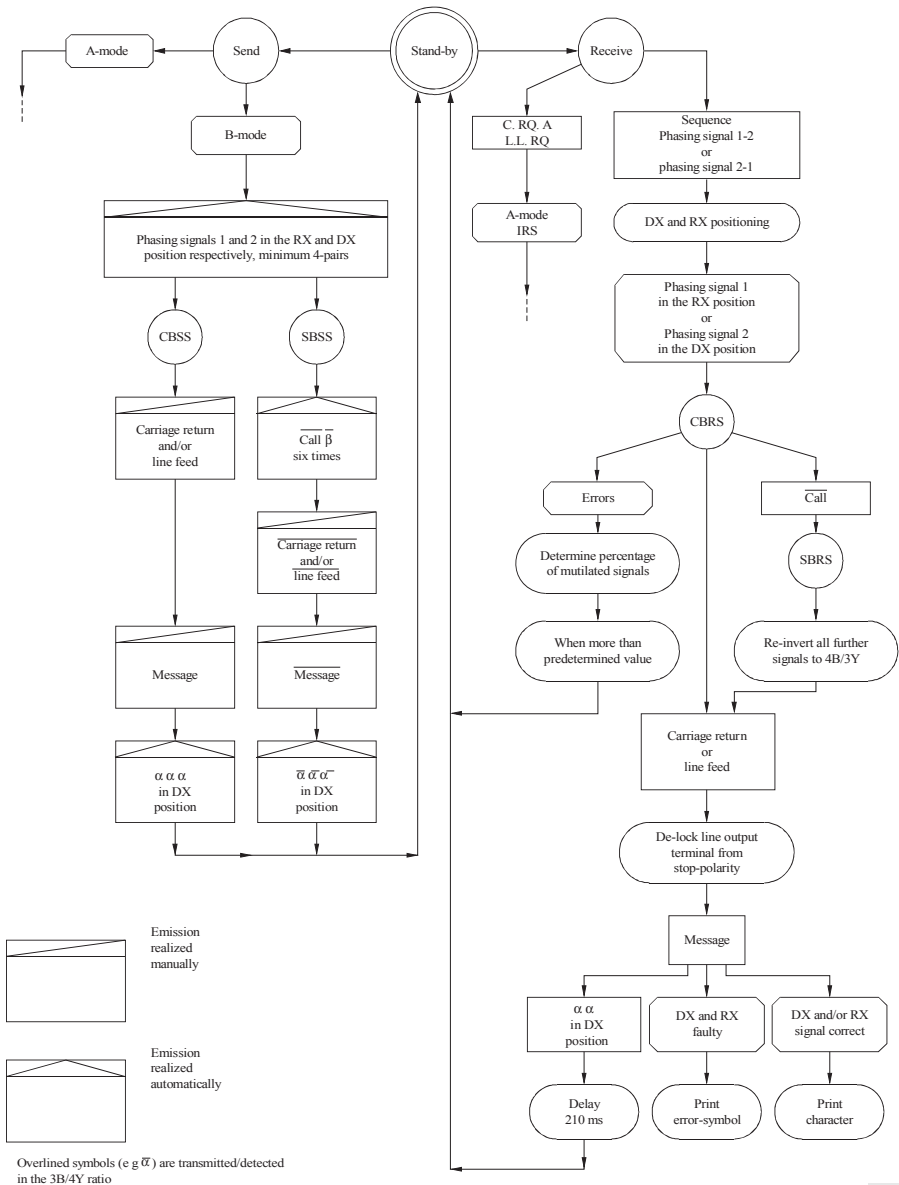
D05

3.2.6   **Output to line**

3.2.6.1   The signal offered to the line output terminal is a 5-unit start-stop ITU-T International Telegraph Alphabet No. 2 signal at a modulation rate of 50 Bd.

3.2.7   **End of emission**

3.2.7.1   The station sending in the B-mode (CBSS or SBSS) that wishes to terminate the emission transmits the "end of emission signal";

3.2.7.2   the "end of emission signal" consists of three consecutive "idle signals α" (see § 2.2) transmitted in the DX position only, immediately after the last transmitted traffic information signal in the DX position, after which the station terminates its emission and reverts to the "stand-by" position;
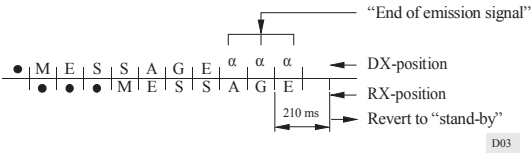
3.2.7.3   the CBRS or the SBRS reverts to the "stand-by" position not less than 210 ms after receipt of at least two consecutive "idle signals α" in the DX position.

RECOMMENDATION ITU-R M.489-2*

TECHNICAL CHARACTERISTICS OF VHF RADIOTELEPHONE EQUIPMENT OPERATING IN THE MARITIME MOBILE SERVICE IN CHANNELS SPACED BY 25 kHz

(1974-1978-1995)

Summary

The Recommendation describes the technical characteristics of VHF radiotelephone transmitters and receivers (or transceivers) used in the maritime mobile service when operating in 25 kHz channels of Appendix S18 [Appendix 18] of the Radio Regulations (RR). It also contains those additional characteristics of transceivers required to operate digital selective calling.

The ITU Radiocommunication Assembly,

considering

a)   that Resolution No. 308 of the World Administrative Radio Conference (Geneva, 1979) stipulated that:

–   all maritime mobile VHF radiotelephone equipment shall conform to 25 kHz standards by 1 January 1983;

b)   that RR Appendix S18 [Appendix 18] gives a table of transmitting frequencies which is based upon the principle of 25 kHz channel separations for the maritime mobile service;

c)   that in Opinion 42, the International Electrotechnical Commission (IEC) has been invited to advise the ITU Radiocommunication Sector of any methods of measurement applicable to radio equipment used in land mobile services; and that such methods of measurement may also be suitable for radio equipment used in maritime mobile services;

d)   that there is a need to specify the technical characteristics of VHF radiotelephone equipment operating in the maritime mobile service in channels spaced by 25 kHz,

recommends

1   that the following characteristics should be met by VHF (metric) FM radiotelephone equipment used for the maritime mobile services operating on the frequencies specified in RR Appendix S18 [Appendix 18].

1.1   General characteristics

1.1.1   The class of emission should be F3E/G3E.

1.1.2   The necessary bandwidth should be 16 kHz.

1.1.3   Only phase modulation (frequency modulation with a pre-emphasis characteristic of 6 dB/octave) should be used.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the Telecommunication Standardization Sector (ITU-T).

Note by the Secretariat: The references made to the Radio Regulations (RR) in this Recommendation refer to the RR as revised by the World Radiocommunication Conference 1995. These elements of the RR will come into force on 1 June 1998. Where applicable, the equivalent references in the current RR are also provided in square brackets.

1.1.4　　The frequency deviation corresponding to 100% modulation should approach ± 5 kHz as nearly as practicable. In no event should the frequency deviation exceed ± 5 kHz. Deviation limiting circuits should be employed such that the maximum frequency deviation attainable should be independent of the input audio frequency.

1.1.5　　Where duplex or semi-duplex systems are in use, the performance of the radio equipment should continue to comply with all the requirements of this Recommendation.

1.1.6　　The equipment should be designed so that frequency changes between assigned channels can be carried out within 5 s.

1.1.7　　Emissions should be vertically polarized at the source.

1.1.8　　Stations using digital selective calling shall have the following capabilities:

a)　　sensing to determine the presence of a signal on 156.525 MHz (channel 70); and

b)　　automatic prevention of the transmission of a call, except for distress and safety calls, when the channel is occupied by calls.

1.2　　Transmitters

1.2.1　　The frequency tolerance for coast station transmitters should not exceed 5 parts in 10^6, and that for ship station transmitters should not exceed 10 parts in 10^6.

1.2.2　　Spurious emissions on discrete frequencies, when measured in a non-reactive load equal to the nominal output impedance of the transmitter, should be in accordance with the provisions of RR Appendix S3 [Appendix 8].

1.2.3　　The carrier power for coast stations should not normally exceed 50 W.

1.2.4　　The carrier power for ship station transmitters should not exceed 25 W. Means should be provided to readily reduce this power to 1 W or less for use at short ranges, except for digital selective calling equipment operating on 156.525 MHz (channel 70) in which case the power reduction facility is optional (see also Recommendation ITU-R M.541 *recommends* 3.7).

1.2.5　　The upper limit of the audio-frequency band should not exceed 3 kHz.

1.2.6　　The cabinet radiated power should not exceed 25 μW. In some radio environments, lower values may be required.

1.3　　Receivers

1.3.1　　The reference sensitivity should be equal to or less than 2.0 μV, e.m.f., for a given reference signal-to-noise ratio at the output of the receiver.

1.3.2　　The adjacent channel selectivity should be at least 70 dB.

1.3.3　　The spurious response rejection ratio should be at least 70 dB.

1.3.4　　The radio frequency intermodulation rejection ratio should be at least 65 dB.

1.3.5　　The power of any conducted spurious emission, measured at the antenna terminals, should not exceed 2.0 nW at any discrete frequency. In some radio environments lower values may be required.

1.3.6　　The effective radiated power of any cabinet radiated spurious emission on any frequency up to 70 MHz should not exceed 10 nW. Above 70 MHz, the spurious emissions should not exceed 10 nW by more than 6 dB/octave in frequency up to 1 000 MHz. In some radio environments, lower values may be required;

2　　that reference should also be made to Recommendations ITU-R SM.331 and ITU-R SM.332 and to the relevant IEC publications on methods of measurement.

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RECOMMENDATION ITU-R M.492-6*

OPERATIONAL PROCEDURES FOR THE USE OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question ITU-R 5/8)

(1974-1978-1982-1986-1990-1992-1995)

Summary

The Recommendation provides in Annex 1 operational procedures for the use of direct-printing telegraph equipment in communication between a ship and a coast station in the selective ARQ-mode on a fully automated or semi-automated basis and to a number of ship stations or a single ship in the broadcast FEC-mode. It also specifies interworking between equipments in accordance with technical characteristics given in Recommendations ITU-R M.476 and ITU-R M.625. Appendix 1 contains procedures for setting up of calls.

The ITU Radiocommunication Assembly,

considering

a)   that narrow-band direct-printing telegraph services are in operation using equipment as described in Recommendations ITU-R M.476, ITU-R M.625 and ITU-R M.692;

b)   that an improved narrow-band direct-printing telegraph system providing automatic identification and capable of using the 9-digit ship station identity is described in Recommendation ITU-R M.625;

c)   that the operational procedures necessary for such services should be agreed upon;

d)   that, as far as possible, these procedures should be similar for all services and for all frequency bands (different operational procedures may be required in frequency bands other than the HF and MF bands);

e)   that a large number of equipments complying with Recommendation ITU-R M.476 exist;

f)   that interworking between equipments in accordance with Recommendations ITU-R M.476 and ITU-R M.625 is required, at least for a transitionary period,

recommends

1   that the operational procedures given in Annex 1 be observed for the use of narrow-band direct-printing telegraph equipment in accordance with either Recommendation ITU-R M.476 or ITU-R M.625 in the MF and HF bands of the maritime mobile service;

2   that when using direct-printing telegraphy or similar systems in any of the frequency bands allocated to the maritime mobile service, the call may, by prior arrangement, be made on a working frequency available for such systems.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the Telecommunication Standardization Sector (ITU-T).

ANNEX 1

Operational procedures

1   Mode A (ARQ)

1.1   Methods used for setting up narrow-band direct-printing telegraph communications between a ship station and a coast station in the ARQ-mode should be on a fully automatic or semi-automatic basis, insofar that a ship station should have direct access to a coast station on a coast station receiving frequency and a coast station should have direct access to a ship station on a coast station transmitting frequency.

1.2   However, where necessary, prior contact by Morse telegraphy, radiotelephony or other means is not precluded.

1.3   Through connection to a remote teleprinter station over a dedicated circuit or to a subscriber of the international telex network may be achieved by manual, semi-automatic or automatic means.

NOTE 1 – Before an international automatic service can be introduced, agreement has to be reached on a numbering plan, traffic routing and charging. This should be considered by both the ITU-T and the ITU-R.

NOTE 2 – Recommendations ITU-R M.476 (see § 3.1.5) and ITU-R M.625 (see § 3.8) make provision for automatic re-establishment of radio circuits by rephasing in the event of interruption. However, it has been reported that this procedure has, in some countries, resulted in technical and operational problems when radio circuits are extended into the public switched network or to certain types of automated switching or store-and-forward equipments. For this reason, some coast stations do not accept messages if the rephasing procedure is used.

NOTE 3 – When a connection is set up in the ARQ mode with the international telex network via a coast station, where practicable the general requirements specified in ITU-T Recommendation U.63 should be met.

1.4   When, by prior arrangement, unattended operation is required for communication from a coast station to a ship station, or between two ship stations, the receiving ship station should have a receiver tuned to the other station's transmitting frequency and a transmitter tuned or a transmitter capable of being tuned automatically to the appropriate frequency and ready to transmit on this frequency.

1.5   For unattended operation a ship station should be called selectively by the initiating coast or ship station as provided for by Recommendations ITU-R M.476 and ITU-R M.625. The ship station concerned could have available traffic stored ready for automatic transmission on demand of the calling station.

1.6   At the "over" signal, initiated by the calling station, any available traffic in the ship's traffic store could be transmitted.

1.7   At the end of the communication, an "end of communication" signal should be transmitted, whereupon the ship's equipment should automatically revert to the "stand-by" condition.

1.8   A "free channel" signal may be transmitted by a coast station where necessary to indicate when a channel is open for traffic. The "free channel" signals should preferably be restricted to only one channel per HF band and their duration should be kept as short as possible. In accordance with Article 18 of the Radio Regulations and recognizing the heavy loading of the frequencies available for narrow-band direct printing in the HF bands, "free channel" signals should not be used in future planned systems.

1.9   The format of the "free channel" signal should be composed of signals in the 7-unit error detecting code as listed in § 2 of Annex 1 to Recommendation ITU-R M.476 and § 2 of Annex 1 to Recommendation ITU-R M.625. Three of these signals should be grouped into a block, the middle signal being the "signal repetition" (RQ), the first signal of the block being any of the signals VXKMCF TBOZA and the third signal of the block being any of the signals VMPCYFS OIRZDA (see Recommendation ITU-R M.491). These signals should be indicated in the ITU List of Coast Stations.

Selections of new signals should preferably be chosen to correspond to the first two digits of that coast station's 4-digit identification number. If this is not possible because the characters needed are not listed above, or if this is not desired because this combination is already in use by another coast station, it is preferred that a combination of characters be selected from those listed above in the second part of each row, i.e. TBOZA for the first signal and OIRZDA for the third signal of the free channel block. The signals in the block are transmitted at a modulation rate of 100 Bd and the blocks are separated by pauses of 240 ms. For manual systems this "free channel" signal should be interrupted either by a period of no signal or by a signal or signals, that would enable an operator to recognize the "free channel" condition by ear. An aurally recognizable signal, e.g. a Morse signal, may be used alone as the "free channel" signal in manual systems. At least 8 blocks of the 7-unit signal should be transmitted before interruption.

1.10   In the case of single frequency operation, as described in Recommendation ITU-R M.692, the free channel signal should be interrupted by listening periods of at least 3 s.

1.11   General operational procedures for setting up calls between ship stations and between ship stations and coast stations are given below and specific procedures are given in Appendix 1.

1.12   Manual procedures

1.12.1   Ship to coast station

1.12.1.1 The operator of the ship station establishes communication with the coast station by A1A Morse telegraphy, telephony or by other means using normal calling procedures. The operator then requests direct-printing communication, exchanges information regarding the frequencies to be used and, when applicable, gives the ship station the direct-printing selective call number assigned in accordance with Recommendation ITU-R M.476 or ITU-R M.625 as appropriate, or the ship station identity assigned in accordance with the Preface to List VII A.

1.12.1.2 The operator of the coast station then establishes direct-printing communication on the frequency agreed, using the appropriate identification of the ship.

1.12.1.3 Alternatively the operator of the ship station, using the direct-printing equipment, calls the coast station on a predetermined coast station receive frequency using the identification of the coast station assigned in accordance with Recommendation ITU-R M.476 or ITU-R M.625 as appropriate, or the coast station identity assigned in accordance with the Preface to List VII A.

1.12.1.4 The operator of the coast station then establishes direct-printing communication on the corresponding coast station transmit frequency.

1.12.2   Coast station to ship

1.12.2.1 The operator of the coast station calls the ship station by A1A Morse telegraphy, telephony or other means, using normal calling procedures.

1.12.2.2 The operator of the ship station then applies the procedures of § 1.12.1.1 or § 1.12.1.3.

1.12.3   Intership

1.12.3.1 The operator of the calling ship station establishes communication with the called ship station by A1A Morse telegraphy, telephony, or by other means, using normal calling procedures. The operator then requests direct-printing communication, exchanges information regarding the frequencies to be used and, when applicable, gives the direct-printing selective call number of the calling ship station assigned in accordance with Recommendation ITU-R M.476 or ITU-R M.625 as appropriate, or the ship station identity assigned in accordance with the Preface to List VII A.

1.12.3.2 The operator of the called ship station then establishes direct-printing communication on the frequency agreed, using the appropriate identification of the calling ship.

1.13 Procedures for automatic operation

1.13.1 Ship to coast station

1.13.1.1 The ship station calls the coast station on a predetermined coast station receive frequency, using the direct-printing equipment and the identification signal of the coast station assigned in accordance with Recommendation ITU-R M.476 or ITU-R M.625 as appropriate, or the coast station identity assigned in accordance with the Preface to List VII A.

1.13.1.2 The coast station's direct-printing equipment detects the call and the coast station responds directly on the corresponding coast station transmit frequency, either automatically or under manual control.

1.13.2 Coast station to ship

1.13.2.1 The coast station calls the ship station on a predetermined coast station transmit frequency, using the direct-printing equipment and the ship station direct-printing selective call number assigned in accordance with Recommendation ITU-R M.476 or ITU-R M.625 as appropriate, or the ship station identity assigned in accordance with the Preface to List VII A.

1.13.2.2 The ship station's direct-printing equipment tuned to receive the predetermined coast station transmit frequency detects the call, whereupon the reply is given in one of the following ways:

a) the ship station replies either immediately on the corresponding coast station receive frequency or at a later stage, using the procedure of § 1.12.1.3; or

b) the ship station's transmitter is automatically started on the corresponding coast station receive frequency and the direct-printing equipment responds by sending appropriate signals to indicate readiness to receive traffic automatically.

1.14 Message format

1.14.1 Where the appropriate facilities are provided by the coast station, traffic may be exchanged with the telex network:

a) in a conversational mode where the stations concerned are connected directly, either automatically or under manual control; or

b) in a store-and-forward mode where traffic is stored at the coast station until the circuit to the called station can be set up, either automatically or under manual control.

1.14.2 In the shore-to-ship direction, the message format should conform to normal telex network practice (see also Appendix 1, § 2).

1.14.3 In the ship-to-shore direction, the message format should conform to the operational procedures specified in Appendix 1, § 1.

2 Mode B (FEC)

2.1 Messages may, by prior arrangement, be sent in the B mode from a coast station or a ship station to a number of ships or to a single ship, preceded if desired by the selective call code of the ship(s) concerned where:

2.1.1 a receiving ship station is not permitted or not able to use its transmitter, or

2.1.2 communications are intended for more than one ship, or

2.1.3 unattended reception of the B mode is required and automatic acknowledgement is not necessary.

In such cases, the ship station receivers should be tuned to the appropriate coast or ship station transmitting frequency.

2.2   All B mode messages should start with "carriage return" and "line feed" signals.

2.3   When the ship station receives phasing signals in the B mode, its teleprinter should start automatically and should stop automatically when reception of the emission ceases.

2.4   Ship stations may acknowledge the reception of B mode messages by A1A Morse telegraphy, telephony or by other means.

3   Inter-working between equipments in accordance with Recommendations ITU-R M.476 and ITU-R M.625

3.1   Recommendation ITU-R M.625 provides for automatic inter-working with equipment which is in accordance with Recommendation ITU-R M.476. The criteria for determining whether one or both stations are of the Recommendation ITU-R M.476 type are the length of the call signal and the composition of the call blocks.

3.2   If both stations have equipment in accordance with Recommendation ITU-R M.625, automatic station identification is a part of the automatic call set-up procedures. However, if one or both stations have equipment in accordance with Recommendation ITU-R M.476, no automatic station identification takes place. For this reason, and because Recommendation ITU-R M.625 accommodates the use of the 9-digit ship station identity for the direct-printing equipment call signal, it is desirable that all new equipment be in accordance with Recommendation ITU-R M.625 at the earliest practicable time.

3.3   In order to attain full compatibility with the large number of existing equipment, it will be necessary to assign both a 9-digit and a 5- (or 4-) digit identity (i.e. 7- and 4-signal call signals) to such new stations. Ship and coast station lists should contain both signals.

APPENDIX 1

1   Procedure for setting up a call in the ship-to-coast station direction

Coast station   Step   Ship station

                                  ↓
                                  1 —————————— Ship initiates the call
                                  2
| Exchange answer-backs [1] |
<≡↓ GA ↑ +? ——————————   3
                                  4 —————————— [2] <≡↓ MSG ↑ +   (2.1) or
                                                 <≡↓ TLX ↑ xy+   (2.2) or
                                                 <≡↓ DIRTLX ↑ xy +   (2.3) or
                                                 <≡↓ TGM ↑+   (2.4) or
                                                 <≡↓ URG ↑+   (2.5) or
                                                 <≡↓ RTL ↑+   (2.6) or
                                                 <≡↓ OPR ↑+   (2.7) or
                                                 <≡↓ WX ↑+   (2.8) or
                                                 <≡↓ NAV ↑+   (2.9) or
                                                 <≡↓ STA ↑+   (2.10) or
                                                 <≡↓ POS ↑+   (2.11) or
                                                 <≡↓ FREQ ↑+   (2.12) or
                                                 <≡↓ SVC ↑+   (2.13) or
                                                 <≡↓ MAN ↑+   (2.14) or
                                                 <≡↓ MED ↑+   (2.15) or
                                                 <≡↓ OBS ↑+   (2.16) or
                                                 <≡↓ HELP ↑+   (2.17) or
                                                 <≡↓ HELP... ↑+   (2.18) or
                                                 <≡↓ AMV ↑+   (2.19) or
                                                 <≡↓ BRK ↑+   (2.20) or
                                           < ≡↓ MULTLX ↑ xy/xy/xy+   (2.21) or
                                                 <≡↓ STS ↑ x +   (2.22) or
                                                 <≡↓ INF ↑+   (2.23) or
                                                 <≡↓ VBTLX ↑ xy+   (2.24) or
                                                 <≡↓ FAX ↑ xy +   (2.25) or
                                                 <≡↓ TEL ↑ xy +   (2.26) or
                                                 <≡↓ DATA ↑ xy +   (2.27) or
                                                 <≡↓ RPT ↑ ×...+   (2.28) or
                                                 <≡↓ TST ↑+   (2.29) or
                                                 <≡↓ TRF ↑+   (2.30)

                                  5 —————————— ? [3]
< ≡ ↓ QRC ↑ + ? ——————————   6
                                  7 —————————— Ship transmits its
                                                 AAIC, followed by + ? [3]   } [4]
< ≡ ↓ MSG ↑ + ? [5] ——————————   8
                                  9
| Message procedure [6] |
                                  10 —————————— <≡↓ KKKK [7]
                                  11
| Exchange answer-backs [1] |
< ≡ "Message reference charged   12
      time, etc." [8]
<≡↓ GA ↑+? ——————————   13
                                  14 —————————— Go to step 4 or
                                                 end of communication   D01

Note 2 applies

2   Procedure for setting up a call in the coast-to-ship station direction

Operation in the direction coast station to ship may need to be in the store-and-forward mode owing to the fact that radio propagation conditions may not allow the setting up of a call at the intended time.
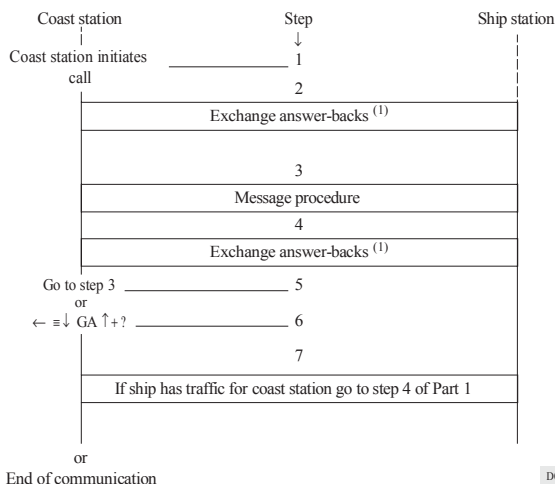
```
        Coast station              Step              Ship station
                                     ↓
   Coast station initiates  _____  1
           call
                                     2
                    Exchange answer-backs (1)

                                     3
                       Message procedure
                                     4
                    Exchange answer-backs (1)

     Go to step 3  _____  5
         or
    ← ≡↓ GA ↑+?  _____  6

                                     7
         If ship has traffic for coast station go to step 4 of Part 1


         or
   End of communication                              D02
```

Notes relative to § 1 and 2:

(1)   a)   In automatic operation the answer-back exchange is initiated and controlled by the coast station. For calls set up by the ship station the answer-back exchange in manual operation may be initiated by the ship station.

For calls set up by the coast station the answer-back exchange in manual operation is initiated by the coast station, thereby defining the order in which the exchange takes place.

b)   Answer-back code as defined in ITU-T Recommendations F.130 for ship stations and F.60 for coast stations.

(2)   A coast station need not provide all of the facilities indicated. However, where specific facilities are provided, the facility codes indicated should be used. The facility "HELP" should always be available.

(2.1)   MSG indicates that the ship station needs to immediately receive any messages held for it at the coast station.

(2.2)   TLX ↑ xy indicates that the following message is for immediate connection to a store-and-forward facility located at the coast station.

y indicates the subscriber's national telex number.

x is used where applicable to indicate the country code (ITU-T Recommendation F.69) preceded by 0 (when applicable). (Where the store-and-forward system is remote from the coast station, TLX alone may be used.)

TLXA may optionally be used instead of TLX which indicates that ship wishes to be advised (using the normal shore-to-ship procedures) when the message has been delivered to the indicated telex number.

(2.3)   DIRTLX ↑ xy indicates that a direct telex connection is required.

y indicates the subscriber's national telex number.

x is used where applicable to indicate the country code (ITU-T Recommendation F.69) preceded by 0 (when applicable).

RDL + may optionally be used to indicate that the last DIRTLX ↑ xy telex number should be redialled.

(2.4)   TGM indicates that the following message is a radio telegram.

(2.5) URG indicates that the ship station needs to be connected immediately to a manual assistance operator and an audible alarm may be activated. This code should only be used in case of emergency.

(2.6) RTL indicates that the following message is a radio telex letter.

(2.7) OPR indicates that connection to a manual assistance operator is required.

(2.8) WX indicates that the ship station needs to immediately receive weather information.

(2.9) NAV indicates that the ship station needs to immediately receive navigational warnings.

(2.10) STA indicates that the ship station needs to immediately receive a status report of all store-and-forward messages which have been sent by that ship station, but which the ship station has not already received on retransmitted or non-delivered information (see also (6)). STA ↑ x may also be used where the ship station needs to immediately receive a status report of such a message where x indicates the message reference provided by the coast station.

(2.11) POS indicates that the following message contains the ship's position. Some administrations use this information to assist in the subsequent automatic transmission or reception of messages (e.g. for calculating the optimum traffic frequency and/or the appropriate directional antennas to use).

(2.12) FREQ indicates that the following message indicates the frequency on which the ship is keeping watch.

(2.13) SVC indicates that the following message is a service message (for subsequent manual attention).

(2.14) MAN indicates that the following message is to be stored and manually forwarded to a country which cannot be accessed automatically.

(2.15) MED indicates that an urgent medical message follows.

(2.16) OBS indicates that the following message is to be sent to the meteorological organization.

(2.17) HELP indicates that the ship station needs to immediately receive a list of available facilities within the system.

(2.18) If information is needed on the application of procedures for individual facilities at a coast station, request for further details concerning the specific procedure can be obtained by the facility code HELP followed by the appropriate facility code for which the information is needed, e.g.: < ≡ ↓HELP DIRTLX ↑ + indicates that the ship station needs information on the procedures (action by ship operator) for ordering a dialogue-mode connection with a telex network subscriber via the coast station.

(2.19) AMV indicates that the following message is to be sent to the AMVER organization.

(2.20) BRK indicates that the use of the radio path is to be immediately discontinued (for use where the ship's operator can only use a teleprinter for controlling the ARQ equipment).

(2.21) MULTLX ↑ xy/xy/xy€+ indicates that the following message is a multiple address message for immediate connection to a store-and-forward facility located at the coast station.

y indicates the subscriber's national telex number.

x is used where applicable to indicate the country code (ITU-T Recommendation F.69) preceded by 0 (when applicable).

Each separate xy indicates a different telex number to which the same message should be forwarded. At least two separate telex numbers should be included.

MULTLXA may optionally be used instead of MULTLX which indicates that the ship wishes to be advised (using the normal shore-to-ship procedures) when the messages have been delivered to the indicated telex numbers.

(2.22) STS ↑ x + indicates that the following message is for transmission to a ship using a store-and-forward facility located at the coast station. x indicates the addressed ship's 5- or 9-digit identity number.

(2.23) INF indicates that the ship station needs to immediately receive information from the coast station's database. Some administrations provide a variety of different database information in which case INF returns a directory listing and a subsequent facility code is used to select the desired information.

(2.24) VBTLX ↑ xy indicates that the following message should be dictated, by the coast station, to a voicebank (voice messaging) telephone number for subsequent retrieval by the addressee, and that a copy of the message should be forwarded to telex number xy. The voicebank telephone number should be included in the first line of the message text.

(2.25) FAX ↑ xy indicates that the following message should be forwarded, via the PSTN, by facsimile to the telephone number xy.

(2.26) TEL ↑ xy indicates that the following message should be telephoned, by the coast station, to the telephone number xy.

(2.27) DATA ↑ xy indicates that the following message should be forwarded by the coast station using data facilities to the subscriber number xy (via the PSTN).

(2.28) RPT ↑ xy… indicates that the ship needs to receive, using the ARQ mode, a specific identified message (e.g., earlier transmitted in the FEC mode), if still available for automatic retransmission. x… is used as the message identifier.

(2.29) TST indicates that the ship needs to receive an automatically transmitted test text (e.g. "the quick brown fox …").

(2.30) TRF indicates that the ship needs to receive information, automatically transmitted, on tariffs currently applicable to the coast station.

(3)   The symbol "?" is not necessary where the coast station is automatic. It is normally required only for manual systems.

(4)   In cases where the coast station requires information about the relevant Accounting Authority Identification Code (AAIC), this information should be provided by the ship operator on receipt of the combination $< \equiv \downarrow$ QRC $\uparrow +$ from the coast station.

Some coast stations may request additional information, e.g. ship's name, call sign, etc.

(5)   This sequence may be preceded where necessary by suitable prompts or facility selection information and, if appropriate, any consequent ship station reply, or may be deleted where not applicable (e.g. where facility codes WX, NAV, STA, MSG or HELP are input at step 4). Where facility code DIRTLX $\uparrow$ xy was input at step 4, this sequence may be replaced by the distant end answer-back or by any service signal (e.g. NC, OCC, etc.) received from the telex network.

(6)   Message procedures depend on which facility is used:

For TLX where the store-and-forward system is remote from the coast station, ITU-T Recommendation F.72 may apply. Where the store-and-forward system is located at the coast station, the complete information content of the message sent at this step will be forwarded to the subscriber whose telex number is given by xy.

For DIRTLX, see ITU-T Recommendation F.60.

For TGM, see ITU-T Recommendations F.1 and F.31.

For SVC and MED, the message will normally be plain text and no specific message procedure is required.

For RTL, the message will be plain text but should include the postal address of the addressee.

For STA, the appropriate status information is returned to the ship in accordance with ITU-T Recommendation F.72, § 11.3 and 11.4.

For POS and FREQ, specific national procedures may apply.

(7)   This sequence of 4 K's "KKKK" (4 combination No. 11 signals in the letter case) indicates that any network connection should be cleared but that the radio path should be maintained and that the procedure should immediately proceed to step 11. This sequence may be used elsewhere in the procedure in which case the procedure reverts to step 3.

(8)   This step is optional and may not apply to all facilities.

—————————

RECOMMENDATION ITU-R P.525-2*

CALCULATION OF FREE-SPACE ATTENUATION

(1978-1982-1994)

The ITU Radiocommunication Assembly,

considering

a)   that free-space propagation is a fundamental reference for radio-engineering,

recommends

1.   that the methods in Annex 1 be used for the calculation of attenuation in free space.

ANNEX 1

1.   Introduction

As free-space propagation is often used as a reference in other texts, this Annex presents relevant formulae.

2.   Basic formulae for telecommunication links

Free-space propagation may be calculated in two different ways, each of which is adapted to a particular type of service.

2.1   Point-to-area links

If there is a transmitter serving several randomly-distributed receivers (broadcasting, mobile service), the field is calculated at a point located at some appropriate distance from the transmitter by the expression:

$$e = \frac{\sqrt{30p}}{d} \tag{1}$$

where:

e :   r.m.s. field strength (V/m) (see Note 1)

p :   equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (W) (see Note 2)

d :   distance from the transmitter to the point in question (m).

Equation (1) is often replaced by equation (2) which uses practical units:

$$e_{mV/m} = 173 \frac{\sqrt{p_{kW}}}{d_{km}} \tag{2}$$

For antennas operating in free-space conditions the cymomotive force may be obtained by multiplying together e and d in equation (1). Its dimension is volts.

_____

Note 1 – If the wave is elliptically polarized and not linear, and if the electric field components along two orthogonal axes are expressed by e_x and e_y, the left-hand term of equation (1) should be replaced by $\sqrt{e_x^2 + e_y^2}$. e_x and e_y can be deduced only if the axial ratio is known. e should be replaced by $e\sqrt{2}$ in the case of circular polarization.

Note 2 – In the case of antennas located at ground level and operating on relatively low frequencies with vertical polarization, radiation is generally considered only in the upper half-space. This should be taken into account in determining the e.i.r.p. (see Recommendation ITU-R PN.368).

2.2   Point-to-point links

With a point-to-point link it is preferable to calculate the free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf} or A_0), as follows:

$$L_{bf} = 20 \log \left(\frac{4\pi d}{\lambda} \right) \qquad\qquad \text{dB} \qquad\qquad (3)$$

where:

    L_{bf}:   free-space basic transmission loss (dB)

    d: distance

    λ: wavelength, and

    d and λ are expressed in the same unit.

Equation (3) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \qquad\qquad \text{dB} \qquad\qquad (4)$$

where:

    f: frequency (MHz)

    d: distance (km).

2.3   Relations between the characteristics of a plane wave

There are also relations between the characteristics of a plane wave (or a wave which can be treated as a plane wave) at a point:

$$s = \frac{e^2}{120\pi} = \frac{4\pi p_r}{\lambda^2} \qquad\qquad (5)$$

where:

s: power flux-density (W/m²)

e: r.m.s. field strength (V/m)

p_r: power (W) available from an isotropic antenna located at this point

λ: wavelength (m).

3.   The free-space basic transmission loss for a radar system (symbols: L_{br} or A_{0r})

Radar systems represent a special case because the signal is subjected to a loss while propagating both from the transmitter to the target and from the target to the receiver. For radars using a common antenna for both transmitter and receiver, a radar free-space basic transmission loss, L_{br}, can be written as follows:

$$L_{br} = 103.4 + 20 \log f + 40 \log d - 10 \log \sigma \qquad\qquad \text{dB} \qquad\qquad (6)$$

where:

σ: radar target cross-section (m²)

d: distance from the radar to the target (km)

f: frequency of the system (MHz).

The radar target cross-section of an object is the ratio of the total isotropically equivalent scattered power to the incident power density.

4. Conversion formulae

On the basis of free-space propagation, the following conversion formulae may be used.

Field strength for a given isotropically transmitted power:

$$E = P_t - 20 \log d + 74.8 \tag{7}$$

Isotropically received power for a given field strength:

$$P_r = E - 20 \log f - 167.2 \tag{8}$$

Free-space basic transmission loss for a given isotropically transmitted power and field strength:

$$L_{bf} = P_t - E + 20 \log f + 167.2 \tag{9}$$

Power flux-density for a given field strength:

$$S = E - 145.8 \tag{10}$$

where:

P_t : isotropically transmitted power (dB(W))

P_r : isotropically received power (dB(W))

E : electric field strength (dB(μV/m))

f : frequency (GHz)

d : radio path length (km)

L_{bf}: free-space basic transmission loss (dB)

S : power flux-density (dB(W/m^2)).

Note that equations (7) and (9) can be used to derive equation (4).

_____

RECOMMENDATION ITU-R P.526-11

Propagation by diffraction

(Question ITU-R 202/3)

(1978-1982-1992-1994-1995-1997-1999-2001-2003-2005-2007-2009)

Scope

This Recommendation presents several models to enable the reader to evaluate the effect of diffraction on the received field strength. The models are applicable to different obstacle types and to various path geometries.

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to provide engineering information for the calculation of field strengths over diffraction paths,

recommends

1   that the methods described in Annex 1 be used for the calculation of field strengths over diffraction paths, which may include a spherical earth surface, or irregular terrain with different kinds of obstacles.

Annex 1

1   Introduction

Although diffraction is produced only by the surface of the ground or other obstacles, account must be taken of the mean atmospheric refraction on the transmission path to evaluate the geometrical parameters situated in the vertical plane of the path (angle of diffraction, radius of curvature, height of obstacle). For this purpose, the path profile has to be traced with the appropriate equivalent Earth radius (Recommendation ITU-R P.834). If no other information is available, an equivalent Earth radius of 8 500 km may be taken as a basis.

2   Basic concepts

Diffraction of radiowaves over the Earth's surface is affected by terrain irregularities. In this context, before going further into the prediction methods for this propagation mechanism, a few basic concepts are given in this section.

2.1 Fresnel ellipsoids and Fresnel zones

In studying radiowave propagation between two points A and B, the intervening space can be subdivided by a family of ellipsoids, known as Fresnel ellipsoids, all having their focal points at A and B such that any point M on one ellipsoid satisfies the relation:

$$AM + MB = AB + n\frac{\lambda}{2} \tag{1}$$

where n is a whole number characterizing the ellipsoid and $n = 1$ corresponds to the first Fresnel ellipsoid, etc., and λ is the wavelength.

As a practical rule, propagation is assumed to occur in line-of-sight (LoS), i.e. with negligible diffraction phenomena if there is no obstacle within the first Fresnel ellipsoid.

The radius of an ellipsoid at a point between the transmitter and the receiver can be approximated in self-consistent units by:

$$R_n = \left[\frac{n\lambda d_1 d_2}{d_1 + d_2}\right]^{1/2} \tag{2}$$

or, in practical units:

$$R_n = 550\left[\frac{n d_1 d_2}{(d_1 + d_2)f}\right]^{1/2} \tag{3}$$

where f is the frequency (MHz) and d_1 and d_2 are the distances (km) between transmitter and receiver at the point where the ellipsoid radius (m) is calculated.

Some problems require consideration of Fresnel zones which are the zones obtained by taking the intersection of a family of ellipsoids by a plane. The zone of order n is the part between the curves obtained from ellipsoids n and $n - 1$, respectively.

2.2 Penumbra width

The transition from light to shadow defines the penumbra region. This transition takes place along a narrow strip (penumbra width) in the boundary of geometric shadow. Figure 1 shows the penumbra width (W) in the case of a transmitter located a height, h, above a smooth spherical earth, which is given by:

$$w = \left[\frac{\lambda a_e^2}{\pi}\right]^{1/3} \qquad \text{m} \tag{4}$$

where:

  λ: wavelength (m)

  a_e: effective Earth radius (m).

FIGURE 1

Definition of penumbra width

0526-01
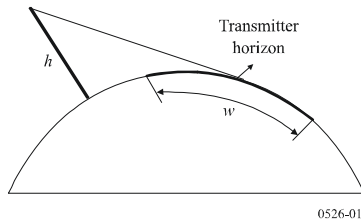
2.3 Diffraction zone

The diffraction zone of a transmitter extends from the LoS distance where the path clearance is equal to 60% of the first Fresnel zone radius, (R_1), up to a distance well beyond the transmitter horizon where the mechanism of troposcatter becomes predominant.

2.4 Obstacle surface smoothness criterion

If the surface of the obstacle has irregularities not exceeding Δh,

where:

$$\Delta h = 0.04 \left[R \lambda^2 \right]^{1/3} \qquad \text{m} \qquad (5)$$

where:

R: obstacle curvature radius (m)

λ: wavelength (m)

then the obstacle may be considered smooth and the methods described in § 3 and 4.2 may be used to calculate the attenuation.

2.5 Isolated obstacle

An obstacle can be considered isolated if there is no interaction between the obstacle itself and the surrounding terrain. In other words, the path attenuation is only due to the obstacle alone without any contribution from the remaining terrain. The following conditions must be satisfied:

– no overlapping between penumbra widths associated with each terminal and the obstacle top;

– the path clearance on both sides of the obstacles should be, at least, 0.6 of the first Fresnel zone radius;

– no specular reflection on both sides of the obstacle.

2.6 Types of terrain

Depending on the numerical value of the parameter Δh (see Recommendation ITU-R P.310) used to define the degree of terrain irregularities, three types of terrain can be classified:

a) *Smooth terrain*

The surface of the Earth can be considered smooth if terrain irregularities are of the order or less than $0.1R$, where R is the maximum value of the first Fresnel zone radius in the propagation path. In this case, the prediction model is based on the diffraction over the spherical Earth (see § 3).

b)   *Isolated obstacles*

The terrain profile of the propagation path consists of one or more isolated obstacles. In this case, depending on the idealization used to characterize the obstacles encountered in the propagation path, the prediction models described in § 4 should be used.

c)   *Rolling terrain*

The profile consists of several small hills, none of which form a dominant obstruction. Within its frequency range Recommendation ITU-R P.1546 is suitable for predicting field strength but it is not a diffraction method.

2.7   Fresnel integrals

The complex Fresnel integral is given by:

$$F_c(v) = \int_0^v \exp\left(j\frac{\pi s^2}{2}\right) \, ds = C(v) + jS(v) \tag{6}$$

where j is the complex operator equal to $\sqrt{-1}$, and $C(v)$ and $S(v)$ are the Fresnel cosine and sine integrals defined by:

$$C(v) = \int_0^v \cos\left(\frac{\pi s^2}{2}\right) \, ds \tag{7a}$$

$$S(v) = \int_0^v \sin\left(\frac{\pi s^2}{2}\right) \, ds \tag{7b}$$

The complex Fresnel integral $F_c(v)$ can be evaluated by numerical integration, or with sufficient accuracy for most purposes for positive v using:

$$F_c(v) = \exp(jx)\sqrt{\frac{x}{4}} \sum_{n=0}^{11} \left[(a_n - jb_n)\left(\frac{x}{4}\right)^n\right] \qquad \text{for} \quad 0 \le x < 4 \tag{8a}$$

$$F_c(v) = \left(\frac{1+j}{2}\right) + \exp(jx)\sqrt{\frac{4}{x}} \sum_{n=0}^{11} \left[(c_n - jd_n)\left(\frac{4}{x}\right)^n\right] \qquad \text{for} \quad x \ge 4 \tag{8b}$$

where:

$$x = 0.5 \, \pi \, v^2 \tag{9}$$

and a_n, b_n, c_n and d_n are the Boersma coefficients given below:

a_0	= +1.595769140	b_0	= −0.000000033	c_0	= +0.000000000	d_0	= +0.199471140
a_1	= −0.000001702	b_1	= +4.255387524	c_1	= −0.024933975	d_1	= +0.000000023
a_2	= −6.808568854	b_2	= −0.000092810	c_2	= +0.000003936	d_2	= −0.009351341
a_3	= −0.000576361	b_3	= −7.780020400	c_3	= +0.005770956	d_3	= +0.000023006
a_4	= +6.920691902	b_4	= −0.009520895	c_4	= +0.000689892	d_4	= +0.004851466
a_5	= −0.016898657	b_5	= +5.075161298	c_5	= −0.009497136	d_5	= +0.001903218
a_6	= −3.050485660	b_6	= −0.138341947	c_6	= +0.011948809	d_6	= −0.017122914
a_7	= −0.075752419	b_7	= −1.363729124	c_7	= −0.006748873	d_7	= +0.029064067
a_8	= +0.850663781	b_8	= −0.403349276	c_8	= +0.000246420	d_8	= −0.027928955
a_9	= −0.025639041	b_9	= +0.702222016	c_9	= +0.002102967	d_9	= +0.016497308
a_{10}	= −0.150230960	b_{10}	= −0.216195929	c_{10}	= −0.001217930	d_{10}	= −0.005598515
a_{11}	= +0.034404779	b_{11}	= +0.019547031	c_{11}	= +0.000233939	d_{11}	= +0.000838386

$C(v)$ and $S(v)$ may be evaluated for negative values of v by noting that:

$$C(-v) = -C(v) \tag{10a}$$

$$S(-v) = -S(v) \tag{10b}$$

3 Diffraction over a spherical Earth

The additional transmission loss due to diffraction over a spherical Earth can be computed by the classical residue series formula. A computer program GRWAVE, available from the ITU, provides the complete method. A subset of the outputs from this program (for antennas close to the ground and at lower frequencies) is presented in Recommendation ITU-R P.368.

The following subsections describe numerical and nomogram methods which may be used for frequencies 10 MHz and above. For frequencies below 10 MHz, GRWAVE should always be used. Section 3.1 gives methods for over-the-horizon paths. Section 3.1.1 is a numerical method. Section 3.1.2 is a nomogram method. Section 3.2 is a method applicable for the smooth earth case for any distance and for frequencies 10 MHz and above. This utilizes the numerical method in § 3.1.1.

3.1 Diffraction loss for over-the-horizon paths

At long distances over the horizon, only the first term of the residue series is important. Even near or at the horizon this approximation can be used with a maximum error around 2 dB in most cases.

This first term can be written as the product of a distance term, F, and two height gain terms, G_T and G_R § 3.1.1 and § 3.1.2 describe how these terms can be obtained from simple formula or from nomograms.

3.1.1 Numerical calculation

3.1.1.1 Influence of the electrical characteristics of the surface of the Earth

The extent to which the electrical characteristics of the surface of the Earth influence the diffraction loss can be determined by calculating a normalized factor for surface admittance, K, given by the formulae:

in self-consistent units:

$$K_H = \left(\frac{2\pi a_e}{\lambda} \right)^{-1/3} \left[(\varepsilon - 1)^2 + (60\lambda\sigma)^2 \right]^{-1/4} \qquad \text{for horizontal polarization} \tag{11}$$

and

$$K_V = K_H \left[\varepsilon^2 + (60\lambda\sigma)^2 \right]^{1/2} \qquad \text{for vertical polarization} \tag{12}$$

or, in practical units:

$$K_H = 0.36(a_e f)^{-1/3} \left[(\varepsilon - 1)^2 + (18000\sigma/f)^2 \right]^{-1/4} \tag{11a}$$

$$K_V = K_H \left[\varepsilon^2 + (18000\sigma/f)^2 \right]^{1/2} \tag{12a}$$

where:

a_e : effective radius of the Earth (km)

ε : effective relative permittivity

σ : effective conductivity (S/m)

f : frequency (MHz).

Typical values of K are shown in Fig. 2.

FIGURE 2

Calculation of K
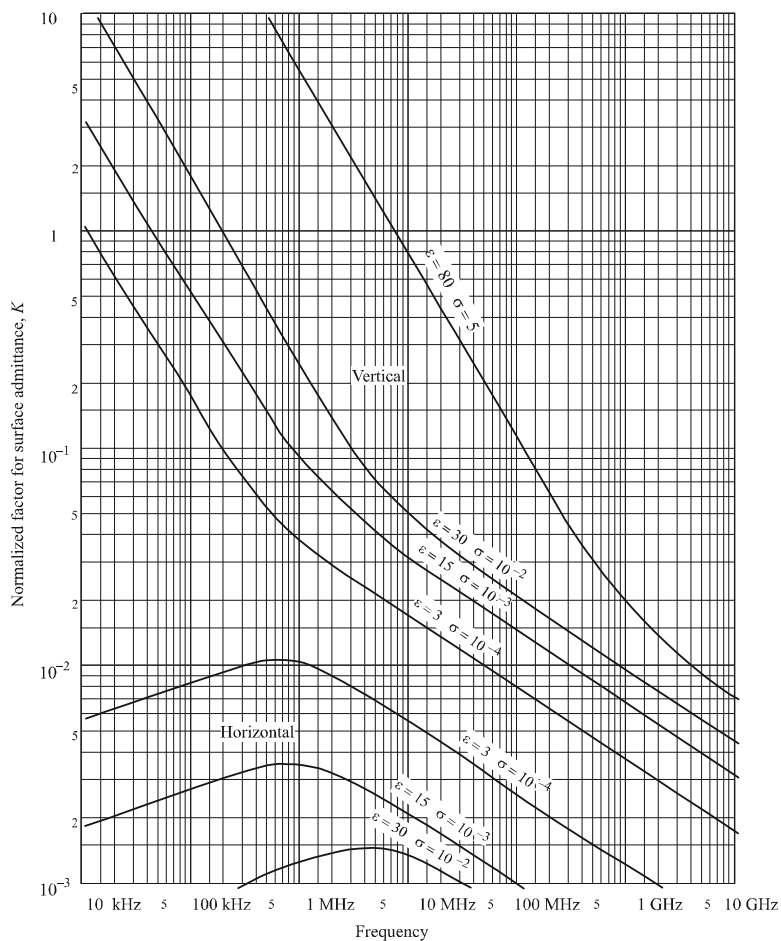
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If K is less than 0.001, the electrical characteristics of the Earth are not important. For values of K greater than 0.001 and less than 1, the appropriate formulae given in § 3.1.1.2 can be used. When K has a value greater than about 1, the diffraction field strength calculated using the method of § 3.1.1.2 differs from the results given by the computer program GRWAVE, and the difference increases rapidly as K increases. GRWAVE should be used for K greater than 1. This only occurs for vertical polarization, at frequencies below 10 MHz over sea, or below 200 kHz over land. In all other cases the method of § 3.1.1.2 is valid.

3.1.1.2 Diffraction field strength formulae

The diffraction field strength, E, relative to the free-space field strength, E_0, is given by the formula:

$$20\log \frac{E}{E_0} = F(X) + G(Y_1) + G(Y_2) \qquad \text{dB} \tag{13}$$

where X is the normalized length of the path between the antennas at normalized heights Y_1 and Y_2 (and where $20 \log \frac{E}{E_0}$ is generally negative).

In self-consistent units:

$$X = \beta \left(\frac{\pi}{\lambda a_e^2} \right)^{1/3} d \tag{14}$$

$$Y = 2\beta \left(\frac{\pi^2}{\lambda^2 a_e} \right)^{1/3} h \tag{15}$$

or, in practical units:

$$X = 2.188\,\beta\,f^{1/3} a_e^{-2/3}\,d \tag{14a}$$

$$Y = 9.575 \times 10^{-3}\,\beta\,f^{2/3}\,a_e^{-1/3}\,h \tag{15a}$$

where:

d: path length (km)

a_e: equivalent Earth's radius (km)

h: antenna height (m)

f: frequency (MHz).

β is a parameter allowing for the type of ground and for polarization. It is related to K by the following semi-empirical formula:

$$\beta = \frac{1 + 1.6\,K^2 + 0.67\,K^4}{1 + 4.5\,K^2 + 1.53\,K^4} \tag{16}$$

For horizontal polarization at all frequencies, and for vertical polarization above 20 MHz over land or 300 MHz over sea, β may be taken as equal to 1.

For vertical polarization below 20 MHz over land or 300 MHz over sea, β must be calculated as a function of K. However, it is then possible to disregard ε and write:

$$K^2 \approx 6.89 \frac{\sigma}{k^{2/3} \, f^{5/3}} \tag{16a}$$

where σ is expressed in S/m, f (MHz) and k is the multiplying factor of the Earth's radius.

The distance term is given by the formula:

$$F(X) = 11 + \log(X) - 17.6 X \qquad \text{for } X \geq 1.6 \tag{17a}$$

$$F(X) = -20 \log(X) - 5.6488X^{1.425} \qquad \text{for } X < 1.6 \tag{17b}$$

The height gain term, $G(Y)$ is given by the following formulae:

$$G(Y) \cong 17.6(B - 1.1)^{1/2} - 5 \log(B - 1.1) - 8 \qquad \text{for } B > 2 \tag{18}$$

For $B < 2$ the value of $G(Y)$ is a function of the value of K computed in § 3.1.1.1:

$$G(Y) \cong 20 \log(B + 0.1B^3) \qquad \text{for } 10 K < B \leq 2 \tag{18a}$$

$$G(Y) \cong 2 + 20 \log K + 9 \log(B/K)\big[\log(B/K) + 1\big] \qquad \text{for } K/10 < B \leq 10 K \tag{18b}$$

$$G(Y) \cong 2 + 20 \log K \qquad \text{for } B \leq K/10 \tag{18c}$$

where:

$$B = \beta Y \tag{18d}$$

Equations (18) to (18c) have been formulated on the assumption that $K < 0.2$. If used for $K > 0.2$ it should be noted that the inequalities defining the applicability of each equation imply a switch from equations (18) to (18b) or to (18c) as Y is varied, depending on the value of K. In these cases there will be a discontinuity in the value of $G(Y)$ at the switch. For values of Y and K where more than one of equations (18) to (18c) are applicable according to the inequalities, it is recommended that equation (18) is used in preference to equations (18a) to (18c). Note that even for values of $K < 0.2$, there can be a discontinuity between equations (18a) and (18b) of up to 3 dB.

The accuracy of the diffracted field strength given by equation (13) is limited by the approximation inherent in only using the first term of the residue series. Equation (13) is accurate to better than 2 dB for values of X, Y_1 and Y_2 that are constrained by the formula:

$$X - (\beta Y_1)^{1/2} \Delta(Y_1, K) - (\beta Y_2)^{1/2} \Delta(Y_2, K) > X_{lim} \tag{19}$$

where:

$$X_{lim} = 1.096 - 1.280(1 - \beta) \tag{19a}$$

$$\Delta(Y, K) = \Delta(Y, 0) + 1.779(1 - \beta)[\Delta(Y, \infty) - \Delta(Y, 0)] \tag{19b}$$

$\Delta(Y,0)$ and $\Delta(Y,\infty)$ are given by:

$$\Delta(Y,0) = 0.5\left[1 + \tanh\left(\frac{0.5\log(\beta Y) - 0.255}{0.3}\right)\right] \tag{19c}$$

$$\Delta(Y,\infty) = 0.5\left[1 + \tanh\left(\frac{0.5\log(\beta Y) + 0.255}{0.25}\right)\right] \tag{19d}$$

Consequently, the minimum distance d_{min} for which equation (13) is valid is given by:

$$X_{min} = X_{lim} + (\beta Y_1)^{1/2}\Delta(Y_1, K) + (\beta Y_2)^{1/2}\Delta(Y_2, K) \tag{19e}$$

and d_{min} is obtained from X_{min} using equation (14a).

3.1.2   Calculation by nomograms

Under the same approximation condition (the first term of the residue series is dominant), the calculation may also be made using the following formula:

$$20\log\frac{E}{E_0} = F(d) + H(h_1) + H(h_2) \qquad \text{dB} \tag{20}$$

where:

E: received field strength

E_0: field strength in free space at the same distance

d: distance between the extremities of the path

h_1 and h_2: heights of the antennas above the spherical earth.

The function F (influence of the distance) and H (height-gain) are given by the nomograms in Figs. 3, 4, 5 and 6.

These nomograms (Figs. 3 to 6) give directly the received level relative to free space, for $k = 1$ and $k = 4/3$, and for frequencies greater than approximately 30 MHz. k is the effective Earth radius factor, defined in Recommendation ITU-R P.310. However, the received level for other values of k may be calculated by using the frequency scale for $k = 1$, but replacing the frequency in question by a hypothetical frequency equal to f/k^2 for Figs. 3 and 5 and $f/\sqrt{k}$, for Figs. 4 and 6.

Very close to the ground the field strength is practically independent of the height. This phenomenon is particularly important for vertical polarization over the sea. For this reason Fig. 6 includes a heavy black vertical line AB. If the straight line should intersect this heavy line AB, the real height should be replaced by a larger value, so that the straight line just touches the top of the limit line at A.

NOTE 1 – Attenuation relative to free space is given by the negative of the values given by equation (20). If equation (20) gives a value above the free-space field, the method is invalid.

NOTE 2 – The effect of line AB is included in the numerical method given in § 3.1.1.

FIGURE 3

Diffraction by a spherical Earth – effect of distance
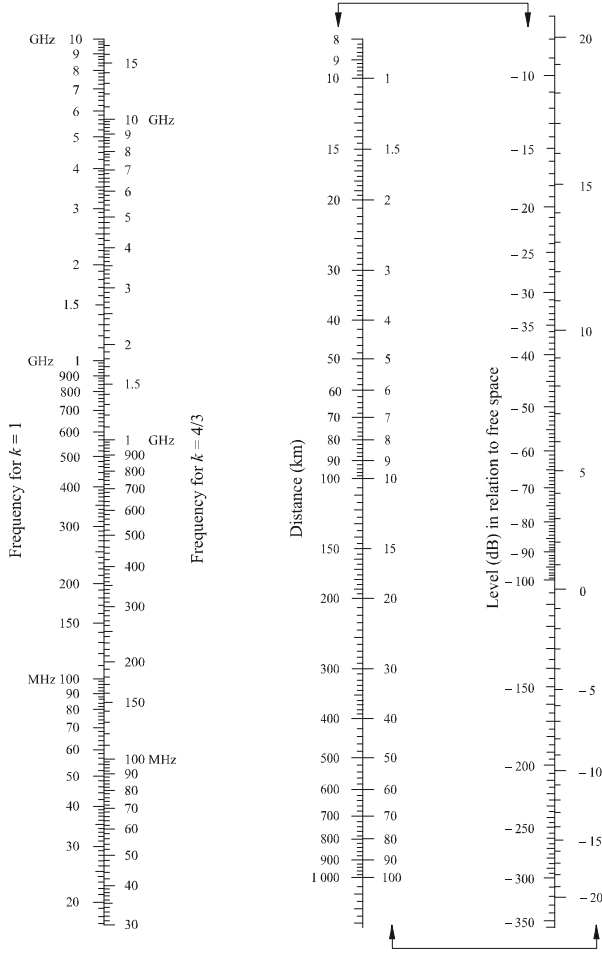
Horizontal polarization over land and sea
Vertical polarization over land

(The scales joined by arrows should be used together)

0526-03

FIGURE 4

Diffraction by a spherical Earth – height-gain
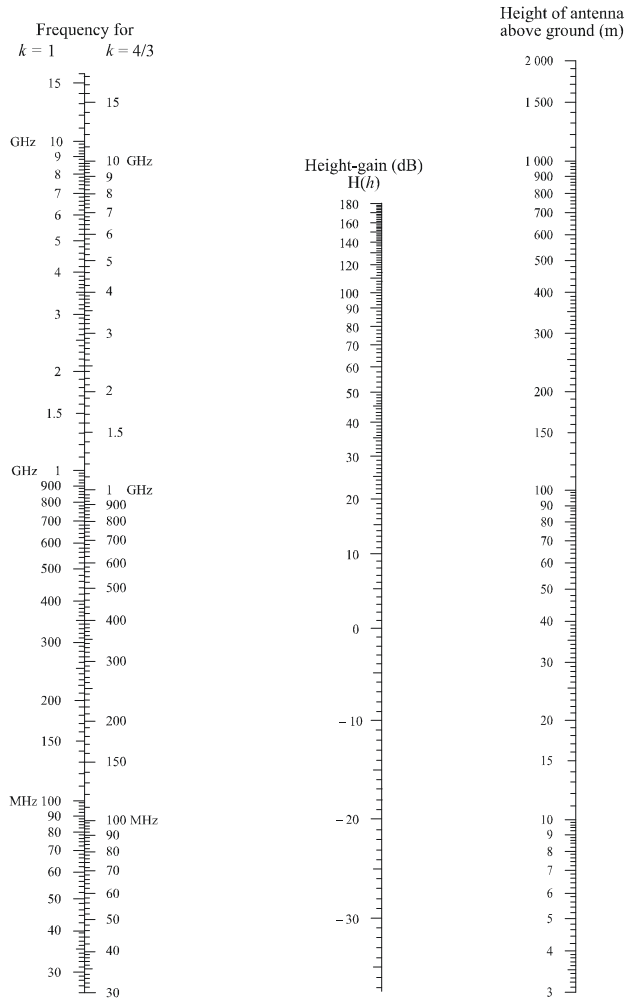
Horizontal polarization – land and sea
Vertical polarization – land

0526-04

FIGURE 5

Diffraction by a spherical Earth – effect of distance
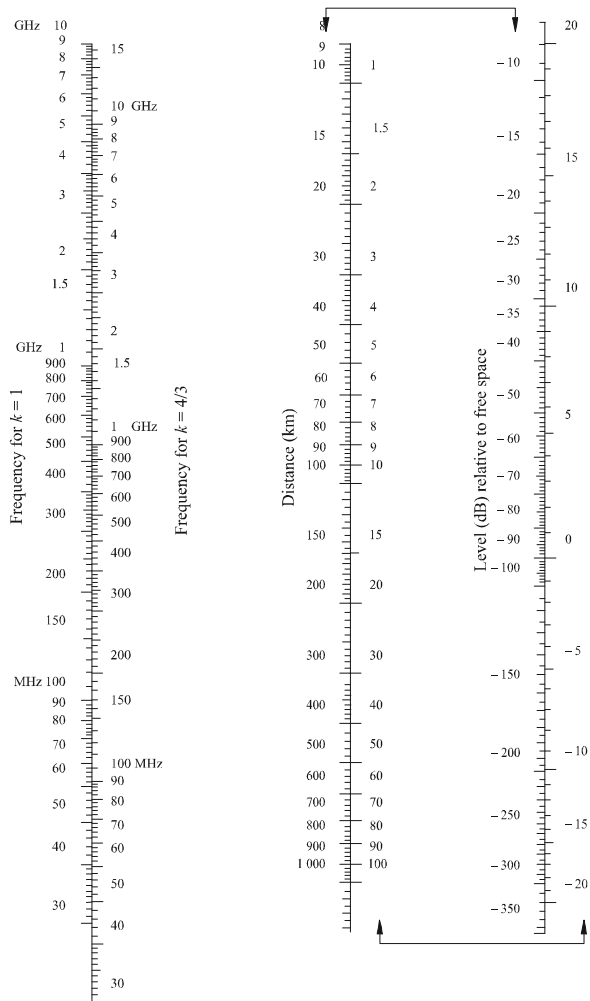
Vertical polarization over sea
(The scales joined by arrows should be used together)

0526-05

FIGURE 6

Diffraction by a spherical Earth – height-gain
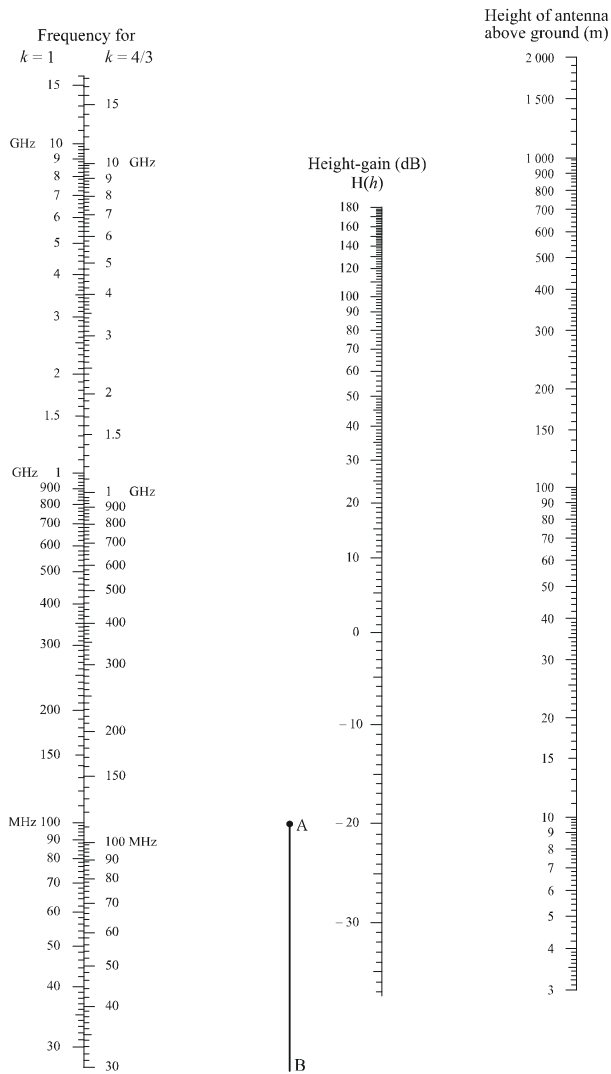
Vertical polarization – sea

0526-06

3.2 Diffraction loss for any distance at 10 MHz and above

The following step-by-step procedure should be used for a spherical-earth path of any length at frequencies of 10 MHz and above. The method uses the calculation in § 3.1.1 for over-the-horizon cases, and otherwise an interpolation procedure based on a notional effective-earth radius.

The procedure uses self-consistent units and proceeds as follows:

Calculate the marginal line-of-sight distance given by:

$$d_{los} = \sqrt{2a_e} \left(\sqrt{h_1} + \sqrt{h_2} \right) \tag{21}$$

If $d \geq d_{los}$ calculate diffraction loss using the method in § 3.1.1. No further calculation is necessary.

Otherwise continue:

Calculate the smallest clearance height between the curved-earth path and the ray between the antennas, h (see Fig. 7), given by:

$$h = \frac{\left(h_1 - \dfrac{d_1^2}{2a_e} \right)d_2 + \left(h_2 - \dfrac{d_2^2}{2a_e} \right)d_1}{d} \tag{22}$$

$$d_1 = \frac{d}{2}(1 + b) \tag{22a}$$

$$d_2 = d - d_1 \tag{22b}$$

$$b = 2\sqrt{\frac{m+1}{3m}} \cos\left\{ \frac{\pi}{3} + \frac{1}{3} \arccos\left(\frac{3c}{2}\sqrt{\frac{3m}{(m+1)^3}} \right) \right\} \tag{22c}$$

$$c = \frac{h_1 - h_2}{h_1 + h_2} \tag{22d}$$

$$m = \frac{d^2}{4a_e(h_1 + h_2)} \tag{22e}$$

Calculate the required clearance for zero diffraction loss, h_{req}, given by:

$$h_{req} = 0.552\sqrt{\frac{d_1 d_2 \lambda}{d}} \tag{23}$$

If $h > h_{req}$ the diffraction loss for the path is zero. No further calculation is required.

Otherwise continue:

Calculate the modified effective earth radius, a_{em}, which gives marginal line-of-sight at distance d given by:

$$a_{em} = 0.5\left(\frac{d}{\sqrt{h_1} + \sqrt{h_2}}\right)^2 \tag{24}$$

Use the method in § 3.1.1. to calculate the diffraction loss for the path using the modified effective earth radius a_{em} in place of the effective earth radius a_e, and designate this loss A_h.

If A_h is negative, the diffraction loss for the path is zero, and no further calculation is necessary.

Otherwise calculate the interpolated diffraction loss, A (dB), given by:

$$A = \left[1 - h/h_{req}\right]A_h \tag{25}$$

4   Diffraction over isolated obstacles

Many propagation paths encounter one obstacle or several separate obstacles and it is useful to estimate the losses caused by such obstacles. To make such calculations it is necessary to idealize the form of the obstacles, either assuming a knife-edge of negligible thickness or a thick smooth obstacle with a well-defined radius of curvature at the top. Real obstacles have, of course, more complex forms, so that the indications provided in this Recommendation should be regarded only as an approximation.

In those cases where the direct path between the terminals is much shorter than the diffraction path, it is necessary to calculate the additional transmission loss due to the longer path.

The data given below apply when the wavelength is fairly small in relation to the size of the obstacles, i.e., mainly to VHF and shorter waves ($f > 30$ MHz).

FIGURE 7

Path clearance
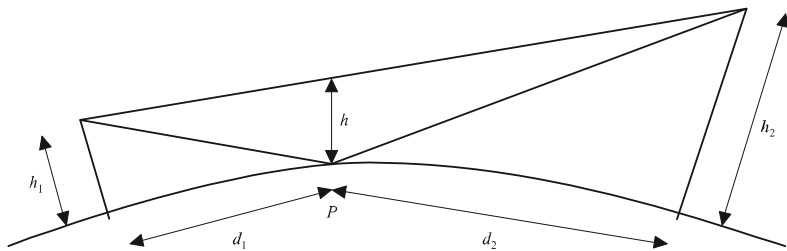
P: Reflection point

0526-07

4.1   Single knife-edge obstacle

In this extremely idealized case (see Figs. 8a) and 8b)), all the geometrical parameters are combined together in a single dimensionless parameter normally denoted by ν which may assume a variety of equivalent forms according to the geometrical parameters selected:

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)} \tag{26}$$

$$v = \theta\sqrt{\frac{2}{\lambda\left(\frac{1}{d_1} + \frac{1}{d_2}\right)}} \tag{27}$$

$$v = \sqrt{\frac{2\,h\,\theta}{\lambda}} \qquad (v \text{ has the sign of } h \text{ and } \theta) \tag{28}$$

$$v = \sqrt{\frac{2\,d}{\lambda} \cdot \alpha_1\alpha_2} \qquad (v \text{ has the sign of } \alpha_1 \text{ and } \alpha_2) \tag{29}$$

where:

h :   height of the top of the obstacle above the straight line joining the two ends of the path. If the height is below this line, h is negative

d_1 and d_2 :   distances of the two ends of the path from the top of the obstacle

d :   length of the path

θ :   angle of diffraction (rad); its sign is the same as that of h. The angle θ is assumed to be less than about 0.2 rad, or roughly 12º

α_1 and α_2 :   angles between the top of the obstacle and one end as seen from the other end. α_1 and α_2 are of the sign of h in the above equations.

NOTE 1 – In equations (26) to (29) inclusive h, d, d_1, d_2 and γ should be in self-consistent units.

FIGURE 8

Geometrical elements

(For definitions of θ, α_1, α_2, d, d_1, d_2 and R, see § 4.1 and 4.2)
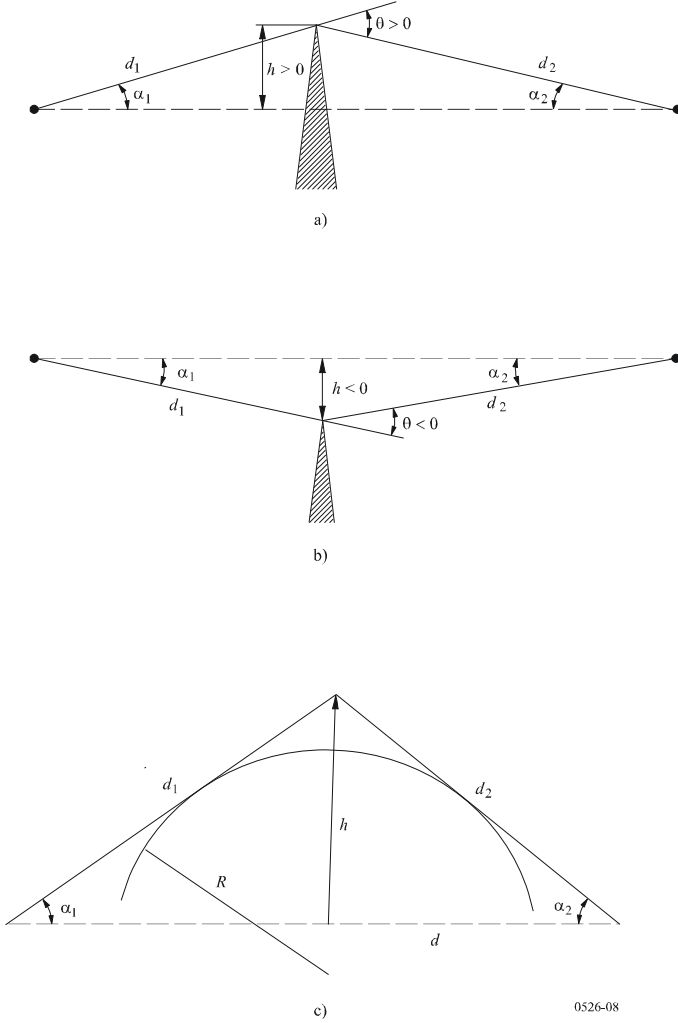
0526-08

Figure 9 gives, as a function of v, the loss $J(v)$ (dB).

$J(v)$ is given by:

$$J(v) = -20 \, \log \left(\frac{\sqrt{[1 - C(v) - S(v)]^2 + [C(v) - S(v)]^2}}{2} \right) \tag{30}$$

where $C(v)$ and $S(v)$ are the real and imaginary parts respectively of the complex Fresnel integral $F(v)$ defined in § 2.7.

For v greater than -0.78 an approximate value can be obtained from the expression:

$$J(v) = 6.9 + 20\log\left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1\right) \qquad \text{dB} \qquad (31)$$

FIGURE 9

Knife-edge diffraction loss
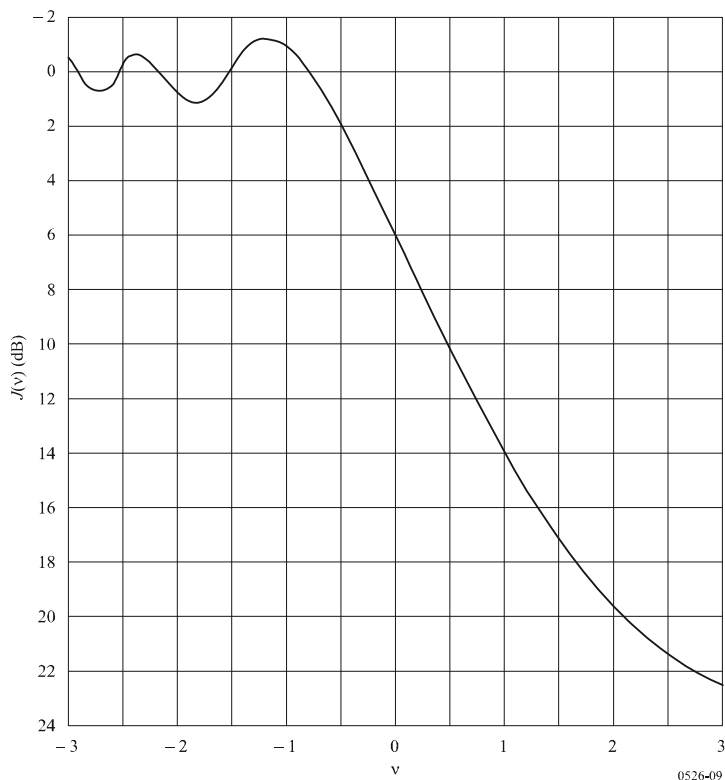
0526-09

4.2   Single rounded obstacle

The geometry of a rounded obstacle of radius R is illustrated in Fig. 8c). Note that the distances d_1 and d_2, and the height h above the baseline, are all measured to the vertex where the projected rays intersect above the obstacle. The diffraction loss for this geometry may be calculated as:

$$A = J(v) + T(m,n) \qquad \text{dB} \qquad (32)$$

where:

a) $J(v)$ is the Fresnel-Kirchoff loss due to an equivalent knife-edge placed with its peak at the vertex point. The dimensionless parameter v may be evaluated from any of equations (26) to (29) inclusive. For example, in practical units equation (26) may be written:

$$v = 0.0316\, h \left[\frac{2(d_1 + d_2)}{\lambda\, d_1\, d_2} \right]^{1/2} \tag{33}$$

where h and λ are in metres, and d_1 and d_2 are in kilometres.

$J(v)$ may be obtained from Fig. 9 or from equation (31). Note that for an obstruction to LoS propagation, v is positive and equation (31) is valid.

b) $T(m,n)$ is the additional attenuation due to the curvature of the obstacle:

$$T(m,n) = 7.2 m^{1/2} - (2 - 12.5n)m + 3.6 m^{3/2} - 0.8 m^2 \qquad \text{dB} \qquad \text{for } mn \le 4 \tag{34a}$$

$$T(m,n) = -6 - 20 \log (mn) + 7.2 m^{1/2} - (2 - 17n)m + 3.6 m^{3/2} - 0.8 m^2 \quad \text{dB} \quad \text{for } mn > 4 \tag{34b}$$

and

$$m = R \left[\frac{d_1 + d_2}{d_1 d_2} \right] \bigg/ \left[\frac{\pi R}{\lambda} \right]^{1/3} \tag{35}$$

$$n = h \left[\frac{\pi R}{\lambda} \right]^{2/3} \bigg/ R \tag{36}$$

and R, d_1, d_2, h and λ are in self-consistent units.

Note that as R tends to zero, $T(m,n)$ also tend to zero. Thus equation (32) reduces to knife-edge diffraction for a cylinder of zero radius.

The obstacle radius of curvature corresponds to the radius of curvature at the apex of a parabola fitted to the obstacle profile in the vicinity of the top. When fitting the parabola, the maximum vertical distance from the apex to be used in this procedure should be of the order of the first Fresnel zone radius where the obstacle is located. An example of this procedure is shown in Fig. 10, where:

$$y_i = \frac{x_i^2}{2 r_i} \tag{37}$$

and r_i is the radius of curvature corresponding to the sample i of the vertical profile of the ridge. In the case of N samples, the median radius of curvature of the obstacle is given by:

$$r = \frac{1}{N} \sum_{1}^{N} \frac{x_i^2}{2 y_i} \tag{38}$$

FIGURE 10

Vertical profile of the obstacle

0526-10
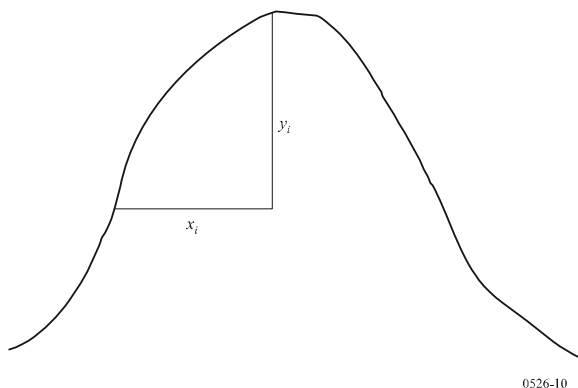
4.3   Double isolated edges

This method consists of applying single knife-edge diffraction theory successively to the two obstacles, with the top of the first obstacle acting as a source for diffraction over the second obstacle (see Fig. 11). The first diffraction path, defined by the distances a and b and the height h'_1, gives a loss L_1 (dB). The second diffraction path, defined by the distances b and c and the height h'_2, gives a loss L_2 (dB). L_1 and L_2 are calculated using formulae of § 4.1. A correction term L_c (dB) must be added to take into account the separation b between the edges. L_c may be estimated by the following formula:

$$L_c = 10 \log \left[\frac{(a + b)\,(b + c)}{b\,(a + b + c)} \right]$$ (39)

which is valid when each of L_1 and L_2 exceeds about 15 dB. The total diffraction loss is then given by:

$$L = L_1 + L_2 + L_c$$ (40)

The above method is particularly useful when the two edges give similar losses.

FIGURE 11

Method for double isolated edges

a b c 0526-11
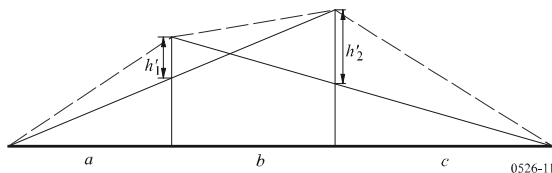
If one edge is predominant (see Fig. 12), the first diffraction path is defined by the distances a and $b + c$ and the height h_1. The second diffraction path is defined by the distances b and c and the height h'_2.

Figure showing the main and the second obstacle

0526-12
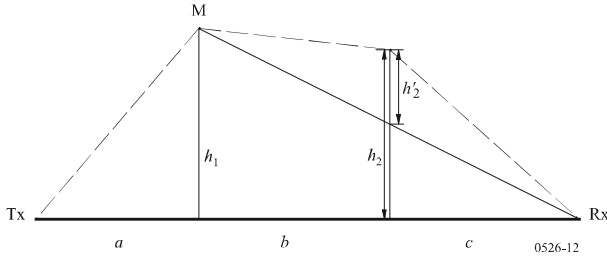
The method consists of applying single knife-edge diffraction theory successively to the two obstacles. First, the higher h/r ratio determines the main obstacle, M, where h is the edge height from the direct path TxRx as shown in Fig. 12, and r is the first Fresnel ellipsoid radius given by equation (2). Then h'_2, the height of the secondary obstacle from the sub-path MR, is used to calculate the loss caused by this secondary obstacle. A correction term T_c (dB) must be subtracted, in order to take into account the separation between the two edges as well as their height. T_c (dB) may be estimated by the following formula:

$$T_c = \left[12 - 20\log_{10}\left(\frac{2}{1-\frac{\alpha}{\pi}}\right)\right]\left(\frac{q}{p}\right)^{2p} \tag{41}$$

with:

$$p = \left[\frac{2}{\lambda}\frac{(a+b+c)}{(b+c)a}\right]^{1/2} h_1 \tag{42a}$$

$$q = \left[\frac{2}{\lambda}\frac{(a+b+c)}{(a+b)c}\right]^{1/2} h_2 \tag{42b}$$

$$\tan\alpha = \left[\frac{b(a+b+c)}{ac}\right]^{1/2} \tag{42c}$$

h_1 and h_2 are the edge heights from the direct path transmitter-receiver.

The total diffraction loss is given by:

$$L = L_1 + L_2 - T_c \tag{43}$$

The same method may be applied to the case of rounded obstacles using § 4.3.

In cases where the diffracting obstacle may be clearly identified as a flat-roofed building a single knife-edge approximation is not sufficient. It is necessary to calculate the phasor sum of two components: one undergoing a double knife-edge diffraction and the other subject to an additional reflection from the roof surface. It has been shown that, where the reflectivity of the roof surface and any difference in height between the roof surface and the side walls are not accurately known, then a double knife-edge model produces a good prediction of the diffracted field strength, ignoring the reflected component.

4.4 Multiple isolated obstacles

Two methods are recommended for the diffraction over irregular terrain which forms one or more obstacles to LoS propagation. The first method assumes that each obstacle can be represented by a cylinder with a radius equal to the radius of curvature at the obstacle top, being advisable when detailed vertical profile through the ridge is available.

The second one corresponds to an empirical solution based on the supposition of knife-edge obstacles plus a correction to compensate for the higher loss due to a radius of curvature different from zero. The calculation takes Earth curvature into account via the concept of an effective Earth radius (see Recommendation ITU-R P.452, § 4.3). This method is suitable in cases where a single general procedure is required for terrestrial paths over land or sea and for both LoS and transhorizon.

A profile of the radio path should be available consisting of a set of samples of ground height above sea level ordered at intervals along the path, the first and last being the heights of the transmitter and receiver above sea level, and a corresponding set of horizontal distances from the transmitter. Each height and distance pair are referred to as a profile point and given an index, with indices incrementing from one end of the path to the other. Although it is not essential to the method, in the following description it is assumed that indices increment from the transmitter to the receiver. It is preferable but not essential for the profile samples to be equally spaced horizontally.

4.4.1 Cascaded cylinder method

The terrain height profile should be available as a set of samples of ground height above sea level, the first and last being the heights of the transmitter and receiver above sea level. Distance and height values are described as though stored in arrays indexed from 1 to N, where N equals the number of profile samples.

In the following a systematic use of suffices is made:

h_i: height above sea level of the i-th point

d_i: distance from the transmitter to the i-th point

d_{ij}: distance from the i-th to the j-th points.

The first step is to perform a "stretched string" analysis of the profile. This identifies the sample points which would be touched by a string stretched over the profile from transmitter to receiver. This may be done by the following procedure, in which all values of height and distance are in self-consistent units, and all angles are in radians. The method includes approximations which are valid for radio paths making small angles to the horizontal. If a path has ray gradients exceeding about 5° more exact geometry may be justified.

Each string point is identified as the profile point with the highest angular elevation above the local horizontal as viewed from the previous string point, starting at one end of the profile and finishing at the other. Viewed from point s, the elevation of the i-th profile sample ($i > s$) is given by:

$$e = \left[(h_i - h_s) / d_{si} \right] - \left[d_{si} / 2a_e \right] \tag{44}$$

where:

a_e: effective Earth radius, given by:

$= k \times 6\,371$ (km)

and

k: effective Earth-radius factor.

A test is now applied to determine whether any group of two or more string points should represent the same terrain obstruction. For samples at spacings of 250 m or less any group of string points which are consecutive profile samples, other than the transmitter or receiver, should be treated as one obstruction.

Each obstruction is now modelled as a cylinder, as illustrated in Fig. 13. The geometry of each individual cylinder corresponds with Fig. 8c). Note that in Fig. 13 the distances s_1, s_2 for each cylinder are shown as measured horizontally between the vertex points, and that for near-horizontal rays these distances approximate to the slope distances d_1 and d_2 in Fig. 8c). For ray angles to the horizontal greater than about 5º it may be necessary to set s_1 and s_2 to the inter-vertex slope distances d_1 and d_2.

FIGURE 13

The cascaded cylinder model a), overall problem b), details

a)

b)
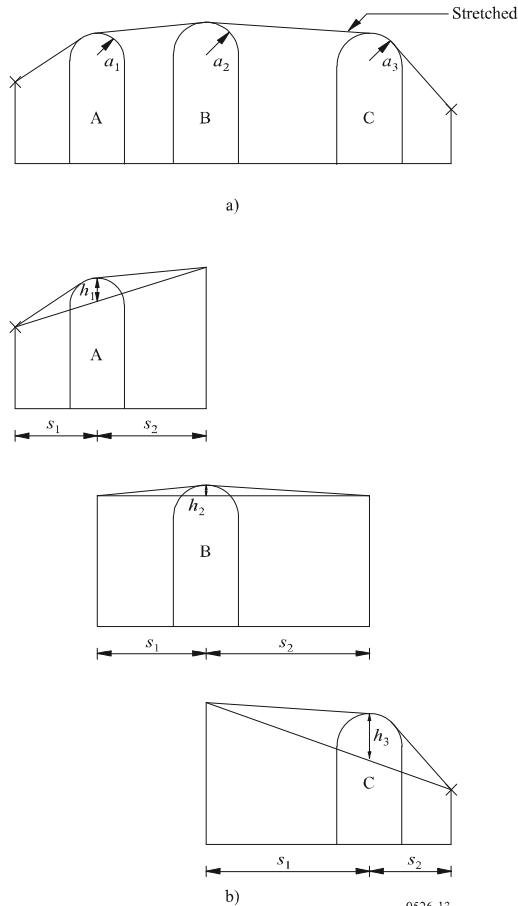
0526-13

Similarly in Fig. 13, the height h of each cylinder is shown as measured vertically from its vertex down to the straight line joining the adjacent vertex or terminal points. The value of h for each cylinder corresponds to h in Fig. 8c). Again, for near-horizontal rays the cylinder heights may be computed as though vertical, but for steeper ray angles it may be necessary to compute h at right angles to the baseline of its cylinder.

Figure 14 illustrates the geometry for an obstruction consisting of more than one string point. The following points are indicated by:

w: closest string point or terminal on the transmitter side of the obstruction which is not part of the obstruction

x: string point forming part of the obstruction which is closest to the transmitter

y: string point forming part of the obstruction which is closest to the receiver

z: closest string point or terminal on the receiver side of the obstruction which is not part of the obstruction

v: vertex point made by the intersection of incident rays above the obstruction.

FIGURE 14

Geometry of a multipoint obstacle
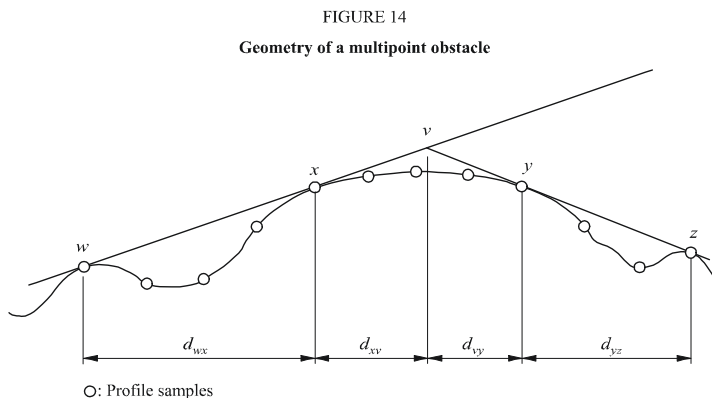
O: Profile samples

0526-14

The letters w, x, y and z will also be indices to the arrays of profile distance and height samples. For an obstruction consisting of an isolated string point, x and y will have the same value, and will refer to a profile point which coincides with the vertex. Note that for cascaded cylinders, points y and z for one cylinder are points w and x for the next, etc.

A step-by-step method for fitting cylinders to a general terrain profile is described in Appendix 1 to Annex 1. Each obstruction is characterized by w, x, y and z. The method of Appendix 1 to Annex 1 is then used to obtain the cylinder parameters s_1, s_2, h and R. Having modelled the profile in this way, the diffraction loss for the path is computed as the sum of three terms:

–   the sum of diffraction losses over the cylinders;

–   the sum of sub-path diffraction between cylinders (and between cylinders and adjacent terminals);

–   a correction term.

The total diffraction loss, in dB relative to free-space loss, may be written:

$$L_d = \sum_{i=1}^{N} L'_i + L''(w\,x)_1 + \sum_{i=1}^{N} L''(y\,z)_i - 20\log C_N \qquad \text{dB} \qquad (45)$$

where:

L'_i : diffraction loss over the i-th cylinder calculated by the method of § 4.2

$L''(w\,x)_1$: sub-path diffraction loss for the section of the path between points w and x for the first cylinder

$L''(y\,z)_i$: sub-path diffraction loss for the section of the path between points y and z for all cylinders

C_N : correction factor to account for spreading loss due to diffraction over successive cylinders.

Appendix 2 to Annex 1 gives a method for calculating L'' for each LoS section of the path between obstructions.

The correction factor, C_N, is calculated using:

$$C_N = (P_a / P_b)^{0.5} \qquad (46)$$

where:

$$P_a = s_1 \prod_{i=1}^{N} [(s_2)_i] \left(s_1 + \sum_{j=1}^{N} [(s_2)_j] \right) \qquad (47)$$

$$P_b = (s_1)_1 (s_2)_N \prod_{i=1}^{N} [(s_1)_i + (s_2)_i] \qquad (48)$$

and the suffices to round brackets indicate individual cylinders.

4.4.2 Cascaded knife edge method

The method is based on a procedure which is used from 1 to 3 times depending on the path profile. The procedure consists of finding the point within a given section of the profile with the highest value of the geometrical parameter ν as described in § 4.1. The section of the profile to be considered is defined from point index a to point index b (a < b). If a + 1 = b there is no intermediate point and the diffraction loss for the section of the path being considered is zero. Otherwise the construction is applied by evaluating $ν_n$ (a < n < b) and selecting the point with the highest value of ν. The value of ν for the n-th profile point is given by:

$$\nu_n = h\sqrt{2d_{ab}/\lambda d_{an}d_{nb}} \qquad (49)$$

where:

$$h = h_n + [d_{an}d_{nb}/2\,r_e] - [(h_a\,d_{nb} + h_b\,d_{an})/d_{ab}] \qquad (49a)$$

h_a, h_b, h_n : vertical heights as shown in Fig. 15

d_{an}, d_{nb}, d_{ab} : horizontal distances as shown in Fig. 15

r_e : effective Earth radius

λ : wavelength

and all h, d, r_e and λ are in self-consistent units.

The diffraction loss is then given as the knife-edge loss $J(v)$ according to equation (31) for $v > -0.78$, and is otherwise zero.

Note that equation (49) is derived directly from equation (26). The geometry of equation (49a) is illustrated in Fig. 15. The second term in equation (49a) is a good approximation to the additional height at point n due to Earth curvature.

FIGURE 15

Geometry for a single edge
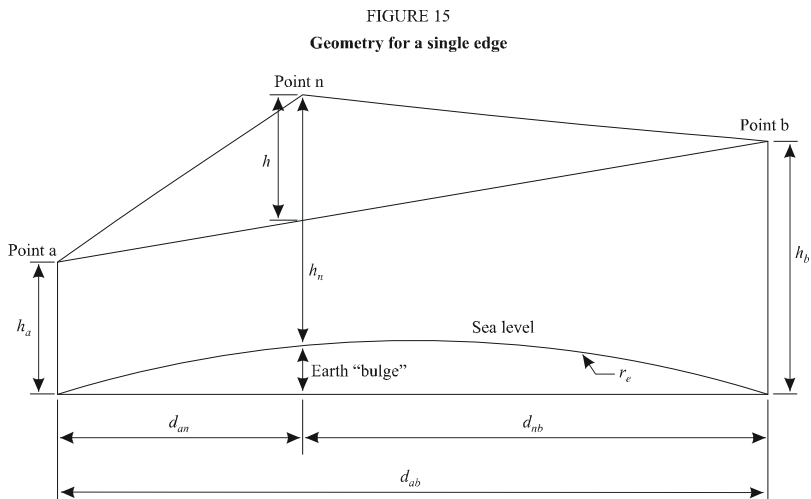
0526-15

The above procedure is first applied to the entire profile from transmitter to receiver. The point with the highest value of v is termed the principal edge, p, and the corresponding loss is $J(v_p)$.

If $v_p > -0.78$ the procedure is applied twice more:

–   from the transmitter to point p to obtain v_t and hence $J(v_t)$;

–   from point p to the receiver to obtain v_r and hence $J(v_r)$.

The excess diffraction loss for the path is then given by:

$$L = J(v_p) + T[J(v_t) + J(v_r) + C] \qquad \text{for } v_p > -0.78 \qquad (50a)$$

$$L = 0 \qquad \text{for } v_p \leq -0.78 \qquad (50b)$$

where:

   C: empirical correction

$$C = 10.0 + 0.04D \qquad (51)$$

   D: total path length (km)

and

$$T = 1.0 - \exp[-J(v_p)/6.0] \qquad (52)$$

Note that the above procedure, for transhorizon paths, is based on the Deygout method limited to a maximum of 3 edges. For line-of-sight paths it differs from the Deygout construction in that two secondary edges are still used in cases where the principal edge results in a non-zero diffraction loss.

This method can produce discontinuities in predicted diffraction loss as a function of effective Earth radius due to different profile points being selected for the principal or auxiliary edges. To produce a smooth and monotonic prediction of diffraction loss as a function of effective Earth radius, the principal edge, and if they exist the auxiliary edges on either side, can first be found for median effective Earth radius. These edges can then be used when calculating diffraction losses for other values of effective Earth radius, without repeating the procedure for locating these points. However, this method may be less accurate at effective Earth radii greater than or less than the median value.

The cascaded knife-edge method is used for the diffraction model in Recommendation ITU-R P.452-12. Diffraction losses are calculated for two effective Earth radii: the median value, and the value exceeded for β% of an average year, for which and Earth-curvature factor of 3 is used. The parameter $β_0$ represents the percentage of time anomalous propagation will dominate the overall result. An interpolation procedure, based on the inverse complementary cumulative normal distribution, is the used to calculate the diffraction loss not exceeded for any percentage time between $β_0$ and 50%. However, when calculating the diffraction loss for $β_0\%$ time, the method in Recommendation ITU-R P.452 uses the principal edge, and if they exist the auxiliary edges, located for the median case. This avoids the possibility that a small change in profile details might produce a large change in diffraction loss at $β_0\%$ time due to a change in these edges.

5 Diffraction by thin screens

The following methods assume that the obstruction is in the form of a thin screen. They can be applied to propagation around an obstacle or through an aperture.

5.1 Finite-width screen

Interference suppression for a receiving site (e.g. a small earth station) may be obtained by an artificial screen of finite width transverse to the direction of propagation. For this case the field in the shadow of the screen may be calculated by considering three knife-edges, i.e. the top and the two sides of the screen. Constructive and destructive interference of the three independent contributions will result in rapid fluctuations of the field strength over distances of the order of a wavelength. The following simplified model provides estimates for the average and minimum diffraction loss as a function of location. It consists of adding the amplitudes of the individual contributions for an estimate of the minimum diffraction loss and a power addition to obtain an estimate of the average diffraction loss. The model has been tested against accurate calculations using the uniform theory of diffraction (UTD) and high-precision measurements.

Step 1: Calculate the geometrical parameter ν for each of the three knife-edges (top, left side and right side) using any of equations (26) to (29).

Step 2: Calculate the loss factor $j(ν) = 10^{J(ν)/20}$ associated with each edge from equation (31).

Step 3: Calculate minimum diffraction loss J_{min} from:

$$J_{min}(ν) = -20 \, \log \left[\frac{1}{j_1(ν)} + \frac{1}{j_2(ν)} + \frac{1}{j_3(ν)} \right] \qquad \text{dB} \qquad (53)$$

or, alternatively,

Step 4: Calculate average diffraction loss J_{av} from:

$$J_{av}(ν) = -10 \, \log \left[\frac{1}{j_1^2(ν)} + \frac{1}{j_2^2(ν)} + \frac{1}{j_3^2(ν)} \right] \qquad \text{dB} \qquad (54)$$

5.2   Diffraction by rectangular apertures and composite apertures or screens

The method described below can be used to predict the diffraction loss due to a rectangular aperture in an otherwise totally-absorbing thin screen. The method can be extended to cover several rectangular apertures or finite screens, and is thus an alternative method for the finite-width screen discussed in § 5.1.

5.2.1   Diffraction by a single rectangular aperture

Figure 16 shows the geometry used to represent a rectangular aperture in an infinite totally-absorbing thin screen.

FIGURE 16

Geometry for a single rectangular aperture
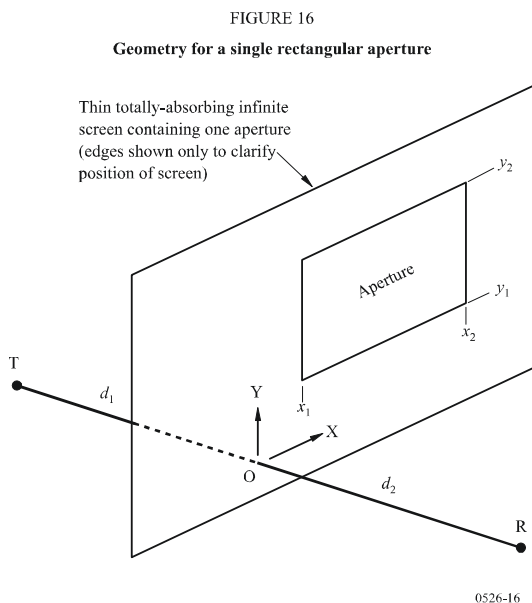
The positions of the aperture edges, x_1, x_2, y_1 and y_2, are given in a Cartesian coordinate system with origin at the point where the straight line from transmitter T to receiver R passes through the screen, with propagation parallel to the Z axis. T and R are at distances d_1 and d_2 respectively behind and in front of the screen.

The field strength, e_a, at the receiver in linear units normalized to free space is given in complex form by:

$$e_a(x_1,x_2,y_1,y_2) = 0.5(C_x\,C_y - S_x\,S_y) + \text{j}\,0.5\,(C_x\,S_y + S_x\,C_y) \tag{55}$$

where:

$$C_x = C(v_{x2}) - C(v_{x1}) \tag{56a}$$

$$C_y = C(v_{y2}) - C(v_{y1}) \tag{56b}$$

$$S_x = S(v_{x2}) - S(v_{x1}) \tag{56c}$$

$$S_y = S(v_{y2}) - S(v_{y1}) \tag{56d}$$

The four values of v are as given by equation (26) substituting x_1, x_2, y_1 and y_2 in turn for h, and $C(v)$ and $S(v)$ are as given in equations (7a) and (7b) and may be evaluated from the complex Fresnel coefficient using equations (8a) and (8b).

The corresponding diffraction loss L_a is given by:

$$L_a = -20 \log (e_a) \qquad \text{dB} \tag{57}$$

5.2.2 Diffraction by composite apertures or screens

The method for a single rectangular aperture can be extended as follows:

Since in the linear units normalized to free space of equation (55) the free-space field is given by $1.0 + j\ 0.0$, the normalized complex field e_s due to a single rectangular screen (isolated from ground) is given by:

$$e_s = 1.0 - e_a \tag{58}$$

where e_a is calculated using equation (55) for an aperture of the same size and position as the screen.

– The normalized field due to combinations of several rectangular apertures or isolated screens can be calculated by adding the results of equation (55) or (58).

– Arbitrarily shaped apertures or screens can be approximated by suitable combinations of rectangular apertures or screens.

– Since the $C(v)$ and $S(v)$ integrals converge to $0.5 + j\ 0.5$ as v approaches infinity, equation (50) can be applied to rectangles of unlimited extent in one or more directions.

6 Diffraction over a finitely conducting wedge

The method described below can be used to predict the diffraction loss due to a finitely conducting wedge. Suitable applications are for diffraction around the corner of a building or over the ridge of a roof, or where terrain can be characterized by a wedge-shaped hill. The method requires the conductivity and relative dielectric constant of the obstructing wedge, and assumes that no transmission occurs through the wedge material.

The method is based on UTD. It takes account of diffraction in both the shadow and line-of-sight region, and a method is provided for a smooth transition between these regions.

The geometry of a finitely conducting wedge-shaped obstacle is illustrated in Fig. 17.

FIGURE 17

Geometry for application of UTD wedge diffraction
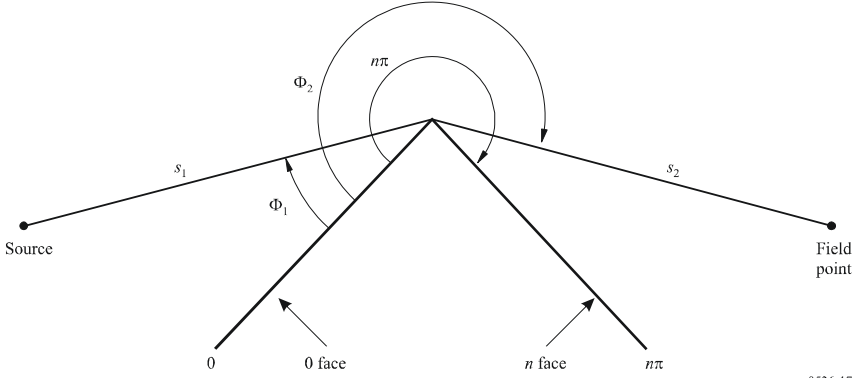
The UTD formulation for the electric field at the field point, specializing to two dimensions, is:

$$e_{UTD} = e_0 \frac{\exp(-jks_1)}{s_1} D^{\perp||} \cdot \sqrt{\frac{s_1}{s_2(s_1 + s_2)}} \cdot \exp(-jks_2) \tag{59}$$

where:

e_{UTD}: electric field at the field point

e_0: relative source amplitude

s_1: distance from source point to diffracting edge

s_2: distance from diffracting edge to field point

k: wave number $2\pi/\lambda$

$D^{\perp||}$: diffraction coefficient depending on the polarization (parallel or perpendicular to the plane of incidence) of the incident field on the edge

and s_1, s_2 and λ are in self-consistent units.

The diffraction coefficient for a finitely conducting wedge is given as:

$$D^{\perp||} = \frac{-\exp(-j\pi/4)}{2n\sqrt{2\pi k}} \left\{ \begin{array}{l} \cot\left(\frac{\pi + (\Phi_2 - \Phi_1)}{2n}\right) \cdot F(kLa^+(\Phi_2 - \Phi_1)) \\[2mm] + \cot\left(\frac{\pi - (\Phi_2 - \Phi_1)}{2n}\right) \cdot F(kLa^-(\Phi_2 - \Phi_1)) \\[2mm] + R_0^{\perp||} \cdot \cot\left(\frac{\pi - (\Phi_2 + \Phi_1)}{2n}\right) \cdot F(kLa^-(\Phi_2 + \Phi_1)) \\[2mm] + R_n^{\perp||} \cdot \cot\left(\frac{\pi + (\Phi_2 + \Phi_1)}{2n}\right) \cdot F(kLa^+(\Phi_2 + \Phi_1)) \end{array} \right\} \tag{60}$$

where:

Φ_1: incidence angle, measured from incidence face (0 face)

Φ_2: diffraction angle, measured from incidence face (0 face)

n : external wedge angle as a multiple of π radians (actual angle $= n\pi$ (rad))

$j = \sqrt{-1}$

and where $F(x)$ is a Fresnel integral:

$$F(x) = 2j\sqrt{x} \cdot \exp(jx) \cdot \int_{\sqrt{x}}^{\infty} \exp(-jt^2)\,dt \tag{61}$$

$$\int_{\sqrt{x}}^{\infty} \exp(-jt^2)\,dt = \sqrt{\frac{\pi}{8}}(1-j) - \int_{0}^{\sqrt{x}} \exp(-jt^2)\,dt \tag{62}$$

The integral may be calculated by numerical integration.

Alternatively a useful approximation is given by:

$$\int_{\sqrt{x}}^{\infty} \exp(-jt^2)\,dt = \sqrt{\frac{\pi}{2}}A(x) \tag{63}$$

where:

$$A(x) = \begin{cases} \dfrac{1-j}{2} - \exp(-jx)\sqrt{\dfrac{x}{4}}\displaystyle\sum_{n=0}^{11}\left[(a_n + jb_n)\left(\dfrac{x}{4}\right)^n\right] & \text{if } x < 4 \\[4mm] -\exp(-jx)\sqrt{\dfrac{4}{x}}\displaystyle\sum_{n=0}^{11}\left[(c_n + jd_n)\left(\dfrac{4}{x}\right)^n\right] & \text{otherwise} \end{cases} \tag{64}$$

and the coefficients a, b, c, d are given in § 2.7.

$$L = \frac{s_2 \cdot s_1}{s_2 + s_1} \tag{65}$$

$$a^{\pm}(\beta) = 2\cos^2\left(\frac{2n\pi N^{\pm} - \beta}{2}\right) \tag{66}$$

where:

$$\beta = \Phi_2 \pm \Phi_1 \tag{67}$$

In equation (45), $N^{\pm}$ are the integers which most nearly satisfy the equation.

$$N^{\pm} = \frac{\beta \pm \pi}{2n\pi} \tag{68}$$

$R_0^{\perp\parallel}, R_n^{\perp\parallel}$ are the reflection coefficients for either perpendicular or parallel polarization given by:

$$R^{\perp} = \frac{\sin(\Phi) - \sqrt{\eta - \cos(\Phi)^2}}{\sin(\Phi) + \sqrt{\eta - \cos(\Phi)^2}} \tag{69}$$

$$R^{\parallel} = \frac{\eta \cdot \sin(\Phi) - \sqrt{\eta - \cos(\Phi)^2}}{\eta \cdot \sin(\Phi) + \sqrt{\eta - \cos(\Phi)^2}} \tag{70}$$

where:

$$\Phi = \Phi_1 \text{ for } R_0 \text{ and } \Phi = (n\pi - \Phi_2) \quad \text{for } R_n$$

$$\eta = \varepsilon_r - j \times 18 \times 10^9 \sigma / f$$

ε_r: relative dielectric constant of the wedge material

σ: conductivity of the wedge material (S/m)

f: frequency (Hz).

Note that if necessary the two faces of the wedge may have different electrical properties.

At shadow and reflection boundaries one of the cotangent functions in equation (60) becomes singular.

However $D^{\perp \|}$ remains finite, and can be readily evaluated. The term containing the singular cotangent function is given for small ε as:

$$\cot\left(\frac{\pi \pm \beta}{2n}\right) \cdot F(kLa^{\pm}(\beta)) \cong n \cdot \left[\sqrt{2\pi kL} \cdot \text{sign}(\varepsilon) - 2kL\varepsilon \cdot \exp(j\pi/4)\right] \cdot \exp(j\pi/4) \tag{71}$$

with ε defined by:

$$\varepsilon = \pi + \beta - 2\pi n N^+ \qquad \qquad \text{for} \qquad \beta = \Phi_2 + \Phi_1 \tag{72}$$

$$\varepsilon = \pi - \beta + 2\pi n N^- \qquad \qquad \text{for} \qquad \beta = \Phi_2 - \Phi_1 \tag{73}$$

The resulting diffraction coefficient will be continuous at shadow and reflection boundaries, provided that the same reflection coefficient is used when calculating reflected rays.

The field e_{LD} due to the diffracted ray, plus the LoS ray for $(\Phi_2 - \Phi_1) < \pi$, is given by:

$$e_{LD} = \begin{cases} e_{UTD} + \dfrac{\exp(-jks)}{s} & \text{for} \quad \Phi_2 < \Phi_1 + \pi \\ e_{UTD} & \text{for} \quad \Phi_2 \geq \Phi_1 + \pi \end{cases} \tag{74}$$

where:

s: straight-line distance between the source and field points.

Note that at $(\Phi_2 - \Phi_1) = \pi$ the 2nd cotangent term in equation (60) will become singular, and that the alternative approximation given by equation (71) must be used.

The field strength at the field point (dB) relative to the field which would exist at the field point in the absence of the wedge-shaped obstruction (i.e. dB relative to free space) is given by setting e_0 to unity in equation (59) and calculating:

$$E_{UTD} = 20 \log\left(\left|\frac{s \cdot e_{UTD}}{\exp(-jks)}\right|\right) \tag{75}$$

where:

s: straight-line distance between the source and field points.

Note that, for $n = 2$ and zero reflection coefficients, this should give the same results as the knife edge diffraction loss curve shown in Fig. 9.

A MathCAD version of the UTD formulation is available from the Radiocommunication Bureau.

7 Guide to propagation by diffraction

A general guide for the evaluation of diffraction loss corresponding to § 3 and 4 is shown in Fig. 18. This flow chart summarizes the procedure to be adopted in each case.

FIGURE 18

Guide to propagation by diffraction
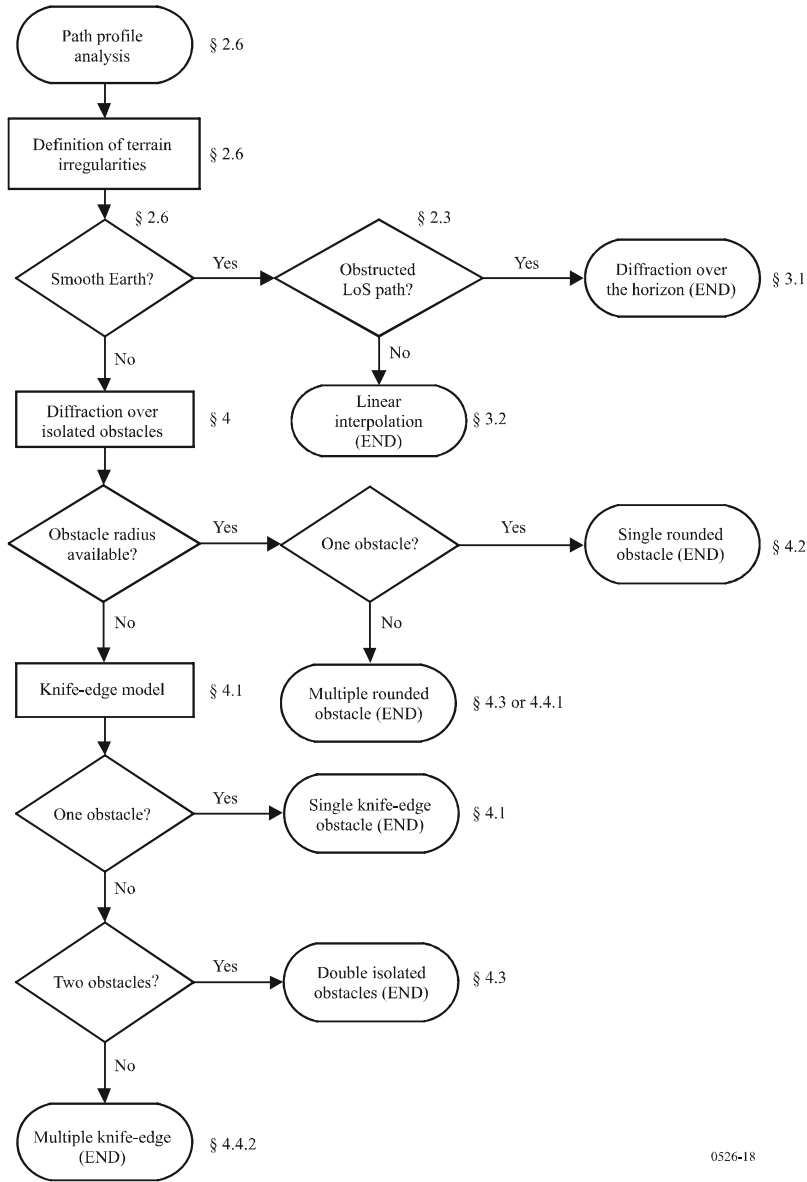
0526-18

Appendix 1
to Annex 1

Calculation of cylinder parameters

The following procedure can be used to calculate the cylinder parameters illustrated in Figs. 8c) and 14 for each of the terrain obstructions. Self-consistent units are used, and all angles are in radians. The approximations used are valid for radio paths which are within about 5° of horizontal.

1   Diffraction angle and position of vertex

Although not used directly as cylinder parameters, both the diffraction angle over the cylinder and the position of the vertex are required.

The diffraction angle over the obstacle is given by:

$$\theta = \alpha_w + \alpha_z + \alpha_e \tag{76}$$

where α_w and α_z are the angular elevations of points x and y above the local horizontal as viewed from points w and z respectively, given by:

$$\alpha_w = (h_x - h_w) / d_{wx} - d_{wx} / 2a_e \tag{77}$$

$$\alpha_z = (h_y - h_z) / d_{yz} - d_{yz} / 2a_e \tag{78}$$

and α_e is the angle subtended by the great-circle distance between points w and z given by:

$$\alpha_e = d_{wz} / a_e \tag{79}$$

The distance of the vertex from point w is calculated according to whether the obstruction is represented by a single profile sample or by more than one:

For a single-point obstruction:

$$d_{wv} = d_{wx} \tag{80}$$

For a multipoint obstruction it is necessary to protect against very small values of diffraction:

$$d_{wv} = \left[(\alpha_z + \alpha_e / 2)\, d_{wz} + h_z - h_w \right] / \theta \qquad \text{for } \theta \cdot a_e \geq d_{xy} \tag{81a}$$

$$d_{wv} = (d_{wx} + d_{wy}) / 2 \qquad \text{for } \theta \cdot a_e < d_{xy} \tag{81b}$$

The distance of point z from the vertex point is given by:

$$d_{vz} = d_{wz} - d_{wv} \tag{82}$$

The height of the vertex point above sea level is calculated according to whether the obstruction is represented by a single profile sample or by more than one.

For a single point obstruction:

$$h_v = h_x \tag{83}$$

For a multipoint obstruction:

$$h_v = d_{wv}\, \alpha_w + h_w + d_{2,wv} / 2a_e \tag{84}$$

2 Cylinder parameters

The cylinder parameters illustrated in Fig. 8c) can now be calculated for each of the terrain obstacles defined by the string analysis:

d_1 and d_2 are the positive inter-vertex distances to the obstacles (or terminals) on the transmitter and receiver sides of the obstacle respectively,

and:

$$h = h_v + d_{wv}\, d_{vz}\,/\,2a_e - (h_w\, d_{vz} + h_z\, d_{wv})\,/\,d_{wz} \tag{85}$$

To calculate the cylinder radius use is made of two further profile samples:

    p: the point adjacent to x on the transmitter side,

and:

    q: the point adjacent to y on the receiver side.

Thus the profile indices p and q are given by:

$$p = x - 1 \tag{86}$$

and:

$$q = y + 1 \tag{87}$$

If a point given by p or q is a terminal, then the corresponding value of h should be the terrain height at that point, not the height above sea level of the antenna.

The cylinder radius is calculated as the difference in slope between the profile section p-x and y-q, allowing for Earth curvature, divided by the distance between p and q.

The distances between profile samples needed for this calculation are:

$$d_{px} = d_x - d_p \tag{88}$$

$$d_{yq} = d_q - d_y \tag{89}$$

$$d_{pq} = d_q - d_p \tag{90}$$

The difference in slope between the p-x and y-q profile sections is given in radians by:

$$t = (h_x - h_p)\,/\,d_{px} + (h_y - h_q)\,/\,d_{yq} - d_{pq}\,/\,a_e \tag{91}$$

where a_e is the effective Earth radius.

The cylinder radius is now given by:

$$R = \left[d_{pq}\,/\,t \right]\, [1 - \exp(-4\,v)]^3 \tag{92}$$

where v is the dimensionless knife-edge parameter in equation (32).

In equation (92), the second factor is an empirical smoothing function applied to the cylinder radius to avoid discontinuities for marginally LoS obstructions.

Appendix 2
to Annex 1

Sub-path diffraction losses

1   Introduction

This Appendix provides a method for computing the sub-path diffraction loss for a LoS subsection of a diffraction path. The path has been modelled by cascaded cylinders each characterized by profile points w, x, y and z as illustrated in Figs. 13 and 14. The sub-path diffraction is to be calculated for each subsection of the overall path between points represented by w and x, or by y and z. These are the LoS sections of the path between obstructions, or between a terminal and an obstruction.

The method can also be used for a LoS with sub-path diffraction, in which case it is applied to the entire path.

2   Method

For a LoS section of the profile between profile samples indexed by u and v, the first task is to identify the profile sample between but excluding u and v which obstructs the largest fraction of the first Fresnel zone for a ray travelling from u to v.

To avoid selecting a point which is essentially part of one of the terrain obstacles already modelled as a cylinder, the profile between u and v is restricted to a section between two additional indices p and q, which are set as follows:

–   Set $p = u + 1$.

–   If both $p < v$ and $h_p > h_{p+1}$, then increase p by 1 and repeat.

–   Set $q = v - 1$.

–   If both $q > u$ and $h_q > h_{q-1}$, then decrease q by 1 and repeat.

If $p = q$ then the sub-path obstruction loss is set to 0. Otherwise the calculation proceeds as follows.

It is now necessary to find the minimum value of normalized clearance, C_F, given by h_z/F_1, where in self-consistent units:

   h_z: height of ray above profile point

   F_1: radius of first Fresnel zone.

The minimum normalized clearance may be written:

$$C_F = \min_{i=p}^{q} \left[(h_z)_i / (F_1)_i \right]$$

(93)

where:

$$(h_z)_i = (h_r)_i - (h_t)_i$$

(94)

$$(F_1)_i = \sqrt{\lambda \cdot d_{ui} \cdot d_{iv} / d_{uv}}$$

(95)

$(h_r)_i$, the height of the ray above a straight line joining sea level at u and v at the i-th profile point is given by:

$$(h_r)_i = (h_u \cdot d_{iv} + h_v \cdot d_{ui}) / d_{uv} \tag{96}$$

$(h_t)_i$, the height of the terrain above a straight line joining sea level at u and v at the i-th profile point is given by:

$$(h_t)_i = h_i + d_{ui} \cdot d_{iv} / 2a_e \tag{97}$$

The minimum value of normalized clearance is used to compute the knife-edge diffraction geometrical parameter for the most significant sub-path obstruction:

$$\nu = -C_F \cdot \sqrt{2} \tag{98}$$

The sub-path diffraction loss L'' is now obtained from Equation (31) or Fig. 9.

For some applications it may be undesirable to include sub-path diffraction enhancements. In this case a value of L'' should be set to zero when it would otherwise be negative.

RECOMMENDATION ITU-R M.541-9*

Operational procedures for the use of digital selective-calling equipment in the maritime mobile service

(1978-1982-1986-1990-1992-1994-1995-1996-1997-2004)

Summary

The Recommendation contains the operational procedures for digital selective-calling (DSC) equipment whose technical characteristics are given in Recommendation ITU-R M.493. The Recommendation contains five annexes. In Annexes 1 and 2 the provisions and procedures are described for distress, urgency and safety calls and for routine calls, respectively. In Annexes 3 and 4 the operational procedures for ships and for coast stations are described and Annex 5 lists the frequencies to be used for DSC.

The ITU Radiocommunication Assembly,

considering

a)   that digital selective-calling (DSC) will be used as described in Recommendation ITU-R M.493;

b)   that the requirements of Chapter IV of the International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended, for the Global Maritime Distress and Safety System (GMDSS) are based on the use of DSC for distress alerting and calling and that operational procedures are necessary for the use of that system;

c)   that, as far as is practicable, operational procedures in all frequency bands and for all types of communications should be similar;

d)   that DSC may provide a useful supplementary means of transmitting a distress alert in addition to the provisions of transmitting the distress alert by existing methods and procedures in the Radio Regulations (RR);

e)   that conditions when alarms have to be actuated should be specified,

recommends

1   that the technical characteristics of equipment used for DSC in the maritime mobile service should be in conformity with the relevant ITU-R Recommendations;

2   that the operational procedures to be observed in the MF, HF and VHF bands for DSC should be in accordance with Annex 1 for distress and safety calls and Annex 2 for other calls;

3   that provisions should be made at stations equipped for DSC for:

3.1   the manual entry of address, type of call, category and various messages into a DSC sequence;

3.2   the verification and if necessary the correction of such manually formed sequences;

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the ITU Telecommunication Standardization Sector (ITU-T).

3.3   a specific aural alarm and visual indication to indicate receipt of a distress or urgency call or a call having distress category. It should not be possible to disable this alarm and indication. Provisions should be made to ensure that they can be reset only manually;

3.4   aural alarm(s) and visual indication for calls other than distress and urgency. The aural alarm(s) may be capable of being disabled;

3.5   such visual indicators to indicate:

3.5.1   type of received call address (to all stations, to a group of stations, geographical, individual);

3.5.2   category;

3.5.3   identity of calling station;

3.5.4   numerical or alpha-numerical type of information, e.g. frequency information and telecommand;

3.5.5   type of "end of sequence" character;

3.5.6   detection of errors, if any;

3.6   monitoring the DSC channel to determine the presence of a signal and, except for distress, urgency, and non-test safety calls, provide facilities for automatically preventing the transmission of a DSC call until the channel is free;

4   that the equipment should be simple to operate;

5   that the operational procedures given in Annexes 3 and 4, which are based on the relevant procedures from Annexes 1 and 2 and from the RR, be used as guidance for ships and coast stations;

6   that the frequencies used for distress and safety purposes using DSC are those contained in Annex 5 to this Recommendation (see RR Appendix 15).

NOTE 1 – The following definitions are used throughout this Recommendation:

Single frequency: the same frequency is used for transmission and reception.

Paired frequencies: frequencies which are associated in pairs; each pair consisting of one transmitting and one receiving frequency.

International DSC frequencies: those frequencies designated in the RR for exclusive use for DSC on an international basis.

National DSC frequencies: those frequencies assigned to individual coast stations or a group of stations on which DSC is permitted (this may include working frequencies as well as calling frequencies). The use of these frequencies must be in accordance with the RR.

Automatic DSC operation at a ship station: a mode of operation employing automatic tunable transmitters and receivers, suitable for unattended operation, which provide for automatic call acknowledgements upon reception of a DSC and automatic transfer to the appropriate working frequencies.

Call attempt: one or a limited number of call sequences directed to the same stations on one or more frequencies and within a relatively short time period (e.g. a few minutes). A call attempt is considered unsuccessful if a calling sequence contains the symbol RQ at the end of the sequence and no acknowledgement is received in this time interval.

Annex 1

Provisions and procedures for distress, urgency and safety calls

1 Introduction

The terrestrial elements of the GMDSS adopted by the 1988 Amendments to the International Convention for SOLAS, 1974, are based on the use of DSC for distress and safety communications.

1.1 Method of calling

The provisions of RR Chapter VII are applicable to the use of DSC in cases of distress, urgency or safety.

2 DSC distress alert

The DSC distress alert provides for alerting, self-identification, ship's position including time, and nature of distress as defined in the RR (See RR Chapter VII).

3 Procedures for DSC distress alerts

3.1 Transmission by a mobile unit in distress

3.1.1 The DSC equipment should be capable of being preset to transmit the distress alert on at least one distress alerting frequency.

3.1.2 The distress alert shall be composed in accordance with Recommendation ITU-R M.493; the ship's position information, the time at which it was taken and the nature of distress should be entered as appropriate. If the position of the ship cannot be entered, then the position information signals shall be transmitted automatically as the digit 9 repeated ten times. If the time cannot be included, then the time information signals shall be transmitted automatically as the digit 8 repeated four times.

3.1.3 Distress alert attempt

At MF and HF a distress alert attempt may be transmitted as a single frequency or a multi-frequency call attempt. At VHF only single frequency call attempts are used.

3.1.3.1   Single frequency call attempt

A distress alert attempt should be transmitted as 5 consecutive calls on one frequency. To avoid call collision and the loss of acknowledgements, this call attempt may be transmitted on the same frequency again after a random delay of between 3 ½ and 4 ½ min from the beginning of the initial call. This allows acknowledgements arriving randomly to be received without being blocked by retransmission. The random delay should be generated automatically for each repeated transmission, however it should be possible to override the automatic repeat manually.

At MF and HF, single frequency call attempts may be repeated on different frequencies after a random delay of between 3 ½ and 4 ½ min from the beginning of the initial call. However, if a station is capable of receiving acknowledgements continuously on all distress frequencies except for the transmit frequency in use, then single frequency call attempts may be repeated on different frequencies without this delay.

3.1.3.2   Multi-frequency call attempt

A distress alert attempt may be transmitted as up to 6 consecutive (see Note 1) calls dispersed over a maximum of 6 distress frequencies (1 at MF and 5 at HF). Stations transmitting multi-frequency distress alert attempts should be able to receive acknowledgements continuously on all frequencies except for the transmit frequency in use, or be able to complete the call attempt within 1 min.

Multi-frequency call attempts may be repeated after a random delay of between 3 ½ and 4 ½ min from the beginning of the previous call attempt.

NOTE 1 – A VHF call may be transmitted simultaneously with an MF/HF call.

3.1.4   Distress

In the case of distress the operator should:

3.1.4.1   enter the desired mode of the subsequent communication and if time permits, enter the ship's position and time (see Note 1) it was taken and the nature of distress (see Note 1);

NOTE 1 – If these are not provided automatically.

3.1.4.2   select the distress frequency(ies) to be used (see Note 1 of § 3.1.4.1);

3.1.4.3   activate the distress alert attempt by a dedicated distress button.

3.2   Reception

The DSC equipment should be capable of maintaining a reliable watch on a 24-hour basis on appropriate DSC distress alerting frequencies.

3.3   Acknowledgement of distress alerts

Acknowledgements of distress alerts should be initiated manually.

Acknowledgements should be transmitted on the same frequency as the distress alert was received.

3.3.1   Distress alerts should normally be acknowledged by DSC only by appropriate coast stations. Coast stations should, in addition, set watch on radiotelephony and, if the "mode of subsequent communication" signal in the received distress alert indicates teleprinter, also on narrow-band direct-printing (NBDP) (see Recommendation ITU-R M.493). In both cases, the radiotelephone and NBDP frequencies should be those associated with the frequency on which the distress alert was received.

3.3.2   Acknowledgements by coast stations of DSC distress alerts transmitted on MF or HF should be initiated with a minimum delay of 1 min after receipt of a distress alert, and normally within a maximum delay of 2¾ min. This allows all calls within a single frequency or multi-frequency call attempt to be completed and should allow sufficient time for coast stations to respond to the distress alert. Acknowledgements by coast stations on VHF should be transmitted as soon as practicable.

3.3.3   The acknowledgement of a distress alert consists of a single DSC acknowledgement call which should be addressed to "all ships" and include the identification (see Recommendation ITU-R M.493) of the ship whose distress alert is being acknowledged.

3.3.4   Ships receiving a DSC distress alert from another ship should set watch on an associated radiotelephone distress and safety traffic frequency and acknowledge the call by radiotelephony.

If a ship station continues to receive a DSC distress alert on an MF or VHF channel, a DSC acknowledgement should be transmitted to terminate the call only after consulting with a Rescue Coordination Centre or a Coast Station and being directed to do so.

3.3.5   The automatic repetition of a distress alert attempt should be terminated automatically on receipt of a DSC distress acknowledgement.

3.3.6   When distress, urgency, and safety traffic cannot be successfully conducted using radiotelephony, an affected station may indicate its intention to conduct subsequent communications on the associated frequency for NBDP telegraphy.

3.4   Distress relays

Distress relay calls should be initiated manually.

3.4.1   A distress relay call should use the telecommand signal "distress relay" in accordance with Recommendation ITU-R M.493 and the calling attempt should follow the procedures described in § 3.1.3 to 3.1.3.2 for distress alerts, except that the alert is sent manually as a single call on a single frequency.

3.4.2   Any ship, receiving a distress alert on an HF channel which is not acknowledged by a coast station within 5 min, should transmit a distress relay call to the appropriate coast station.

3.4.3   Distress relay calls transmitted by coast stations, or by ship stations addressed to more than one vessel, should be acknowledged by ship stations using radiotelephony. Distress relay calls transmitted by ship stations should be acknowledged by a coast station transmitting a "distress relay acknowledgement" call in accordance with the procedures for distress acknowledgements given in § 3.3 to 3.3.3.

4   Procedures for DSC urgency and safety calls

4.1   DSC, on the distress and safety calling frequencies, should be used by coast stations to advise shipping, and by ships to advise coast stations and/or ship stations, of the impending transmission of urgency, vital navigational and safety messages, except where the transmissions take place at routine times. The call should indicate the working frequency which will be used for the subsequent transmission of an urgent, vital navigational or safety message.

4.2   The announcement and identification of medical transports should be carried out by DSC techniques, using appropriate distress and safety calling frequencies. Such calls should use the category "urgency", and telecommand "medical transport" and be addressed to all ships at VHF and Geographic Area at MF/HF.

4.3   The operational procedures for urgency and safety calls should be in accordance with the relevant parts of Annex 3, § 2.1 or 2.2 and 3.1. or 3.2.

5   Testing the equipment used for distress and safety calls

Testing on the exclusive DSC distress and safety calling frequencies should be avoided as far as possible by using other methods. VHF, MF and HF test calls should be in accordance with Recommendation ITU-R M.493 (see Table 4.7) and the call may be acknowledged by the called station. Normally there would be no further communication between the two stations involved.

Annex 2

Provisions and procedures for routine calls

1   Frequency/channels

1.1   As a rule, paired frequencies should be used at HF and MF, in which case an acknowledgement is transmitted on the frequency paired with the frequency of the received call. In exceptional cases for national purposes a single frequency may be used. If the same call is received on several calling channels, the most appropriate shall be chosen to transmit the acknowledgement. A single frequency channel should be used at VHF.

1.2   International calling

The paired frequencies listed in RR Appendix 17, Part A and in Annex 5 of this Recommendation should be used for international DSC calling.

1.2.1   At HF and MF international DSC frequencies should only be used for shore-to-ship calls and for the associated call acknowledgements from ships fitted for automatic DSC operation where it is known that the ships concerned are not listening to the coast station's national frequencies.

1.2.2 All ship-to-shore DSC calling at HF and MF should preferably be done on the coast station's national frequencies.

1.3 National calling

Coast stations should avoid using the international DSC frequencies for calls that may be placed using national frequencies.

1.3.1 Ship stations should keep watch on appropriate national and international channels. (Appropriate measures should be taken for an even loading of national and international channels.)

1.3.2 Administrations are urged to find methods and negotiate terms to improve the utilization of the DSC channels available, e.g.:

– coordinated and/or joint use of coast station transmitters;

– optimizing the probability of successful calls by providing information to ships on suitable frequencies (channels) to be watched and by information from ships to a selected number of coast stations on the channels watched on-board.

1.4 Method of calling

1.4.1 The procedures set out in this section are applicable to the use of DSC techniques, except in cases of distress, urgency or safety, to which the provisions of RR Chapter VII are applicable.

1.4.2 The call shall contain information indicating the station or stations to which the call is directed, and the identification of the calling station.

1.4.3 The call should also contain information indicating the type of communication to be set up and may include supplementary information such as a proposed working frequency or channel; this information shall always be included in calls from coast stations, which shall have priority for that purpose.

1.4.4 An appropriate digital selective calling channel chosen in accordance with the provisions of RR Nos. 52.128 to 52.137 or Nos. 52.145 to 52.153, as appropriate, shall be used for the call.

2 Operating procedures

The technical format of the call sequence shall be in conformity with the relevant ITU-R Recommendations.

The reply to a DSC requesting an acknowledgement shall be made by transmitting an appropriate acknowledgement using DSC techniques.

Acknowledgements may be initiated either manually or automatically. When an acknowledgement can be transmitted automatically, it shall be in conformity with the relevant ITU-R Recommendations.

The technical format of the acknowledgement sequence shall be in conformity with the relevant ITU-R Recommendations.

For communication between a coast station and a ship station, the coast station shall finally decide the working frequency or channel to be used.

The forwarding traffic and the control for working for radiotelephony shall be carried out in accordance with Recommendation ITU-R M.1171.

A typical DSC calling and acknowledgement sequence contains the following signals (see Recommendation ITU-R M.493).

Composition of a typical routine DSC calling and acknowledgement sequence

Signal	*Method of composition*
– format specifier	operator selected
– address	operator entered
– category (routine)	automatically selected
– self-identification	pre-programmed
– telecommand information	seleccionada por el operador
– frequency information (if appropriate)	operator selected or entered
– telephone number (semi-automatic/automatic ship-to-shore connections only)	operator entered
– end of sequence signal	automatically selected.

2.1   Coast station initiates call to ship station (see Note 1)

Figures 1 and 2 illustrate the procedures below in flow chart and by time sequence diagram respectively.

NOTE 1 – See Recommendations ITU-R M.689 and ITU-R M.1082 for further details of procedures applicable only to the semi-automatic/automatic services.

2.1.2   If a direct connection exists between the calling subscriber and the coast station, the coast station asks the calling subscriber for the approximate position of the ship.

2.1.3   If the ship's position cannot be indicated by the caller, the coast station operator tries to find the location in the information available at the coast station.

2.1.4   The coast station checks to see whether the call would be more appropriate through another coast station (see § 1.3.2).

2.1.5   The coast station checks to see whether the transmission of a DSC is inappropriate or restricted (e.g. ship not fitted with DSC or barred).

2.1.6   Assuming a DSC is appropriate the coast station composes the calling sequence as follows:

–   selects format specifier,

–   enters address of the ship,

–   selects category,

–   selects telecommand information,

–   inserts working frequency information in the message part of the sequence, if appropriate,

–   usually selects "end of sequence" signal "RQ". However, if the coast station knows that the ship station cannot respond or the call is to a group of ships the frequency is omitted and the end of sequence signal should be 127, in which case the following procedures (§ 2.1.13 to 2.1.15) relating to an acknowledgement are not applicable.

FIGURE 1

Flow chart of operational procedures for calling in the shore-to-ship direction
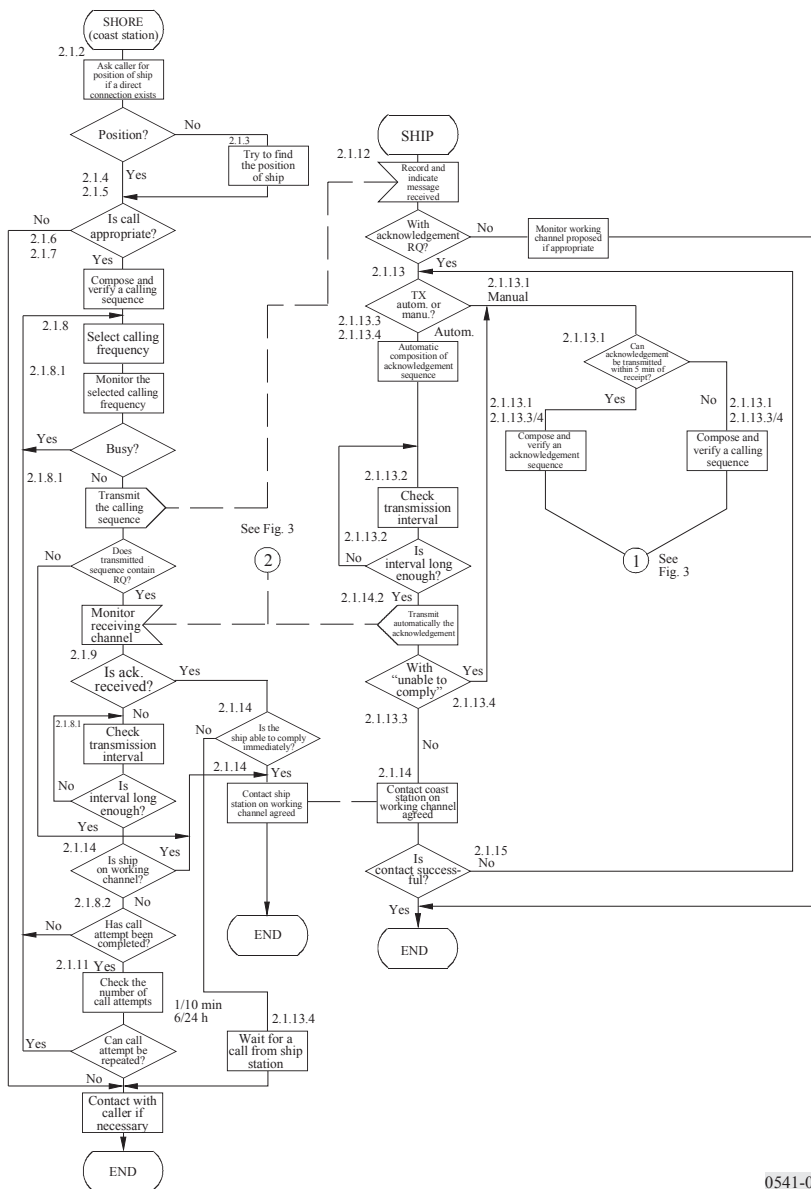
0541-01

FIGURE 2

Examples of timing diagrams for calling in shore-to-ship direction
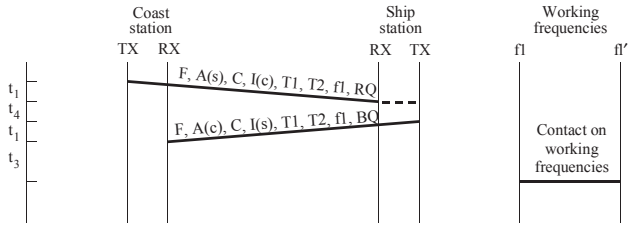
a) Automated transmitter (able to comply)
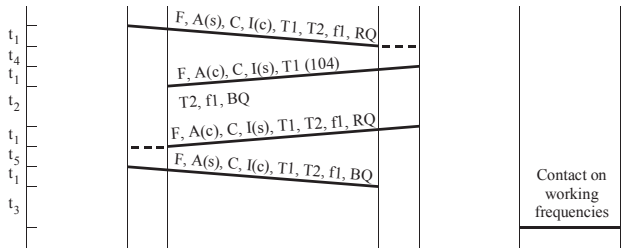
b) Automated transmitter (unable to comply)
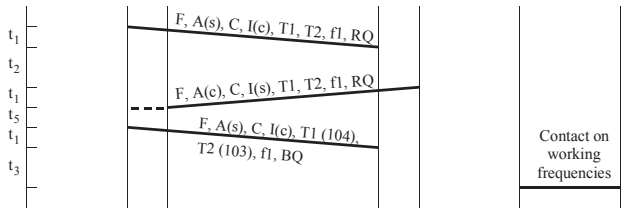
c) Ship transmitter not automated. Ship makes a delayed (>5 min) response to coast station
and encounters queue on working frequency

t_1:	transmission time of a DSC sequence	F : format specifier
t_2:	interval between the DSC reception at the ship and transmission from the ship after the operator's appearance in the radio room (from several minutes up to several hours)	A : called station address
		I : calling station self-identification } suffix (c) or (s) indicates coast station or ship station respectively
		C : category
t_3:	transition time from calling to working frequency including, if necessary, the time for working channel clearing (queue waiting time)	T1 : first telecommand signal, (104) indicates unable to comply
		T2 : second telecommand signal, (103) indicates queue
t_4:	as defined in § 2.1.13.2	
t_5:	time for coast station to prepare acknowledgement (see § 2.2.6)	fl, fl′ : working frequencies
		RQ, BQ : end of sequence signals

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2.1.7   The coast station verifies the calling sequence.

The call shall be transmitted once on a single appropriate calling channel or frequency only. Only in exceptional circumstances may a call be transmitted simultaneously on more than one frequency.

2.1.8   The coast station operator chooses the calling frequencies which are most suitable for the ship's location.

2.1.8.1 After checking as far as possible that there are no calls in progress, the coast station operator initiates the transmission of the sequence on one of the frequencies chosen. Transmission on any one frequency should be limited to no more than 2 call sequences separated by intervals of at least 45 s to allow for reception of an acknowledgement from the ship.

2.1.8.2 If appropriate, a "call attempt" may be transmitted, which may include the transmission of the same call sequence on other frequencies (if necessary with a change of working frequency information to correspond to the same band as the calling frequency) made in turn at intervals of not less than 5 min, following the same pattern as in § 2.1.8.1.

2.1.9   If an acknowledgement is received further transmission of the call sequence should not take place.

The coast station shall then prepare to transmit traffic on the working channel or frequency it has proposed.

2.1.10   The acknowledgement of the received call should only be transmitted upon receipt of a calling sequence which terminates with an acknowledgement request.

2.1.11   When a station called does not reply, the call attempt should not normally be repeated until after an interval of at least 15 min. The same call attempt should not be repeated more than five times every 24 h. The aggregate of the times for which frequencies are occupied in one call attempt, should normally not exceed 1 min.

The following procedures apply at the ship:

2.1.12   Upon receipt of a calling sequence at the ship station, the received message should be displayed.

2.1.13   When a received call sequence contains an end of sequence signal "RQ", an acknowledgement sequence should be composed and transmitted.

The format specifier and category information should be identical to that in the received calling sequence.

2.1.13.1   If the ship station is not equipped for automatic DSC operation, the ship's operator initiates an acknowledgement to the coast station after a delay of at least 5 s but no later than 4 ½ min of receiving the calling sequence, using the ship-to-shore calling procedures detailed in § 2.2. However the transmitted sequence should contain a "BQ" end of sequence signal in place of the "RQ" signal.

If such an acknowledgement cannot be transmitted within 5 min of receiving the calling sequence then the ship station should instead transmit a calling sequence to the coast station using the ship-to-shore calling procedure detailed in § 2.2.

2.1.13.2   If the ship is equipped for automatic DSC operation, the ship station automatically transmits an acknowledgement with an end of sequence signal "BQ". The start of the transmission of this acknowledgement sequence should be within 30 s for HF and MF or within 3 s for VHF after the reception of the complete call sequence.

2.1.13.3   If the ship is able to comply immediately the acknowledgement sequence should include a telecommand signal which is identical to that received in the calling sequence indicating that it is able to comply.

If no working frequency was proposed in the call, the ship station should include a proposal for a working frequency in its acknowledgement.

2.1.13.4   If the ship is not able to comply immediately the acknowledgement sequence should include the telecommand signal 104 (unable to comply), with a second telecommand signal giving additional information (see Recommendation ITU-R M.493).

At some later time when the ship is able to accept the traffic being offered, the ship's operator initiates a call to the coast station using the ship-to-shore calling procedures detailed in § 2.2.

2.1.14   If a call is acknowledged indicating ability to comply immediately and communication between coast station and ship station on the working channel agreed is established, the DSC call procedure is considered to be completed.

2.1.15   If the ship station transmits an acknowledgement which is not received by the coast station then this will result in the coast station repeating the call (in accordance with § 2.1.11). In this event the ship station should transmit a new acknowledgement. If no repeated call is received the ship station should transmit an acknowledgement or calling sequence in accordance with § 2.1.13.1.

2.2   Ship station initiates call to coast station (see Note 1)

Figures 3 and 4 illustrate the procedures below in flow chart and by time sequence diagram respectively.

This procedure should also be followed both as a delayed response to a call received earlier from the coast station (see § 2.1.13.1) and to initiate traffic from the ship station.

NOTE 1 – See Recommendations ITU-R M.689 and ITU-R M.1082 for further details of procedures applicable only to the semi-automatic/automatic services.

2.2.1   The ship composes the calling sequence as follows:

–   operator selects the format specifier,

–   operator enters address,

–   automatically selected category,

–   pre-programmed self-identification,

–   operator selects the telecommand information,

–   operator inserts (selects or enters) working frequency, or enters position (for MF/HF only) information in the message part of the sequence if appropriate,

–   operator enters telephone number required (semi-automatic/automatic connections only),

–   automatically selected "end of sequence" signal RQ.

FIGURE 3

Flow chart of operational procedures for calling in the ship-to-shore direction
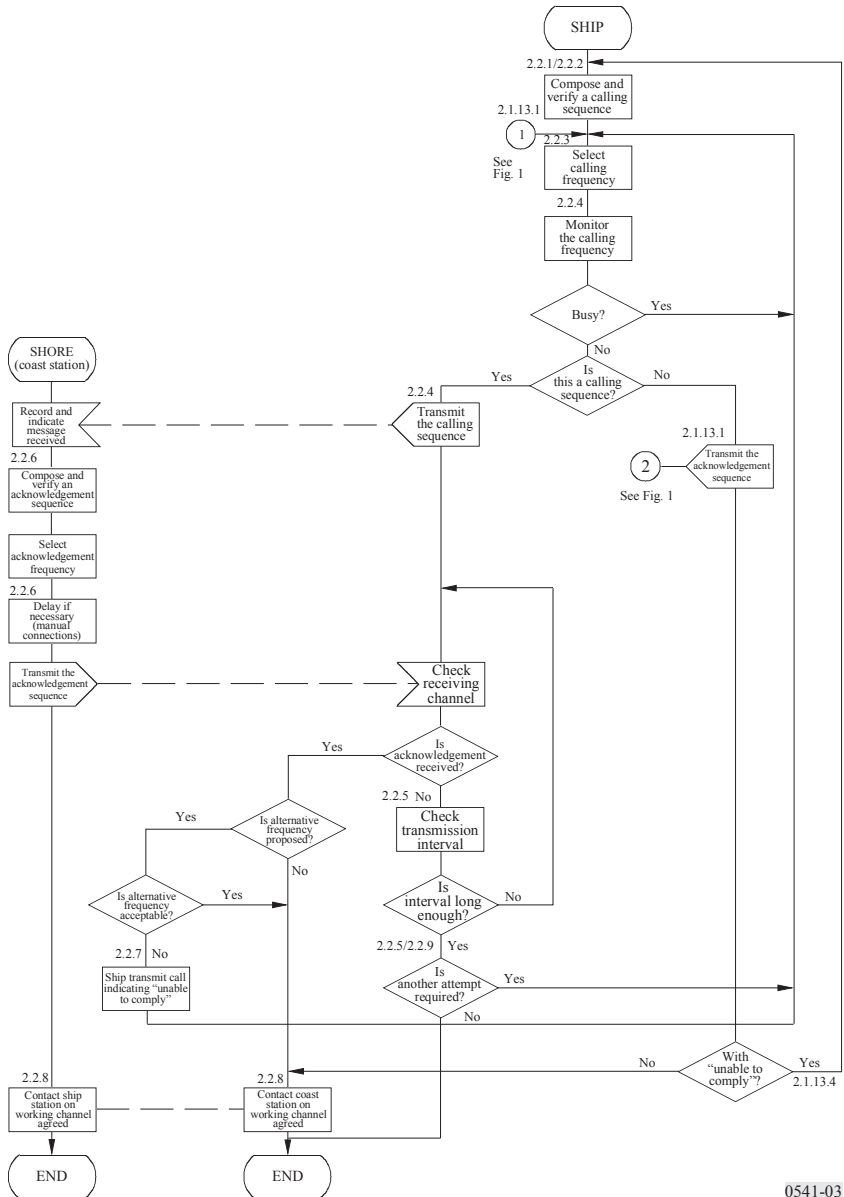
0541-03

FIGURE 4

Examples of timing diagrams for calling in ship-to-shore direction
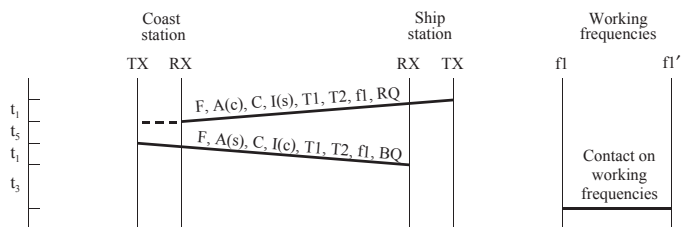
a) Able to comply immediately
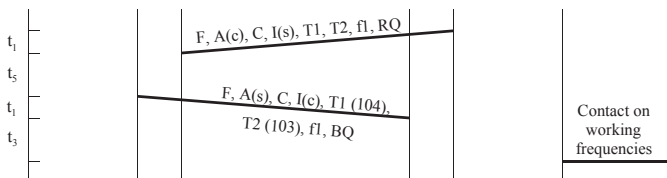
b) Queue exists on working frequency

t_1	:	transmission time of a DSC sequence
t_3	:	transition time from calling to working frequency including, if necessary, the time for working channel clearing (queue waiting time)
t_5	:	time for coast station to prepare acknowledgement (see § 2.2.6)
F	:	format specifier
A	:	called station address
I	:	calling station ⎰ suffix (c) or (s) indicates coast station self-identification ⎱ or ship station respectively
C	:	category
T1	:	first telecommand signal, (104) indicates unable to comply
T2	:	second telecommand signal, (103) indicates queue
f1, f1′	:	working frequencies
RQ, BQ	:	end of sequence signals

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2.2.2   The ship verifies the calling sequence.

2.2.3   The ship selects the single most appropriate calling frequency preferably using the coast station's nationally assigned calling channels, for which purpose it shall send a single calling sequence on the selected frequency.

2.2.4   The ship initiates the transmission of the sequence on the frequency selected after checking as far as possible that there are no calls in progress on that frequency.

FIGURE 5

Composition procedures for calling and acknowledgement sequences
(for calls other than distress and safety)
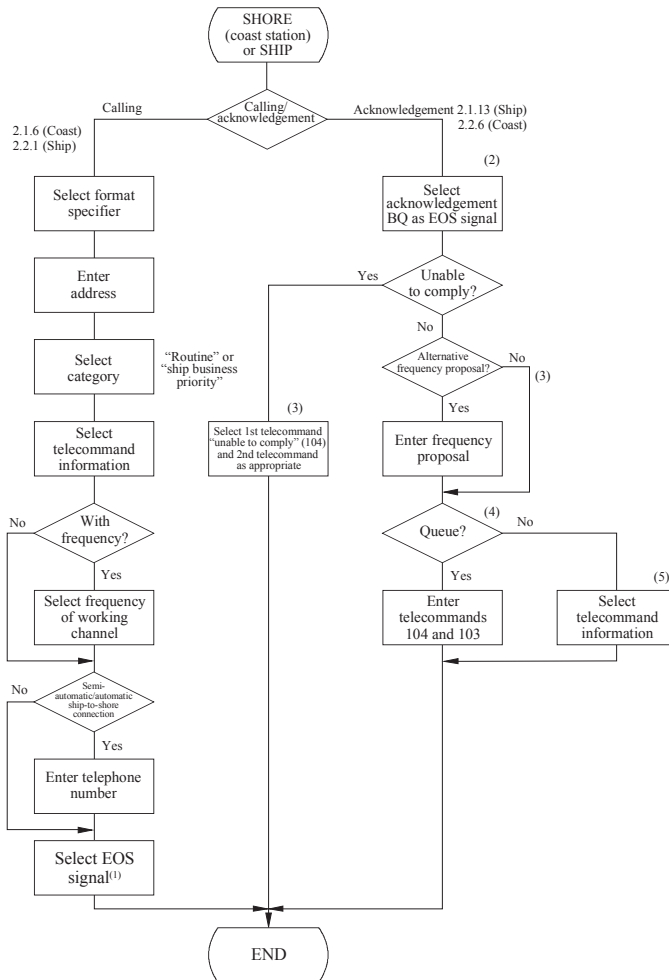
(1) Normally acknowledgement RQ may automatically be selected as an EOS signal of a calling
sequence to an individual station.
(2) The format specifier and the category are automatically transferred from the received
call. The self-ID in the received sequence is automatically transferred into the
address part of acknowledgement sequence by selecting acknowledgement BQ.
(3) The frequency information is automatically transferred from the received call.
(4) This procedure is only for coast stations.
(5) When able to comply, and no queue exists, then the telecommand information is
automatically transferred from the received call.

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2.2.5   If a called station does not reply, the call sequence from the ship station should not normally be repeated until after an interval of at least 5 min for manual connections, or 5 s or 25 s in the case of semi-automatic/automatic VHF or MF/HF connections respectively. These repetitions may be made on alternative frequencies if appropriate. Any subsequent repetitions to the same coast station should not be made until at least 15 min have elapsed.

2.2.6   The coast station should transmit an acknowledgement sequence (after checking as far as possible that there are no calls in progress on the frequency selected), after a delay of at least 5 s but not later than 4½ min for manual connections, or, within 3 s for semi-automatic/automatic connections, containing the format specifier, the address of the ship, the category, the coast station self-identification and:

–   if able to comply immediately on the working frequency suggested, the same telecommand and frequency information as in the call request;

–   if no working frequency was suggested by the ship station then the acknowledgement sequence should include a channel/frequency proposal;

–   if not able to comply on the working frequency suggested but able to comply immediately on an alternative frequency, the same telecommand information as in the call request but an alternative working frequency;

–   if unable to comply immediately the telecommand signal 104 with a second telecommand signal giving additional information. For manual connections only, this second telecommand signal may include a queue indication.

The end of sequence signal BQ should also be included.

2.2.7   For manual connections, if a working frequency is proposed in accordance with § 2.2.6 but this is not acceptable to the ship station, then the ship station should immediately transmit a new call requesting an alternative frequency.

2.2.8   If an acknowledgement is received further transmission of the call sequence should not take place. On receipt of an acknowledgement which indicates ability to comply, the DSC procedures are complete and both coast station and ship station should communicate on the working frequencies agreed with no further exchange of DSC calls.

2.2.9   If the coast station transmits an acknowledgement which is not received at the ship station then the ship station should repeat the call in accordance with § 2.2.5.

2.3   **Ship station initiates call to ship station**

The ship-to-ship procedures should be similar to those given in § 2.2, where the receiving ship station complies with the procedures given for coast stations, as appropriate, except that, with respect to § 2.2.1, the calling ship should always insert working frequency information in the message part of the calling sequence.

Annex 3

Operational procedures for ships for DSC communications on MF, HF and VHF

Introduction

Procedures for DSC communications on MF and VHF are described in § 1 to 5 below.

The procedures for DSC communications on HF are in general the same as for MF and VHF. Special conditions to be taken into account when making DSC communications on HF are described in § 6 below.

1 Distress

1.1 Transmission of DSC distress alert

A distress alert should be transmitted if, in the opinion of the Master, the ship or a person is in distress and requires immediate assistance.

A DSC distress alert should as far as possible include the ship's last known position and the time (in UTC) when it was valid. The position and the time may be included automatically by the ship's navigational equipment or may be inserted manually.

The DSC distress alert is transmitted as follows:

– tune the transmitter to the DSC distress channel (2 187.5 kHz on MF, channel 70 on VHF (see Note 1)).

  NOTE 1 – Some maritime MF radiotelephony transmitters shall be tuned to a frequency 1 700 Hz lower than 2 187.5 kHz, i.e. 2 185.8 kHz, in order to transmit the DSC distress alert on 2 187.5 kHz;

– if time permits, key in or select on the DSC equipment keyboard

  – the nature of distress,

  – the ship's last known position (latitude and longitude),

  – the time (in UTC) the position was valid,

  – type of subsequent distress communication (telephony),

in accordance with the DSC equipment manufacturer's instructions;

– transmit the DSC distress alert;

– prepare for the subsequent distress traffic by tuning the transmitter and the radiotelephony receiver to the distress traffic channel in the same band, i.e. 2 182 kHz on MF, channel 16 on VHF, while waiting for the DSC distress acknowledgement.

1.2 Actions on receipt of a distress alert

Ships receiving a DSC distress alert from another ship should normally not acknowledge the distress alert by DSC since acknowledgement of a DSC distress alert by use of DSC is normally made by coast stations only (see Annex 1 § 3.3.4 and Annex 3 § 6.1.4).

If a ship station continues to receive a DSC distress alert on an MF or VHF channel, a DSC acknowledgement should be transmitted to terminate the call only after consulting with a Rescue Coordination Centre or a Coast Station and being directed to do so.

Ships receiving a DSC distress alert from another ship should also defer the acknowledgement of the distress alert by radiotelephony for a short interval, if the ship is within an area covered by one or more coast stations, in order to give the coast station time to acknowledge the DSC distress alert first.

Ships receiving a DSC distress alert from another ship shall:

–   watch for the reception of a distress acknowledgement on the distress channel (2 187.5 kHz on MF and channel 70 on VHF);

–   prepare for receiving the subsequent distress communication by tuning the radiotelephony receiver to the distress traffic frequency in the same band in which the DSC distress alert was received, i.e. 2 182 kHz on MF, channel 16 on VHF;

–   acknowledge the receipt of the distress alert by transmitting the following by radiotelephony on the distress traffic frequency in the same band in which the DSC distress alert was received, i.e. 2 182 kHz on MF, channel 16 on VHF:

    –   "MAYDAY",

    –   the 9-digit identity of the ship in distress, repeated 3 times,

    –   "this is",

    –   the 9-digit identity or the call sign or other identification of own ship, repeated 3 times,

    –   "RECEIVED MAYDAY".

1.3 Distress traffic

On receipt of a DSC distress acknowledgement the ship in distress should commence the distress traffic by radiotelephony on the distress traffic frequency (2 182 kHz on MF, channel 16 on VHF) as follows:

–   "MAYDAY",

–   "this is",

–   the 9-digit identity *and* the call sign or other identification of the ship,

–   the ship's position in latitude and longitude or other reference to a known geographical location,

–   the nature of distress and assistance wanted,

–   any other information which might facilitate the rescue.

1.4 Transmission of a DSC distress relay call

In no case is a ship permitted to transmit an all ships DSC distress relay call on receipt of a DSC distress alert on either VHF or MF channels. If no aural watch is present on the relative channel (2 182 kHz on MF, channel 16 on VHF), the coast station should be contacted by sending an individual DSC distress relay call.

1.4.1 Transmission of a DSC distress relay call on behalf of someone else

A ship knowing that another ship is in distress shall transmit a DSC distress relay call if:

– the ship in distress is not itself able to transmit the distress alert,

– the Master of the ship considers that further help is necessary.

The DSC distress relay call is transmitted as follows:

– tune the transmitter to the DSC distress channel (2 187.5 kHz on MF, channel 70 on VHF),

– select the distress relay call format on the DSC equipment,

– key in or select on the DSC equipment keyboard:

– All Ships Call (VHF). Geographic Area Call (MF/HF) or the 9-digit identity of the appropriate coast station,

– the 9-digit identity of the ship in distress, if known,

– the nature of distress,

– the latest position of the ship in distress, if known,

– the time (in UTC) the position was valid (if known),

– type of subsequent distress communication (telephony);

– transmit the DSC distress relay call;

– prepare for the subsequent distress traffic by tuning the transmitter and the radiotelephony receiver to the distress traffic channel in the same band, i.e. 2 182 kHz on MF and channel 16 on VHF, while waiting for the DSC distress acknowledgement.

1.5 Acknowledgement of a DSC distress relay call received from a coast station

Coast stations, after having received and acknowledged a DSC distress alert, may if necessary, retransmit the information received as a DSC distress relay call, addressed to all ships (VHF only), all ships in a specific geographical area (MF/HF only), or a specific ship.

Ships receiving a distress relay call transmitted by a coast station shall not use DSC to acknowledge the call, but should acknowledge the receipt of the call by radiotelephony on the distress traffic channel in the same band in which the relay call was received, i.e. 2 182 kHz on MF, channel 16 on VHF.

Acknowledge the receipt of the distress relay call by transmitting the following by radiotelephony on the distress traffic frequency in the same band in which the DSC distress relay call was received:

– "MAYDAY" RELAY,

– the 9-digit identity or the call sign or other identification of the calling coast station,

– "this is",

– the 9-digit identity or call sign or other identification of own ship,

– "RECEIVED MAYDAY RELAY".

1.6 Acknowledgement of a DSC distress relay call received from another ship

Ships receiving a distress relay call from another ship shall follow the same procedure as for acknowledgement of a distress alert, i.e. the procedure given in § 1.2 above.

1.7 Cancellation of an inadvertent distress alert

A station transmitting an inadvertent distress alert shall cancel the distress alert using the following procedure:

1.7.1 Immediately cancel the distress alert aurally over the telephony distress traffic channel associated with each DSC channel on which the "distress alert" was transmitted.

1.7.2 Monitor the telephony distress traffic channel associated with the DSC channel on which the distress was transmitted, and respond to any communications concerning that distress alert as appropriate.

2 Urgency

2.1 Transmission of urgency messages

Transmission of urgency messages shall be carried out in two steps:

– announcement of the urgency message,

– transmission of the urgency message.

The announcement is carried out by transmission of a DSC urgency call on the DSC distress calling channel (2 187.5 kHz on MF, channel 70 on VHF).

The urgency message is transmitted on the distress traffic channel (2 182 kHz on MF, channel 16 on VHF).

The DSC urgency call may be addressed to all stations at VHF, or a geographic area at MF/HF, or to a specific station. The frequency on which the urgency message will be transmitted shall be included in the DSC urgency call.

The transmission of an urgency message is thus carried out as follows:

Announcement:

–   tune the transmitter to the DSC distress calling channel (2 187.5 kHz on MF, channel 70 on VHF);

–   select the appropriate calling format on the DSC equipment (all ships (VHF only), geographical area (MF/HF only) or individual);

–   key in or select on the DSC equipment keyboard:

–   specific area or 9-digit identity of the specific station, if appropriate,

–   the category of the call (urgency),

–   the frequency or channel on which the urgency message will be transmitted,

–   the type of communication in which the urgency message will be given (radiotelephony),

in accordance with the DSC equipment manufacturer's instructions;

–   transmit the DSC urgency call.

Transmission of the urgency message:

–   tune the transmitter to the frequency or channel indicated in the DSC urgency call;

–   transmit the urgency message as follows:

–   "PAN PAN", repeated 3 times,

–   "ALL STATIONS" or called station, repeated 3 times,

–   "this is",

–   the 9-digit identity *and* the call sign or other identification of own ship,

–   the text of the urgency message.

2.2   Reception of an urgency message

Ships receiving a DSC urgency call announcing an urgency message addressed to more than one station shall NOT acknowledge the receipt of the DSC call, but should tune the radiotelephony receiver to the frequency indicated in the call and listen to the urgency message.

3   Safety

3.1   Transmission of safety messages

Transmission of safety messages shall be carried out in two steps:

–   announcement of the safety message,

–   transmission of the safety message.

The announcement is carried out by transmission of a DSC safety call on the DSC distress calling channel (2 187.5 kHz on MF, channel 70 on VHF).

The safety message is normally transmitted on the distress and safety traffic channel in the same band in which the DSC call was sent, i.e. 2 182 kHz on MF, channel 16 on VHF.

The DSC safety call may be addressed to all ships (VHF only), ships in a specific geographical area (MF/HF only), or to a specific station.

The frequency on which the safety message will be transmitted shall be included in the DSC call.

The transmission of a safety message is thus carried out as follows:

Announcement:

–   tune the transmitter to the DSC distress calling channel (2 187.5 kHz on MF, channel 70 on VHF);

–   select the appropriate calling format on the DSC equipment (all ships (VHF only), geographical area (MF/HF only), or individual);

–   key in or select on the DSC equipment keyboard:

    –   specific area or 9-digit identity of specific station, if appropriate,

    –   the category of the call (safety),

    –   the frequency or channel on which the safety message will be transmitted,

    –   the type of communication in which the safety message will be given (radiotelephony),

    in accordance with the DSC equipment manufacturer's instructions;

–   transmit the DSC safety call.

Transmission of the safety message:

–   tune the transmitter to the frequency or channel indicated in the DSC safety call;

–   transmit the safety message as follows:

    –   "SECURITE", repeated 3 times,

    –   "ALL STATIONS" or called station, repeated 3 times,

    –   "this is",

    –   the 9-digit identity *and* the call sign or other identification of own ship,

    –   the text of the safety message.

3.2   Reception of a safety message

Ships receiving a DSC safety call announcing a safety message addressed to more than one station shall NOT acknowledge the receipt of the DSC safety call, but should tune the radiotelephony receiver to the frequency indicated in the call and listen to the safety message.

4   Public correspondence

4.1   DSC channels for public correspondence

4.1.1   VHF

The VHF DSC channel 70 is used for DSC for distress and safety purposes as well as for DSC for public correspondence.

4.1.2 MF

International and national DSC channels separate from the DSC distress and safety calling channel 2 187.5 kHz are used for digital selective-calling on MF for public correspondence.

Ships calling a coast station by DSC on MF for public correspondence should preferably use the coast station's national DSC channel.

The international DSC channel for public correspondence may as a general rule be used between ships and coast stations of different nationality. The ships transmitting frequency is 2 189.5 kHz, and the receiving frequency is 2 177 kHz.

The frequency 2 177 kHz is also used for DSC between ships for general communication.

4.2 Transmission of a DSC call for public correspondence to a coast station or another ship

A DSC call for public correspondence to a coast station or another ship is transmitted as follows:

– tune the transmitter to the relevant DSC channel;

– select the format for calling a specific station on the DSC equipment;

– key in or select on the DSC equipment keyboard:

  – the 9-digit identity of the station to be called,

  – the category of the call (routine),

  – the type of the subsequent communication (normally radiotelephony),

  – a proposed working channel if calling another ship. A proposal for a working channel should NOT be included in calls to a coast station; the coast station will in its DSC acknowledgement indicate a vacant working channel,

  in accordance with the DSC equipment manufacturer's instructions;

– transmit the DSC call.

4.3 Repeating a call

A DSC call for public correspondence may be repeated on the same or another DSC channel, if no acknowledgement is received within 5 min.

Further call attempts should be delayed at least 15 min, if acknowledgement is still not received.

4.4 Acknowledgement of a received call and preparation for reception of the traffic

On receipt of a DSC call from a coast station or another ship, a DSC acknowledgement is transmitted as follows:

– tune the transmitter to the transmit frequency of the DSC channel on which the call was received,

– select the acknowledgement format on the DSC equipment,

– transmit an acknowledgement indicating whether the ship is able to communicate as proposed in the call (type of communication and working frequency),

– if able to communicate as indicated, tune the transmitter and the radiotelephony receiver to the indicated working channel and prepare to receive the traffic.

4.5 Reception of acknowledgement and further actions

When receiving an acknowledgement indicating that the called station is able to receive the traffic, prepare to transmit the traffic as follows:

– tune the transmitter and receiver to the indicated working channel;

– commence the communication on the working channel by:

  – the 9-digit identity or call sign or other identification of the called station,

  – "this is",

  – the 9-digit identity or call sign or other identification of own ship.

It will normally rest with the ship to call again a little later in case the acknowledgement from the coast station indicates that the coast station is not able to receive the traffic immediately.

In case the ship, in response to a call to another ship, receives an acknowledgement indicating that the other ship is not able to receive the traffic immediately, it will normally rest with the called ship to transmit a call to the calling ship when ready to receive the traffic.

5 Testing the equipment used for distress and safety

Testing on the exclusive DSC distress and safety calling frequency 2 187.5 kHz should be avoided as far as possible by using other methods.

Test calls should be transmitted by the ship station and acknowledged by the called station. Normally there would be no further communication between the two stations involved.

A VHF and MF test call to a station is transmitted as follows:

– tune the transmitter to the DSC distress and safety calling frequency (i.e. channel 70 and 2 187.5 kHz),

– key in or select the format for the test call on the DSC equipment in accordance with the DSC equipment manufacturer's instructions,

– key in the 9-digit identity of the station to be called,

– transmit the DSC call after checking as far as possible that no calls are in progress on the frequency,

– wait for acknowledgement.

6 Special conditions and procedures for DSC communication on HF

General

The procedures for DSC communication on HF are – with some additions described in § 6.1 to 6.3 below – equal to the corresponding procedures for DSC communications on MF/VHF.

Due regard to the special conditions described in § 6.1 to 6.3 should be given when making DSC communications on HF.

6.1 Distress

6.1.1 Transmission of DSC distress alert

DSC distress alert should be sent to coast stations – e.g. in A3 and A4 sea areas on HF – and on MF and/or VHF to other ships in the vicinity.

The DSC distress alert should as far as possible include the ship's last known position and the time (in UTC) it was valid. If the position and time is not inserted automatically from the ship's navigational equipment, it should be inserted manually.

Ship-to-shore distress alert

Choice of HF band

Propagation characteristics of HF radio waves for the actual season and time of the day should be taken into account when choosing HF bands for transmission of DSC distress alert.

As a general rule the DSC distress channel in the 8 MHz maritime band (8 414.5 kHz) may in many cases be an appropriate first choice.

Transmission of the DSC distress alert in more than one HF band will normally increase the probability of successful reception of the alert by coast stations.

DSC distress alert may be sent on a number of HF bands in two different ways:

a)   either by transmitting the DSC distress alert on one HF band, and waiting a few minutes for receiving acknowledgement by a coast station;

        if no acknowledgement is received within 3 min, the process is repeated by transmitting the DSC distress alert on another appropriate HF band etc.;

b)   or by transmitting the DSC distress alert at a number of HF bands with no, or only very short, pauses between the calls, without waiting for acknowledgement between the calls.

It is recommended to follow procedure a) in all cases, where time permits to do so; this will make it easier to choose the appropriate HF band for commencement of the subsequent communication with the coast station on the corresponding distress traffic channel.

Transmitting the DSC distress alert (see Note 1):

–   tune the transmitter to the chosen HF DSC distress channel (4 207.5, 6 312, 8 414.5, 12 577, 16 804.5 kHz) (see Note 2);

–   follow the instructions for keying in or selection of relevant information on the DSC equipment keyboard as described in § 1.1;

–   transmit the DSC distress alert.

NOTE 1 – Ship-to-ship distress alert should normally be made on MF and/or VHF, using the procedures for transmission of DSC distress alert on MF/VHF described in § 1.1.

NOTE 2 – Some maritime HF transmitters shall be tuned to a frequency 1 700 Hz lower than the DSC frequencies given above in order to transmit the DSC distress alert on the correct frequency.

In special cases, for example in tropical zones, transmission of DSC distress alert on HF may, in addition to ship-to-shore alerting, also be useful for ship-to-ship alerting.

6.1.2 Preparation for the subsequent distress traffic

After having transmitted the DSC distress alert on appropriate DSC distress channels (HF, MF and/or VHF), prepare for the subsequent distress traffic by tuning the radiocommunication set(s) (HF, MF and/or VHF as appropriate) to the corresponding distress traffic channel(s).

Where multiple frequency call attempts are transmitted the corresponding distress traffic frequency should be 8 291 kHz.

If method b) described in § 6.1.1 has been used for transmission of DSC distress alert on a number of HF bands:

–   take into account in which HF band(s) acknowledgement has been successfully received from a coast station;

–   if acknowledgements have been received on more than one HF band, commence the transmission of distress traffic on one of these bands, but if no response is received from a coast station then the other bands should be used in turn.

The distress traffic frequencies are (see RR Appendix 15, Table 15-1):

HF (kHz):

Telephony	4 125	6 215	8 291	12 290	16 420
Telex	4 177.5	6 268	8 376.5	12 520	16 695

MF (kHz):

Telephony	2 182
Telex	2 174.5

VHF: Channel 16 (156.800 MHz).

6.1.3 Distress traffic

The procedures described in § 1.3 are used when the distress traffic on MF/HF is carried out by *radiotelephony*.

The following procedures shall be used in cases where the distress traffic on MF/HF is carried out by *radiotelex*:

–   The forward error correcting (FEC) mode shall be used;

–   all messages shall be preceded by:

    –   at least one carriage return,

    –   line feed,

    –   one letter shift,

    –   the distress signal MAYDAY;

– The ship in distress should commence the distress telex traffic on the appropriate distress telex traffic channel as follows:

  – carriage return, line feed, letter shift,

  – the distress signal "MAYDAY",

  – "this is",

  – the 9-digit identity and call sign or other identification of the ship,

  – the ship's position if not included in the DSC distress alert,

  – the nature of distress,

  – any other information which might facilitate the rescue.

6.1.4 Actions on reception of a DSC distress alert on HF from another ship

Ships receiving a DSC distress alert on HF from another ship shall *not* acknowledge the alert, but should:

– watch for reception of a DSC distress acknowledgement from a coast station;

– while waiting for reception of a DSC distress acknowledgement from a coast station:

  prepare for reception of the subsequent distress communication by tuning the HF radiocommunication set (transmitter and receiver) to the relevant distress traffic channel in the same HF band in which the DSC distress alert was received, observing the following conditions:

  – if radiotelephony mode was indicated in the DSC distress alert, the HF radiocommunication set should be tuned to the radiotelephony distress traffic channel in the HF band concerned;

  – if telex mode was indicated in the DSC distress alert, the HF radiocommunication set should be tuned to the radiotelex distress traffic channel in the HF band concerned. Ships able to do so should additionally watch the corresponding radiotelephony distress channel;

  – if the DSC distress alert was received on more than one HF band, the radiocommunication set should be tuned to the relevant distress traffic channel in the HF band considered to be the best one in the actual case. If the DSC distress alert was received successfully on the 8 MHz band, this band may in many cases be an appropriate first choice;

  – if no distress traffic is received on the HF channel within 1 to 2 min, tune the HF radiocommunication set to the relevant distress traffic channel in another HF band deemed appropriate in the actual case;

  – if no DSC distress acknowledgement is received from a coast station within 5 min, and no distress communication is observed going on between a coast station and the ship in distress:

    – inform a Rescue Coordination Centre (RCC) via appropriate radiocommunications means,

    – transmit a DSC distress relay call.

6.1.5   Transmission of DSC distress relay call

In case it is considered appropriate to transmit a DSC distress relay call:

–   distress relay calls on HF should be initiated manually;

–   tune the transmitter(s) to the relevant DSC distress channel, following the procedures described in § 6.1.1 above (except the call is sent manually as a single call on a single frequency);

–   follow the instructions for keying in or selection of call format and relevant information on the DSC equipment keyboard as described in § 1.4;

–   transmit the DSC distress relay call.

6.1.6   Acknowledgement of a HF DSC distress relay call received from a coast station

Ships receiving a DSC distress relay call from a coast station on HF, addressed to all ships within a specified area, should NOT acknowledge the receipt of the relay alert by DSC, but by *radiotelephony* on the telephony distress traffic channel in the same band(s) in which the DSC distress relay call was received.

6.2   Urgency

Transmission of urgency messages on HF should normally be addressed:

–   either to all ships within a specified geographical area,

–   or to a specific coast station.

Announcement of the urgency message is carried out by transmission of a DSC call with category urgency on the appropriate DSC distress channel.

The transmission of the urgency message itself on HF is carried out by radiotelephony or radiotelex on the appropriate distress traffic channel in the same band in which the DSC announcement was transmitted.

6.2.1   Transmission of DSC announcement of an urgency message on HF

–   choose the HF band considered to be the most appropriate, taking into account propagation characteristics for HF radio waves at the actual season and time of the day; the 8 MHz band may in many cases be an appropriate first choice;

–   tune the HF transmitter to the DSC distress channel in the chosen HF band;

–   key in or select call format for either geographical area call or individual call on the DSC equipment, as appropriate;

–   in case of area call, key in specification of the relevant geographical area;

–   follow the instructions for keying in or selection of relevant information on the DSC equipment keyboard as described in § 2.1, including type of communication in which the urgency message will be transmitted (radiotelephony or radiotelex);

–   transmit the DSC call; and

–   if the DSC call is addressed to a specific coast station, wait for DSC acknowledgement from the coast station. If acknowledgement is not received within a few minutes, repeat the DSC call on another HF frequency deemed appropriate.

6.2.2   Transmission of the urgency message and subsequent action

–   tune the HF transmitter to the distress traffic channel (telephony or telex) indicated in the DSC announcement;

–   if the urgency message is to be transmitted using *radiotelephony*, follow the procedure described in § 2.1;

–   if the urgency message is to be transmitted by *radiotelex*, the following procedure shall be used:

   –   use the forward error correcting (FEC) mode unless the message is addressed to a single station whose radiotelex identity number is known;

   –   commence the telex message by:

      –   at least one carriage return, line feed, one letter shift,

      –   the urgency signal "PAN PAN",

      –   "this is",

      –   the 9-digit identity of the ship and the call sign or other identification of the ship,

      –   the text of the urgency message.

Announcement and transmission of urgency messages addressed to all HF equipped ships within a specified area may be repeated on a number of HF bands as deemed appropriate in the actual situation.

6.3   Safety

The procedures for transmission of DSC safety announcement and for transmission of the safety message are the same as for urgency messages, described in § 6.2, *except* that:

–   in the DSC announcement, the category SAFETY shall be used,

–   in the safety message, the safety signal "SECURITE" shall be used instead of the urgency signal "PAN PAN".

Annex 4

Operational procedures for coast stations for DSC communications on MF, HF and VHF

Introduction

Procedures for DSC communications on MF and VHF are described in § 1 to 5 below.

The procedures for DSC communications on HF are in general the same as for MF and VHF. Special conditions to be taken into account when making DSC communications on HF are described in § 6 below.

1   Distress (see Note 1)

1.1   Reception of a DSC distress alert

The transmission of a distress alert indicates that a mobile unit (a ship, aircraft or other vehicle) or a person is in distress and requires immediate assistance. The distress alert is a digital selective call using a distress call format.

Coast stations in receipt of a distress alert shall ensure that it is routed as soon as possible to an RCC. The receipt of a distress alert is to be acknowledged as soon as possible by the appropriate coast station.

NOTE 1 – These procedures assume that the RCC is sited remotely from the DSC coast station; where this is not the case, appropriate amendments should be made locally.

1.2   Acknowledgement of a DSC distress alert

The coast station shall transmit the acknowledgement on the distress calling frequency on which the call was received and should address it to all ships. The acknowledgement shall include the identification of the ship whose distress alert is being acknowledged.

The acknowledgement of a DSC distress alert is transmitted as follows:

–   use a transmitter which is tuned to the frequency on which the distress alert was received;

–   in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1):

    –   distress alert acknowledgement,

    –   9-digit identity of the ship in distress,

    –   nature of distress,

    –   distress coordinates,

    –   the time (in UTC) when the position was valid.

    NOTE 1 – Some or all of this information might be included automatically by the equipment;

–   transmit the acknowledgement;

–   prepare to handle the subsequent distress traffic by setting watch on radiotelephony and, if the "mode of subsequent communication" signal in the received distress alert indicates teleprinter, also on NBDP, if the coast station is fitted with NBDP. In both cases, the radiotelephone and NBDP frequencies should be those associated with the frequency on which the distress alert was received (on MF 2 182 kHz for radiotelephony and 2 174.5 kHz for NBDP, on VHF 156.8 MHz/channel 16 for radiotelephony; there is no frequency for NBDP on VHF).

1.3   Transmission of a DSC distress relay call

Coast stations shall initiate and transmit a distress relay call in any of the following cases:

–   when the distress of the mobile unit has been notified to the coast station by other means and a broadcast alert to shipping is required by the RCC; and

–   when the person responsible for the coast station considers that further help is necessary (close cooperation with the appropriate RCC is recommended under such conditions).

In the cases mentioned above, the coast station shall transmit a shore-to-ship distress relay call addressed, as appropriate, to all ships (VHF only), to a geographical area (MF/HF only) or to a specific ship.

The distress relay call shall contain the identification of the mobile unit in distress, its position and other information which might facilitate rescue.

The distress relay call is transmitted as follows:

– use a transmitter which is tuned to the frequency for DSC distress alerts (2 187.5 kHz on MF, 156.525 MHz/channel 70 on VHF);

– in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1 of § 1.2 of this Annex):

  – distress relay call,

  – the format specifier (all ships (VHF only), geographical area (MF/HF only), or individual station),

  – if appropriate, the address of the ship, or geographical area,

  – 9-digit identity of the ship in distress, if known,

  – nature of distress,

  – distress coordinates,

  – the time (in UTC) when the position was valid;

– transmit the distress relay call;

– prepare for the reception of the acknowledgements by ship stations and for handling the subsequent distress traffic by switching over to the distress traffic channel in the same band, i.e. 2 182 kHz on MF, 156.8 MHz/channel 16 on VHF.

1.4 Reception of a distress relay call

If the distress relay call is received from a ship station, coast stations on receipt of the distress relay call shall ensure that the call is routed as soon as possible to an RCC. The receipt of the distress relay call is to be acknowledged as soon as possible by the appropriate coast station using a DSC distress relay acknowledgement addressed to the ship station. If the distress relay call is received from a coast station, other coast stations will normally not have to take further action.

2 Urgency

2.1 Transmission of a DSC announcement

The announcement of the urgency message shall be made on one or more of the distress and safety calling frequencies using DSC and the urgency call format.

The DSC urgency call may be addressed to all ships (VHF only), to a geographical area (MF/HF only), or to a specific ship. The frequency on which the urgency message will be transmitted after the announcement shall be included in the DSC urgency call.

The DSC urgency call is transmitted as follows:

– use a transmitter which is tuned to the frequency for DSC distress calls (2 187.5 kHz on MF, 156.525 MHz /channel 70 on VHF);

– in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1 of § 1.2 of this Annex):

  – the format specifier (all ships call (VHF), geographical area (MF/HF only), or individual station),

  – if appropriate, the address of the ship, or geographical area,

  – the category of the call (urgency),

  – the frequency or channel on which the urgency message will be transmitted,

  – the type of communication in which the urgency message will be transmitted (radiotelephony);

– transmit the DSC urgency call.

After the DSC announcement, the urgency message will be transmitted on the frequency indicated in the DSC call.

3 Safety

3.1 Transmission of a DSC announcement

The announcement of the safety message shall be made on one or more of the distress and safety calling frequencies using DSC and the safety call format.

The DSC safety call may be addressed to all ships (VHF only), to a geographical area (MF/HF only), or to a specific ship. The frequency on which the safety message will be transmitted after the announcement shall be included in the DSC safety call.

The DSC safety call is transmitted as follows:

– use a transmitter which is tuned to the frequency for DSC distress alerts (2 187.5 kHz on MF, 156.525 MHz/channel 70 on VHF);

– in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1 of § 1.2 of this Annex):

  – the format specifier (all ships call (VHF only), geographical area (MF/HF only), or individual station),

  – if appropriate, the address of the ship, or geographical area,

  – the category of the call (safety),

  – the frequency or channel on which the safety message will be transmitted,

  – the type of communication in which the safety message will be transmitted (radiotelephony);

– transmit the DSC safety call.

After the DSC announcement, the safety message will be transmitted on the frequency indicated in the DSC call.

4 Public correspondence

4.1 DSC frequencies/channels for public correspondence

4.1.1 VHF

The frequency 156.525 MHz/channel 70 is used for DSC for distress and safety purposes. It may also be used for calling purposes other than distress and safety, e.g. public correspondence.

4.1.2 MF

For public correspondence national and international frequencies are used which are different from the frequencies used for distress and safety purposes.

When calling ship stations by DSC, coast stations should use for the call, in the order of preference:

– a national DSC channel on which the coast station is maintaining watch;

– the international DSC calling channel, with the coast station transmitting on 2 177 kHz and receiving on 2 189.5 kHz. In order to reduce interference on this channel, it may be used as a general rule by coast stations to call ships of another nationality, or in cases where it is not known on which DSC frequencies the ship station is maintaining watch.

4.2 Transmission of a DSC call to a ship

The DSC call is transmitted as follows:

– use a transmitter which is tuned to the appropriate calling frequency;

– in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1 of § 1.2 of this Annex):

– the 9-digit identity of the ship to be called,

– the category of the call routine,

– the type of subsequent communication (radiotelephony),

– working frequency information;

– after checking as far as possible that there are no calls in progress, transmit the DSC call.

4.3 Repeating a call

Coast stations may transmit the call twice on the same calling frequency with an interval of at least 45 s between the two calls, provided that they receive no acknowledgement within that interval.

If the station called does not acknowledge the call after the second transmission, the call may be transmitted again on the same frequency after a period of at least 30 min or on another calling frequency after a period of at least 5 min.

4.4 Preparation for exchange of traffic

On receipt of a DSC acknowledgement with the indication that the called ship station can use the proposed working frequency, the coast station transfers to the working frequency or channel and prepares to receive the traffic.

4.5 Acknowledgement of a received DSC call

Acknowledgements shall normally be transmitted on the frequency paired with the frequency of the received call. If the same call is received on several calling channels, the most appropriate channel shall be chosen for transmission of the acknowledgement.

The acknowledgement of a DSC call is transmitted as follows:

– use a transmitter which is tuned to the appropriate frequency;

– in accordance with the DSC equipment manufacturer's instructions, key in or select on the DSC equipment keyboard (see Note 1 of § 1.2 of this Annex):

– the format specifier (individual station),

– 9-digit identity of the calling ship,

– the category of the call routine,

– if able to comply immediately on the working frequency suggested by the ship station, the same frequency information as in the received call,

– if no working frequency was suggested by the calling ship station, then the acknowledgement should include a channel/frequency proposal,

– if not able to comply on the working frequency suggested, but able to comply immediately on an alternative frequency, the alternative working frequency,

– if unable to comply immediately the appropriate information in that regard;

– transmit the acknowledgement (after checking as far as possible that there are no calls in progress on the frequency selected) after a delay of at least 5 s, but not later than 4½ min.

After having transmitted the acknowledgement, the coast station transfers to the working frequency or channel and prepares to receive the traffic.

5 Testing the equipment used for distress and safety calls

Perform VHF, MF and HF test calls in accordance with Recommendation ITU-R M.493, Table 4.7.

Acknowledgement of a DSC test call

The coast station should acknowledge test calls.

6 Special conditions and procedures for DSC communication on HF

General

The procedures for DSC communication on HF are – with some additions described in § 6.1 to 6.3 below – equal to the corresponding procedures for DSC communications on MF/VHF.

Due regard to the special conditions described in § 6.1 to 6.3 should be given when making DSC communications on HF.

6.1 Distress

6.1.1 Reception and acknowledgement of a DSC distress alert on HF

Ships in distress may in some cases transmit the DSC distress alert on a number of HF bands with only short intervals between the individual calls.

The coast station shall transmit DSC acknowledgement on all HF DSC distress channels on which the DSC distress alert was received in order to ensure as far as possible that the acknowledgement is received by the ship in distress and by all ships which received the DSC distress alert.

6.1.2 Distress traffic

The distress traffic should, as a general rule, be initiated on the appropriate distress traffic channel (radiotelephony or NBDP) in the same band in which the DSC distress alert was received.

For distress traffic by NBDP the following rules apply:

– all messages shall be preceded by at least one carriage return, line feed, one letter shift and the distress signal MAYDAY;

– FEC broadcast mode should be used.

6.1.3 Transmission of DSC distress relay call on HF

HF propagation characteristics should be taken into account when choosing HF band(s) for transmission of DSC distress relay call.

IMO Convention ships equipped with HF DSC for distress and safety purposes are required to keep continuous automatic DSC watch on the DSC distress channel in the 8 MHz band and on at least one of the other HF DSC distress channels.

In order to avoid creating on board ships uncertainty regarding on which band the subsequent establishment of contact and distress traffic should be initiated, the HF DSC distress relay call should be transmitted on one HF band at a time and the subsequent communication with responding ships be established before eventually repeating the DSC distress relay call on another HF band.

6.2 Urgency

6.2.1 Transmission of urgency announcement and message on HF

For urgency messages by NBDP the following apply:

– the urgency message shall be preceded by at least one carriage return, line feed, one letter shift, the urgency signal PAN PAN and the identification of the coast station;

– FEC broadcast mode should normally be used.

ARQ mode should be used only when considered advantageous to do so in the actual situation and provided that the radiotelex number of the ship is known.

6.3   Safety

6.3.1   Transmission of safety announcements and messages on HF

For safety messages by NBDP the following apply:

–   the safety message shall be preceded by at least one carriage return, line feed, one letter shift, the safety signal SECURITE and the identification of the coast station;

–   FEC broadcast mode should normally be used.

    ARQ mode should be used only when considered advantageous to do so in the actual situation and provided that the radiotelex number of the ship is known.

Annex 5

Frequencies used for DSC

1   The frequencies used for distress, urgency, and safety purposes using DSC are as follows (RR Appendix 15):

2 187.5	kHz
4 207.5	kHz
6 312	kHz
8 414.5	kHz
12 577	kHz
16 804.5	kHz
156.525	MHz (Note 1)

NOTE 1 – The frequency 156.525 MHz may also be used for DSC purposes other than distress, urgency, and safety.

2   The frequencies assignable on an international basis to ship and coast stations for DSC, for purposes other than distress, urgency, and safety, are as follows (see Note 2):

2.1   Ship stations (see Note 2)

458.5			kHz
2 177 (Note 3)	2 189.5		kHz
4 208	4 208.5	4 209	kHz
6 312.5	6 313	6 313.5	kHz
8 415	8 415.5	8 416	kHz
12 577.5	12 578	12 578.5	kHz
16 805	16 805.5	16 806	kHz
18 898.5	18 899	18 899.5	kHz
22 374.5	22 375	22 375.5	kHz
25 208.5	25 209	25 209.5	kHz
		156.525	MHz

2.2   Coast stations (see Note 2)

455.5			kHz
2 177			kHz
4 219.5	4 220	4 220.5	kHz
6 331	6 331.5	6 332	kHz
8 436.5	8 437	8 437.5	kHz
12 657	12 657.5	12 658	kHz
16 903	16 903.5	16 904	kHz
19 703.5	19 704	19 704.5	kHz
22 444	22 444.5	22 445	kHz
26 121	26 121.5	26 122	kHz
		156.525	MHz

NOTE 2 – The following (kHz) paired frequencies (for ship/coast stations) 4 208/4 219.5, 6 312.5/6 331, 8 45/8 436.5, 12 577.5/12 657, 16 805/16 903, 18 898.5/19 703.5, 22 374.5/22 444 and 25 208.5/26 121 are the first choice international frequencies for DSC (See RR Appendix 17, Part A, footnote j) and l)).

NOTE 3 – The frequency 2 177 kHz is available to ship stations for intership calling only.

3   In addition to the frequencies listed in § 2 above, appropriate working frequencies in the following bands may be used for DSC (see RR Chapter II, Article 5):

415-526.5	kHz	(Regions 1 and 3)
415-525	kHz	(Region 2)
1 606.5-3 400	kHz	(Regions 1 and 3)
1 605.5-3 400	kHz	(Region 2) (For the band 1 605-1 625 kHz, see RR No. 5.89)
4 000-27 500	kHz	
156-174	MHz	

RECOMMENDATION ITU-R M.585-6*

Assignment and use of identities in the maritime mobile service

(1982-1986-1990-2003-2007-2009-2012)

Scope

This Recommendation provides guidance to administrations for the assignment and conservation of identity resources for the maritime mobile service. The limitations which constrain assignments for ships which utilize the satellite services of the global maritime distress and safety system (GMDSS) are described in this Recommendation.

Annex 1 describes formats for maritime mobile service identities (MMSI) of ship stations, coast stations, aircraft participating in search and rescue operations and other safety-related communications, automatic identification system (AIS) aids to navigation, and craft associated with a parent ship.

Annex 2 describes formats for identification of other maritime devices, such as handheld VHF transceivers with digital selective calling (DSC) and global navigation satellite system (GNSS), AIS-search and rescue transmitter (AIS-SART), man overboard (MOB) and emergency position indicating radio beacon (EPIRB)-AIS.

Annex 3 provides specific guidance to administrations for the assignment, management and conservation of identity resources for the maritime mobile service. This guidance further instructs administrations on methods for the reuse of MMSI assignments, particularly for the reuse of those with three trailing zeroes.

The ITU Radiocommunication Assembly,

considering

a)   the need for structured identities for safety and telecommunication purposes in the maritime mobile service;

b)   that the maritime identifier in the maritime mobile service is based on a 9-digit structure;

c)   that the MMSI is one type of nine digit identifier;

d)   that the identities designated for devices for special purposes consist of a second type of 9-digit identifier;

e)   that the unique identity assigned to stations indicated in Annex 1 to this Recommendation should be the MMSI;

f)   that the identities used for other maritime devices for special purposes indicated in Annex 2 to this Recommendation are not necessarily unique and are not MMSI assignments;

g)   the need for all maritime identities to be usable with automated radiocommunication systems;

h)   that the identities assigned to ship stations, coast stations, aircraft participating in search and rescue operations and other safety-related communications, aids to navigation, craft associated with a parent ship, and used for establishing group calls should be of a similar nature;

i)   that it is possible to use the MMSI to establish a telephone call to a ship after routing through the public switched networks to an appropriate coast station;

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*   This Recommendation should be brought to the attention of International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), International Civil Aviation Organization (ICAO), International Hydrographic Organization (IHO), International Maritime Organization (IMO) and Committee International Radio Maritime (CIRM).

j)   that the public switched networks in many countries have restrictions on the maximum number of digits that may be dialled or keyed to identify the called ship station and the routing coast station, which would prevent the translation of the complete MMSI directly into a diallable number for the ship that is compliant with Recommendation ITU-T E.164;

k)   that whatever restrictions may be required should, in the interests of the development of automatic shore-to-ship operations, be as few as possible;

l)   that mobile-satellite systems enable the maritime community to participate in or interwork with international public correspondence telecommunication systems on a fully automatic basis, utilizing the identities, naming and addressing scheme;

m)   that the current generation of mobile-satellite systems participating in the GMDSS have signalling and routing characteristics requiring ships using these networks to have an MMSI ending with three zeroes;

n)   that the numbering scheme specified for future generations of mobile-satellite systems participating in the GMDSS will be designed to meet the needs of the international public correspondence service and is unlikely to offer the facility to incorporate any part of the MMSI in a diallable number for a ship,

      noting

that all devices referenced in this Recommendation are considered stations as defined in No. **1.61** of the Radio Regulations,

      recommends

1   that ships complying with the International Convention for the Safety of Life at Sea, 1974, as amended, and other ships equipped with automated radiocommunication systems, including AIS, DSC, and/or carrying alerting devices of the GMDSS should be assigned maritime mobile service identities in accordance with the Annex 1 to this Recommendation, as appropriate;

2   that maritime identities used for other maritime devices for special purposes should be assigned as specified in Annex 2;

3   that ship stations, including handheld VHF transceivers with DSC and GNSS, coast stations, and aircraft participating in search and rescue operations using digital selective calling equipment in accordance with Recommendation ITU-R M.493 should use their 9-digit numerical identities transmitted as a 10-digit address/self-identity, normally with a digit 0 added at the end of the identity (see also Recommendation ITU-R M.1080);

4   that ship stations, coast stations, and non-shipborne stations using AIS equipment in accordance with Recommendation ITU-R M.1371 should use their 9-digit numerical identities;

5   for the purpose of ensuring compatibility with the GMDSS, the numbers, names and addresses of ship earth stations participating in international telecommunication services should be made readily available to all authorized entities by the telecommunication service providers concerned;

6   that the guidance given in Annex 3 to this Recommendation should be consulted for the assignment, management and conservation of identities in the maritime mobile service.

Annex 1

Maritime mobile service identities

Section 1

Assignment of identification to ship station

1   Ships participating in the maritime radio services mentioned in recommends 1 should be assigned a nine digit unique ship station identity in the format $M_1I_2D_3X_4X_5X_6X_7X_8X_9$ where in the first three digits represent the Maritime Identification Digits (MID) and X is any figure from 0 to 9. The MID denotes the administration having jurisdiction over the ship station so identified.

2   Restrictions may apply with respect to the maximum number of digits, which can be transmitted on some national telex and/or telephone networks for the purpose of ship station identification.

3   The maximum number of digits that could be transmitted over the national networks of many countries for the purpose of determining ship station identity was six. The digits carried on the network to represent the ship station identity are referred to as the "ship station number" in this text and in the relevant ITU-R Recommendations. The use of the techniques described below should have made it possible for the coast stations of such countries to engage in the automatic connection of calls to ship stations.

To obtain the required nine digit ship station identity a series of trailing zeros would have to be added automatically to the ship station number by the coast station in order to complete a shore-originated telephone call, for example, carried over the public switched telephone network:

Ship station number	*Ship station identity*
$M_1I_2D_3X_4X_5X_6$	$M_1I_2D_3X_4X_5X_60_70_80_9$

4   In accordance with the above, and the relevant ITU-T Recommendations, a numbering plan was instituted for Inmarsat Standard B, C and M systems, which also requires that MMSI with three trailing zeroes be assigned to ships fitting standard B, C and M ship earth stations.

5   The above restrictions do not necessarily apply to Inmarsat Standard C systems, as they are not diallable terminals from the public switched telephone network but are only data terminals.

6   With respect to Inmarsat Standard B and M systems and as long as the above restrictions apply, ships reasonably expected to be affected by the above limitations should only be assigned ship station identities with $X_7X_8X_9 = 000$.

7   Group ship station call identities for calling simultaneously more than one ship are formed as follows:

$$0_1M_2I_3D_4X_5X_6X_7X_8X_9$$

where the first figure is zero and X is any figure from 0 to 9. The MID represents only the territory or geographical area of the administration assigning the group ship station call identity and does not therefore prevent group calls to fleets containing more than one ship nationality.

8   With the evolution of global mobile-satellite systems, ships earth stations are able to participate in international public correspondence telecommunication services. Ship earth stations

having this functionality may be assigned international telecommunication numbers that have no direct correspondence with the ship station MMSI. Those authorized to assign the numbers, names and addresses associated with such ship earth stations should maintain a record of the cross reference relationships with the MMSI, for example in an appropriate database. For the purposes of GMDSS the details of these relationships should be made available to authorized entities such as but not limited to the Rescue Coordination Centres (RCC)[1]. Such availability should be on an automatic basis, 24 hours per day 365 days per year.

Section 2

Assignment of identification to coast station

1 Coast stations and other stations on land participating in the maritime radio services mentioned in *recommends* 3 should be assigned a nine-digit unique coast station identity in the format $0_1 0_2 M_3 I_4 D_5 X_6 X_7 X_8 X_9$ where the digits 3, 4 and 5 represent the MID and X is any figure from 0 to 9. The MID reflects the administration having jurisdiction over the coast station or coast earth station.

2 As the number of coast stations decreases in many countries, an administration may wish to assign MMSI of the format above to harbour radio stations, pilot stations, system identities and other stations participating in the maritime radio services. The stations concerned should be located on land or on an island in order to use the 00MIDXXXX format.

3 The administration may use the sixth digit to further differentiate between certain specific uses of this class of MMSI, as shown in the example applications below:

a) 00MID1XXX Coast radio stations

b) 00MID2XXX Harbour radio stations

c) 00MID3XXX Pilot stations, etc.

4 This format scheme creates blocks of 999 numbers for each category of station, however the method is optional and should be used only as a guidance. Many other possibilities exist if the administration concerned wishes to augment the scheme.

5 Group coast station call identities for calling simultaneously more than one coast station are formed as a subset of coast station identities, as follows:

$$0_1 0_2 M_3 I_4 D_5 X_6 X_7 X_8 X_9$$

where the first two figures are zeros and X is any figure from 0 to 9. The MID represents only the territory or geographical area of the administration assigning the group coast station call identity. The identity may be assigned to stations of one administration which are located in only one geographical region as indicated in the relevant ITU-T Recommendations.

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[1] IMO Resolution A.1001(25) requires that distress priority communications in these systems should, as far as possible, be routed automatically to an RCC.

6 The combination $0_1 0_2 M_3 I_4 D_5 0_6 0_7 0_8 0_9$ should be reserved for a Group Coast Station Identity and should address all 00MIDXXXX stations within the administration. The administration may further augment this use with additional group call identities, i.e. 00MID1111, etc.

7 For the purpose of the GMDSS the details of these MMSI assignments should be made available to authorized entities such as, but not limited to, RCC. Such availability should be on an automatic basis, 24 hours per day 365 days per year.

8 The combination $0_1 0_2 9_3 9_4 9_5 0_6 0_7 0_8 0_9$ is reserved for the all coast stations identity and should address all VHF 00XXXXXXX stations. It is not applicable to MF or HF coast stations.

Section 3

Assignment of identification to aircraft

1 When an aircraft is required to use maritime mobile service identities for the purposes of search and rescue operations and other safety-related communications with stations in the maritime mobile service, the responsible administration should assign a nine-digit unique aircraft identity, in the format $1_1 1_2 1_3 M_4 I_5 D_6 X_7 X_8 X_9$ where the digits 4, 5 and 6 represent the MID and X is any figure from 0 to 9. The MID represents the administration having jurisdiction over the aircraft call identity.

2 The format shown above will accommodate 999 aircraft per MID. If the administration concerned has more search and rescue (SAR) aircraft than 999 they may use an additional country code (MID) if it is already assigned by the ITU.

3 The administration may use the seventh digit to differentiate between certain specific uses of this class of MMSI, as shown in the example applications below:

a)   111MID1XX   Fixed-wing aircraft

b)   111MID5XX   Helicopters

4 This format scheme creates blocks of 99 numbers for each of the category of stations, however, the method shown here is optional.

5 The combination $1_1 1_2 1_3 M_4 I_5 D_6 0_7 0_8 0_9$ should be reserved for a Group Aircraft Identity and should address all 111MIDXXX stations within the administration. The administration may further augment this with additional Group Call identities, i.e. 111MID111, etc.

6 For the purpose of search and rescue the details of these MMSI assignments should be made available to authorized entities such as, but not limited to, RCC. Such availability should be on an automatic basis, 24 hours per day 365 days per year.

7 The MMSI assigned to aircraft should also be available from the ITU MARS database (see RR No. **20.16**).

Section 4

Assignment of identification to automatic identification systems
aids to navigation

1   When a means of automatic identification is required for a station aiding navigation at sea, the responsible administration should assign a nine-digit unique number in the format $9_1 9_2 M_3 I_4 D_5 X_6 X_7 X_8 X_9$ where the digits 3, 4 and 5 represent the MID and X is any figure from 0 to 9. The MID represents the administration having jurisdiction over the call identity for the navigational aid.

2   The format shown above applies to all types of aid to navigation (AtoN) as listed in the most recent version of Recommendation ITU-R M.1371, see AIS Message 21 parameter "Type of aids to navigation" and the associated table for this parameter. This format is used for all AIS stations for the transmission of messages that relate to AtoN. In the case where an AIS base station is collocated with an AIS AtoN station the messages related to the base station operation should be assigned an identification number in the format given in Annex 2.

3   The format scheme shown above will accommodate 10 000 AtoN per MID. If the administration concerned has more than 10 000 they may use an additional country code (MID) if it is already assigned by the ITU giving a further 10 000 identities.

4   The administration may use the sixth digit to differentiate between certain specific uses of the MMSI, as shown in the example applications below:

a)   99MID1XXX   Physical AIS AtoN

b)   99MID6XXX   Virtual AIS AtoN

5   This format scheme creates blocks of 999 numbers for each category of station, however the method shown here is optional and should be used only as a guidance.

6   In addition to the use of the sixth digit to differentiate between specific navigational aids as explained above, the seventh digit may be used for national purposes, to define areas where the AIS AtoN are located or types of AIS AtoN to the discretion of the administration concerned.

7   The details of these MMSI assignments should be made available but not limited to the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and appropriate national authorities.

8   The assigned MMSI to aids of navigation should also be available from the ITU MARS database (see RR No. **20.16**).

Section 5

Assignment of identification to craft associated with a parent ship

1   Craft associated with a parent ship, need unique identification. These crafts which participate in the maritime mobile service should be assigned a nine-digit unique number in the format $9_1 8_2 M_3 I_4 D_5 X_6 X_7 X_8 X_9$ where the digits 3, 4 and 5 represent the MID and X is any figure from 0 to 9. The MID represents the administration having jurisdiction over the call identity for the craft associated with a parent ship.

2   This numbering format is only valid for devices on board craft associated with a parent ship. A craft may carry multiple devices which would be identified by the MMSI assigned to the craft. These devices may be located in lifeboats, life-rafts, rescue-boats or other craft belonging to a parent ship.

3   A unique MMSI should be assigned for each craft associated with a parent ship and will have to be separately registered and linked to the MMSI of the parent ship.

4   The format scheme shown above will accommodate 10 000 crafts associated with parent ships per MID. If the administration concerned has more than 10 000 they may use an additional country code (MID) if it is already assigned by the ITU giving a further 10 000 identities.

5   The assigned MMSI to these craft associated with a parent ship should also be available from the ITU MARS database (see RR No. **20.16**).

Annex 2

Maritime identities used for other maritime devices for special purposes

These identities use MID numbering resources, but have special uses defined in each of the sections below.

Section 1

Assignment of identities for handheld VHF transceivers with digital selective calling and global navigation satellite system

1   A handheld VHF transceiver with DSC and GNSS may require a unique identification showing that this device has restricted battery capacity and restricted coverage area. This may give additional information in an emergency case.

2   The handheld VHF transceiver with DSC and GNSS should be used exclusively in the maritime mobile service.

3   Handheld VHF transceiver with DSC and GNSS participating in the maritime mobile service should be assigned a unique 9-digit number in the format $8_1M_2I_3D_4X_5X_6X_7X_8X_9$ where digits 2, 3 and 4 represents the MID and X is any figure from 0 to 9. The MID represents the administration assigning the identity to the handheld transceiver.

$$8_1M_2I_3D_4X_5X_6X_7X_8X_9$$

4   The procedure and criteria for assignment and registration of these identities should be left to the administration concerned.

5   Some minimum of procedures for registration of this identity should be observed:

a)   all identities in this category should be registered by the national authority concerned, and the local RCC or MRCC should be able to access the data on a 24 hour-per-day, 7 days-per-week basis. In systems that have automatic distress priority, this information should be automatically forwarded to an RCC;

b)   the reuse of this identity should follow the guidance of Annex 3 of this Recommendation.

6   The administration may use the 5th digit to differentiate between certain specific uses/users of the maritime identity. However, this method is optional and for national use only.

Section 2

Devices using a freeform number identity

These identities, which use the 3-digit prefix (allocated from the table of maritime identification digits), are used to identify maritime radio equipment like the AIS-SART, MOB and EPIRB-AIS and similar equipment needing identification.

1   Automatic identification system-search and rescue transponder

The AIS-SART should use an identity:

$$9_17_20_3X_4X_5Y_6Y_7Y_8Y_9$$

(where X_4X_5 = manufacturer ID 01 to 99; $Y_6Y_7Y_8Y_9$ = the sequence number 0000 to 9999. When reaching 9999 the manufacturer should restart the sequence numbering at 0000.)

2   Man overboard

The MOB (Man overboard) device that transmits DSC and/or AIS should use an identity:

$$9_17_22_3X_4X_5Y_6Y_7Y_8Y_9$$

(where X_4X_5 = manufacturer ID 01 to 99; $Y_6Y_7Y_8Y_9$ = the sequence number 0000 to 9999. When reaching 9999 the manufacturer should restart the sequence numbering at 0000.)

3   **Emergency position indicating radio beacon-automatic identification system**

The EPIRB-AIS should use an identity:

$$9_1 7_2 4_3 X_4 X_5 Y_6 Y_7 Y_8 Y_9$$

(where $X_4 X_5$ = manufacturer ID 01 to 99; $Y_6 Y_7 Y_8 Y_9$ = the sequence number 0000 to 9999. When reaching 9999 the manufacturer should restart the sequence numbering at 0000.)

The user identity of the EPIRB-AIS indicates the identity of the homing device of the EPIRB-AIS, and not the MMSI of the ship.

Annex 3

Assignment, management and conservation of maritime identities

Section 1

Maritime mobile service identities

Administrations should employ the following measures to manage the limited identity resource, particularly for the reuse of MMSI with three trailing zeroes, in order to avoid depletion of MID and the corresponding MMSI series:

a)   implement effective national procedures for identity assignment and registration;

b)   provide the Radiocommunication Bureau with regular updates of assigned MMSI numbers in conformity with RR No. **20.16**;

c)   ensure that when ships move from the flag of registration of one administration to that of another administration, all of the assigned means of ship station identification, including the MMSI, are reassigned as appropriate and that the changes are notified to the Radiocommunication Bureau as soon as possible (see RR No. **20.16**);

d)   an MMSI assignment could be considered for reuse after being absent from two successive editions of List V of the ITU service publications or after a period of two years, whichever is the greater.

Section 2

Maritime identities used for other maritime devices for special purposes

Administrations, when assigning maritime identities to handheld VHF transceivers with DSC and GNSS, should employ all available measures to effectively manage the limited identity resource.

a)   The format scheme in Annex 2 Section 1, used for assigning VHF transceiver identities, will accommodate 100 000 VHF transceivers per MID. When the administration concerned has assigned identities to 100 000 VHF transceivers with DSC and GNSS, it may use an additional country code (MID), if it is already assigned by the ITU, giving a further 100 000 identities.

b)   When an administration determines it has a need for additional allocation of a MID, because it has exhausted more than 80% of its allocated MID resource, it should communicate a written formal application to the Director, Radiocommunication Bureau to request allocation of an additional MID.

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RECOMMENDATION ITU-R M.625-3*

DIRECT-PRINTING TELEGRAPH EQUIPMENT EMPLOYING AUTOMATIC IDENTIFICATION IN THE MARITIME MOBILE SERVICE**

(Question ITU-R 5/8)

(1986-1990-1992-1995)

Summary

The Recommendation provides in Annex 1 characteristics of direct-printing telegraph equipment employing a 7-unit ARQ method for selective communication, a 7-unit FEC method for broadcast mode and automatic identification to be used for newly developed equipment to provide compatibility with existing equipment conforming to Recommendation ITU-R M.476.

The ITU Radiocommunication Assembly,

considering

a)   that there is a requirement to interconnect ship stations or ship stations and coast stations, equipped with start-stop apparatus employing the ITU-T International Telegraph Alphabet No. 2, by means of radiotelegraph circuits;

b)   that direct-printing telegraph equipment in the maritime mobile service is used for:

–   telex and/or telegraph service between a ship station and a subscriber of the (international) telex network;

–   telegraph service between a ship station and a coast station or between two ship stations;

–   telegraph service between a ship station and an extended station (ship owner) via a coast station;

–   telegraph service in a broadcast mode from a coast station, or a ship station, to one or more ship stations;

c)   that the broadcast mode cannot take advantage of an ARQ method, as a return path is not used;

d)   that for the broadcast mode a forward error-correcting (FEC) method should be used;

e)   that the period for synchronization and phasing should be as short as possible;

f)   that most of the ship stations do not readily permit the simultaneous use of radio transmitter and receiver;

g)   that a direct-printing telegraph system employing error-detecting and error-correcting methods in accordance with Recommendation ITU-R M.476, is in actual operation;

h)   that the increased use of direct-printing telegraph equipment has emphasized the importance of an unambiguous identification of both stations when a circuit is established or re-established;

j)   that unambiguous identification could be accomplished by the exchange of self-identification signals between the ARQ equipments at the 7-unit level;

k)   that Appendix 43 of the Radio Regulations (RR), Recommendation ITU-R M.585 and ITU-T Recommendations E.210 and F.120 provide for a comprehensive system of assigning maritime mobile service identities;

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the Telecommunication Standardization Sector (ITU-T).

**   Newly developed equipment should conform to the present Recommendation which provides for compatibility with existing equipment built in accordance with Recommendation ITU-R M.476.

Note by the Secretariat: During the re-arrangement of the Radio Regulations carried out at WRC-95, Appendix 43, which is referred to in this Recommendation, was suppressed and its contents was tranferred to other parts of the Radio Regulations.

l)   that, in the interest of having a unique identity assigned to each ship station for distress and safety and other telecommunication purposes, the address capability should allow the use of maritime mobile service identities in accordance with the provisions of Appendix 43 of the RR;

m)   that equipment built in accordance with Recommendation ITU-R M.476 cannot provide for the use of maritime mobile service identities mentioned in § k);

n)   that there is a need to provide for compatibility to the extent possible with equipments built in accordance with Recommendation ITU-R M.476; however, unambiguous identification of both stations cannot be achieved when circuits are established with equipments built in accordance with Recommendation ITU-R M.476,

recommends

1   that for direct-printing telegraph circuits in the maritime mobile service, a 7-unit ARQ method should be employed;

2   that for the direct-printing telegraph service in the broadcast mode, a 7-unit forward acting error-correcting method, using time diversity, should be employed;

3   that equipment designed in accordance with § 1 and 2 should employ automatic identification and have the characteristics given in Annex 1.

ANNEX 1

CONTENTS

1   General (mode A (ARQ) and mode B (FEC))

1.1   The system in both Mode A (ARQ) and Mode B (FEC) is a single-channel synchronous system using the 7-unit constant ratio error-detecting code as listed in § 2.2 and 2.3.

1.2   FSK modulation is used on the radio link at 100 Bd. The equipment clock controlling the modulation rate should have an accuracy of 30 parts in 10^6 or better.

1.3   The class of emission is F1B or J2B with a frequency shift on the radio link of 170 Hz. When frequency shift is effected by applying audio signals to the input of a single-sideband transmitter, the centre frequency of the audio spectrum applied to the transmitter should be 1 700 Hz.

1.4   The radio-frequency tolerance of the transmitter and the receiver should be in accordance with Recommendation ITU-R SM.1137. It is desirable that the receiver employs the minimum practicable bandwidth (see also Report ITU-R M.585).

NOTE 1 – The receiver 6 dB bandwidth should preferably be between 270 and 340 Hz.

1.5   For direct connection to the international telex network, the line input and output signals should be in accordance with the 5-unit start-stop International Telegraph Alphabet No. 2, at a modulation rate of 50 Bd.

1.6   Equipment designed in accordance with this Recommendation is likely to contain high speed digital circuitry. Special care should be taken to avoid interference to other equipment and to minimize susceptibility to interference from other equipment or electrical lines on board ship (see also Recommendation ITU-R M.218).

1.7   When operating in mode A (ARQ), the called station employs a constant time interval between the end of the received signal and the start of the transmitted signal (t_E in Fig. 1). In the case of long propagation distances it is essential to have this t_E as short as practicable. However, in the case of short distances it may be desirable to introduce a longer time interval, e.g. 20-40 ms, to accommodate receiver desensitization at the calling station. This time interval can be introduced at the called station either in the ARQ equipment or in the radio equipment.

2   Conversion tables

2.1   General

Several kinds of "signals" are used in the system, such as:

–   traffic information signals,

–   service information signals (control signals, idle signals, signal repetition),

–   identification signals,

–   check-sum signals.

2.2   Traffic information signals

These signals are used during communication to convey the message information which is passed from an information sending station to one or more information receiving stations. Table 1 lists the traffic information signals which may be used.

2.3   Service information signals

These signals are used to control the procedures taking place over the radio circuit and do not form part of the transmitted messages. Service information signals are not normally printed or displayed. Table 2 lists the service information signals which may be used.

TABLE 1

Combination No.	Traffic information signals		International Telegraph Alphabet No. 2 Code [1]	Transmitted 7-unit signal [2]
	Letter-case	Figure case	Bit position [3] 1 2 3 4 5	Bit position [3] 1 2 3 4 5 6 7
1	A	–	ZZAAA	BBBYYYB
2	B	?	ZAAZZ	YBYYBBB
3	C	:	AZZZA	BYBBBYY
4	D	⊠ [4]	ZAAZA	BBYYBYB
5	E	3	ZAAAA	YBBYBYB
6	F	[5]	ZAZZA	BBYBBYY
7	G	[5]	AZAZZ	BYBYBBY
8	H	[5]	AAZAZ	BYYBYBB
9	I	8	AZZAA	BYBBYYB
10	J	⌒ (Audible signal)	ZZAZA	BBBYBYY
11	K	(	ZZZZA	YBBBBYY
12	L	)	AZAAZ	BYBYYBB
13	M	.	AAZZZ	BYYBBBY
14	N	,	AAZZA	BYYBBYB
15	O	9	AAAZZ	BYYYBBB
16	P	0	AZZAZ	BYBBYBY
17	Q	1	ZZZAZ	YBBBYBY
18	R	4	AZAZA	BYBYBYB
19	S	'	ZAZAA	BBYBYYB
20	T	5	AAAAZ	YYBYBBB
21	U	7	ZZZAA	YBBBYYB
22	V	=	AZZZZ	YYBBBBY
23	W	2	ZZAAZ	BBBYYBY
24	X	/	ZAZZZ	YBYBBBY
25	Y	6	ZAZAZ	BBYBYBY
26	Z	+	ZAAAZ	BBYYYBB
27	←	(Carriage return)	AAAZA	YYYBBBB
28	≡	(Line feed)	AZAAA	YYBYBBB
29	↓	(Letter shift)	ZZZZZ	YBYBBYB
30	↑	(Figure shift)	ZZZAZ	YBBBYBY
31	△	(Space)	AAZAA	YYBBBYB
32	☐	No information	AAAAA	YBYBYBB

[1] A represents start polarity, Z represents stop polarity (see also Recommendation ITU-R M.490).

[2] B represents the higher emitted frequency and Y the lower (see also Recommendation ITU-R M.490).

[3] The bit in bit position 1 is transmitted first; B = 0, Y = 1.

[4] The pictorial representation shown is a schematic of ✠ which may also be used when equipment allows (ITU-T Recommendation F.1, § C9).

[5] At present unassigned (see ITU-T Recommendation F.1, § C8). Reception of these signals, however, should not initiate a request for repetition.

TABLE 2

Mode A (ARQ)	Transmitted signal	Mode B (FEC)
Control signal 1 (CS1)	BYBYYBB	
Control signal 2 (CS2)	YBYBYBB	
Control signal 3 (CS3)	BYYBBYB	
Control signal 4 (CS4)	BYBYBBY	
Control signal 5 (CS5)	BYYBYBB	
Idle signal β	BBYYBBY	Idle signal β
Idle signal α	BBBBYYY	Phasing signal 1, Idle signal α
Signal repetition (RQ)	YBBYYBB	Phasing signal 2

2.4   Identification and check-sum numbers and signals

Identification and check-sum numbers and signals are used in the automatic identification procedure in order to provide a means by which, during the establishment or re-establishment of a radio circuit, the stations concerned are clearly and unambiguously identified to each other. The relationship between the transmitted identification signals and their equivalent numbers is shown in Table 3a; Table 3b indicates the conversion from check-sum numbers to the transmitted check-sum signals.

TABLE 3a   TABLE 3b

Identification signal (IS)	Equivalent number (N)
A	19
B	11
C	6
D	18
E	13
F	8
I	15
K	3
M	4
O	14
P	5
Q	2
R	16
S	9
T	10
U	12
V	0
X	1
Y	7
Z	17

Check-sum number (CN)	Check-sum signal (CK)
0	V
1	X
2	Q
3	K
4	M
5	P
6	C
7	Y
8	F
9	S
10	T
11	B
12	U
13	E
14	O
15	I
16	R
17	Z
18	D
19	A

2.5   Check-sum signal derivation

These identification signals IS1, IS2, IS3, IS4, IS5, IS6 and IS7 are converted into their equivalent numbers N1, N2, N3, N4, N5, N6 and N7 respectively, in accordance with Table 3a. The three numbers N1, N2 and N3 are added and the sum is translated into one check-sum number CN1 using modulo 20-addition. This process is repeated for the numbers N3, N4 and N5 resulting in a check-sum number CN2 and for the numbers N5, N6 and N7 resulting in a check-sum number CN3, as follows:

$$N1 \oplus N2 \oplus N3 = CN1$$

$$N3 \oplus N4 \oplus N5 = CN2$$

$$N5 \oplus N6 \oplus N7 = CN3$$

where $\oplus$ denotes modulo 20-addition.

The last conversion is from check-sum numbers CN1, CN2 and CN3 into "check-sum signal 1", "check-sum signal 2" and "check-sum signal 3" respectively, in accordance with Table 3b.

Example:

The seven identification signals of station 364775427 are: P E A R D B Y (see Recommendation ITU-R M.491).

The check-sum derivation will be as follows:

P E A R D B Y → 5 13 19 16 18 11 7

 5 ⊕ 13 ⊕ 19 = 17 (37-20)

19 ⊕ 16 ⊕ 18 = 13 (53-20-20)

18 ⊕ 11 ⊕ 7 = 16 (36-20)

17 13 16 → Z E R

where ⊕ denotes modulo 20-addition.

Result:

CK1 becomes "Z" (combination No. 26, see Table 1)

CK2 becomes "E" (combination No. 5, see Table 1)

CK3 becomes "R" (combination No. 18, see Table 1)

3 Characteristics, mode A (ARQ)

3.1 General

The system operates in a synchronous mode transmitting blocks of three signals from an information sending station (ISS) towards an information receiving station (IRS). A control signal is transmitted from the IRS to the ISS after reception of each block indicating correct reception or requesting retransmission of the block. These stations can interchange their functions.

3.2 Master and slave arrangements

3.2.1   The station that initiates the establishment of the radio circuit (the calling station) becomes the "master" station, and the station being called will be the "slave" station. This situation remains unchanged during the entire time that the established radio circuit is maintained, regardless of which station, at any given time, is the information sending station (ISS) or the information receiving station (IRS).

3.2.2   The clock in the master station controls the timing of the entire circuit (see circuit timing diagram, Fig. 1). This clock should have an accuracy of 30 parts in 10^6 or better.

3.2.3   The basic timing cycle is 450 ms and consists for each station of a transmission period followed by a transmission pause during which reception is effected.

3.2.4   The master station transmit timing is controlled by the clock in the master station.

3.2.5   The clock controlling the timing of the slave station is phase-locked to the signal received from the master station, i.e. the time interval between the end of the received signal and the start of the transmitted signal (t_E in Fig. 1) is constant (see also § 1.7).

3.2.6   The master station receive timing is phase-locked to the signal received from the slave station.

3.3 The information sending station (ISS)

3.3.1   The ISS groups the information to be transmitted into blocks of three signals (3×7 signal elements).

3.3.2   The ISS sends a block in 210 ms (3×70 ms) after which a transmission pause of 240 ms becomes effective.

3.4 The information receiving station (IRS)

3.4.1   After the reception of each block the IRS sends one signal of 70 ms duration (7-signal elements), after which a transmission pause of 380 ms becomes effective.

FIGURE 1

Basic timing diagram
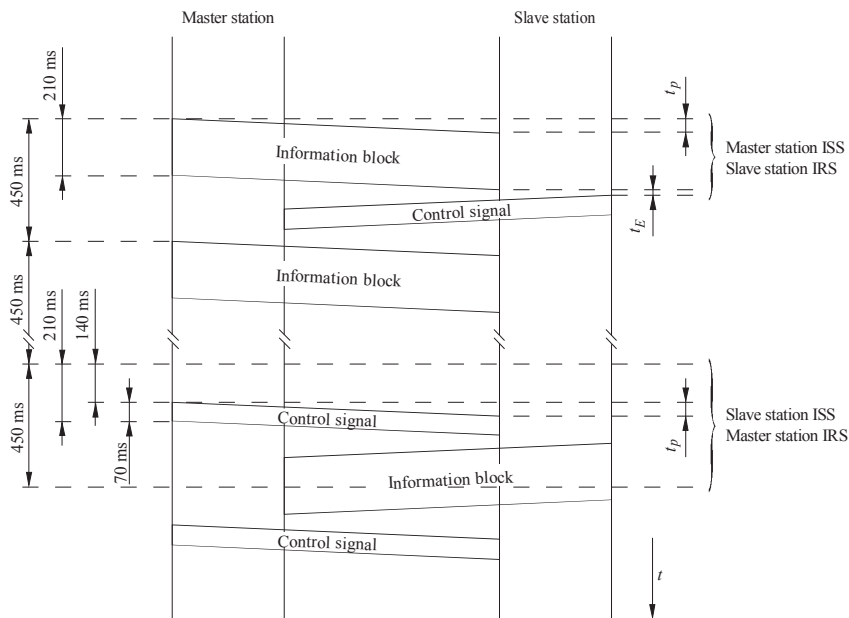
t_p : (one-way) propagation time
t_E : equipment delay (see also § 1.7)

D01

3.5 Phasing procedure

3.5.1 When no circuit is established, both stations are in the "stand-by" condition. In this condition neither of the stations is designated master, slave, ISS or IRS.

3.5.2 The "call signal" contains either four or seven identification signals as applicable. The identification signals are listed in Table 3a. The composition of these "call signals" should be in accordance with Recommendation ITU-R M.491.

3.5.2.1 The equipment should be capable of operating with both 4-signal and 7-signal identity procedures and automatically employing the appropriate procedure for either, as indicated by the composition of the "call signal" received from a calling station or by the number of digits (4, 5 or 9) supplied to the equipment of a calling station to identify the station to be called.

3.5.3 The "call signal" (Note 1) contains:

– in "call block 1": in the first, second and third character places respectively: the first identification signal, the service information signal "signal repetition" and the second identification signal of the called station;

– in "call block 2": in the first, second and third character places respectively, either:

– in the case of a 4-signal call identity: the third and the fourth identification signals of the called station and "signal repetition"; or

– in the case of a 7-signal call identity: "signal repetition", and the third and fourth identification signals of the called station;

–   in the case of a 7-signal call identity in "call block 3": the last three identification signals of the called station.

NOTE 1 – A station using a two block call signal shall be assigned a number in accordance with RR Nos. 2088, 2134 and 2143 to 2146.

A station capable of using a three block call signal, shall employ the maritime identification digits required in accordance with RR Appendix 43 when communicating with stations also capable of using a three block call signal.

3.5.4   The station required to establish the circuit becomes the master station and sends the "call signal" until it receives an appropriate control signal; however, if the circuit has not been established within 128 cycles (128 × 450 ms), the station changes into the "stand-by" condition and waits for a time of at least 128 cycles before sending the same "call signal" again.

3.5.5   The called station becomes the slave station and changes from the "stand-by" to the IRS condition:

–   in the case of a 4-signal call identity following the consecutive reception of "call block 1" and "call block 2", after which it sends "control signal 1" until the first information block has been received;

–   in the case of a 7-signal call identity following the reception of the three call blocks in succession after which it sends "control signal 4" until "identification block 1" has been received.

3.5.6   On receipt of two consecutive identical signals "control signal 1" or "control signal 2" the calling station changes to the ISS condition and proceeds directly with the transmission of traffic information (see § 3.7) without automatic identification.

NOTE 1 – Equipment built in accordance with Recommendation ITU-R M.476 sends "control signal 1" or "control signal 2" on receipt of the appropriate "call signal".

3.5.7   On receipt of "control signal 3" during the phasing procedure, the calling station immediately changes to the "stand-by" condition, and waits 128 cycles before sending the same "call signal" again.

NOTE 1 – Equipment built in accordance with Recommendation ITU-R M.476 may send "control signal 3" on receipt of the appropriate "call signal", if the called station is rephasing and was in the ISS condition at the moment of interruption.

3.5.8   On receipt of "control signal 5" during the phasing procedure, the calling station starts the "end-of-communication" procedure in accordance with § 3.7.14, and waits at least 128 cycles before sending the same "call signal" again. During this waiting time the station is in the "stand-by" condition.

3.6   Automatic identification

Only applicable in the case of a 7-signal call identity.

3.6.1   On receipt of "control signal 4" the calling station changes to the ISS condition and starts the identification procedure. During the identification cycle, information is exchanged about the identities of both stations; the ISS transmits its identification blocks and the IRS returns the check-sum signals derived from its identity in accordance with § 2.5. On receipt of each check-sum signal, the calling station compares this signal with the appropriate check-sum signal locally derived from the identification signals transmitted in the call blocks. If they are identical, the calling station continues with the following procedure, otherwise the procedure of § 3.6.12 is followed.

3.6.2   The ISS sends "identification block 1" containing its own first identification signal, "idle signal α" and its second identification signal in the first, second and third character places respectively.

3.6.3   On receipt of "identification block 1" the called station sends "check-sum signal 1", derived from its identity.

3.6.4   On receipt of "check-sum signal 1" the calling station sends "identification block 2" containing the first, second and third character places respectively, "idle signal α", its third identification signal and its fourth identification signal.

3.6.5   On receipt of "identification block 2" the called station sends "check-sum signal 2", derived from its identity.

3.6.6   On receipt of "check-sum signal 2" the calling station sends "identification block 3" containing its fifth, sixth and seventh identification signals in the first, second and third character places respectively.

3.6.7   On receipt of "identification block 3" the called station sends "check-sum signal 3", derived from its identity.

3.6.8   On receipt of the last check-sum signal the calling station sends the "end-of-identification block" containing three "signal repetition" signals.

3.6.9   On receipt of the "end-of-identification block" the called station sends, either:

–   "control signal 1", thus starting the traffic flow in accordance with § 3.7; or

–   "control signal 3", if the called station is required to start the traffic flow in the ISS condition (in accordance with § 3.7.11).

3.6.10   On receipt of "control signal 1" the calling station ends the identification cycle and starts the traffic flow by transmitting "information block 1" in accordance with § 3.7.

3.6.11   On receipt of "control signal 3" the calling station ends the identification cycle and starts the traffic flow with the change-over procedure in accordance with § 3.7.11.

3.6.12   If any received check-sum signal is not identical to the locally derived check-sum signal, the calling station retransmits the previous identification block. On receipt of this identification block, the called station sends the appropriate check-sum signal once more.

On receipt of this check-sum signal the calling station compares again. If they are still not identical, and the received check-sum signal is the same as the previous one, the calling station initiates the "end of communication" procedure in accordance with § 3.7.14; otherwise the calling station transmits the previous identification block again. Any identification block should not be retransmitted more than four times due to reception of wrong check-sum signals, after which, if the required check-sum signal is still not received, the calling station reverts to the "stand-by" condition.

3.6.13   If, due to mutilated reception, the calling station does not receive:

–   "control signal 4", it continues transmitting the "call signal";

–   "check-sum signal 1", it retransmits "identification block 1";

–   "check-sum signal 2", it retransmits "identification block 2";

–   "check-sum signal 3", it retransmits "identification block 3";

–   "control signal 1" or "control signal 3", it retransmits the "end-of-identification block",

taking into account the time limit mentioned in § 3.6.18.

3.6.14   If, due to mutilated reception, the called station does not receive a block during the identification cycle, it transmits a "signal repetition", taking into account the time limit mentioned in § 3.6.18.

3.6.15   If during the identification cycle the calling station receives a "signal repetition", it retransmits the previous block.

3.6.16   If, due to retransmission of an identification block by the calling station, the identification signals as received by the called station are not identical, the called station sends "signal repetition" until two identical consecutive identification blocks are received after which the corresponding check-sum signal is transmitted, taking into account the time limit mentioned in § 3.6.18.

3.6.17   If during the identification cycle the called station receives the "end-of-communication block" (containing three "idle signals α"), it sends a "control signal 1" and reverts to the "stand-by" condition.

3.6.18   When reception of signals during the identification cycle is continuously mutilated, both stations revert to the "stand-by" condition after 32 cycles of continuous repetition.

3.6.19   Each station should retain the identity of the other station for the duration of the connection (see § 3.7.1) and this information should be accessible locally, e.g. by means of a display or on a separate output circuit for external use. However, this identity information should not appear on the output line to the network.

3.7 Traffic flow

3.7.1   At all times after the start of the traffic flow and until the station reverts to the "stand-by" condition, the station should retain the following information:

–   whether it is in the master or slave condition;

–   the identity of the other station (when applicable);

–   whether it is in the ISS or IRS condition;

–   whether the traffic flow is in the letter case or figure case condition.

3.7.2   The ISS transmits the traffic information in blocks, each block consisting of three signals. If necessary, "idle signals β" are used to complete or to fill information blocks when no traffic information is available.

3.7.3   The ISS retains the transmitted information block in memory until the appropriate control signal confirming correct reception by the IRS has been received.

3.7.4   For internal use, the IRS numbers the received information blocks alternately "information block 1" and "information block 2" dependent on the first transmitted control signal. The numbering is interrupted at the reception of, either:

–   an information block in which one or more signals are mutilated; or

–   an information block containing at least one "signal repetition".

3.7.5   The IRS sends "control signal 1" at the reception of, either:

–   an unmutilated "information block 2"; or

–   a mutilated "information block 1"; or

–   an "information block 1" containing at least one "signal repetition".

3.7.6   The IRS sends "control signal 2" at the reception of, either:

–   an unmutilated "information block 1"; or

–   a mutilated "information block 2"; or

–   an "information block 2" containing at least one "signal repetition".

3.7.7   For internal use, the ISS numbers successive information blocks alternately "information block 1" and "information block 2". The first block should be numbered "information block 1" or "information block 2" dependent on whether the received control signal is a "control signal 1" or a "control signal 2". The numbering is interrupted at the reception of, either:

–   a request for repetition; or

–   a mutilated control signal; or

–   a "control signal 3".

3.7.8   On receipt of "control signal 1" the ISS sends "information block 1".

3.7.9   On receipt of "control signal 2" the ISS sends "information block 2".

3.7.10   On receipt of a mutilated control signal the ISS sends a block containing three "signal repetitions".

3.7.11 Change-over procedure

3.7.11.1 If the ISS is required to initiate a change in the direction of the traffic flow, the station sends the signal sequence ("↑" combination No. 30), "+" (combination No. 26), "?" (combination No. 2) followed, if necessary, by one or more "idle signals β" to complete the information block.

3.7.11.2 On receipt of the signal sequence ("+", "?" (combination No. 26 and combination No. 2)) with the traffic flow in the figure case condition, the IRS sends "control signal 3" until an information block containing the signals "idle signal β", "idle signal α", "idle signal β" has been received.

NOTE 1 – The presence of "idle signals β" between the signals "+" and "?" should not inhibit the response of the IRS.

3.7.11.3 If the IRS is required to initiate a change in the direction of the traffic flow, it sends "control signal 3".

3.7.11.4   On receipt of "control signal 3" the ISS sends an information block containing "idle signal β", "idle signal α" and "idle signal β" in the first, second and third character places respectively.

3.7.11.5   On receipt of the information block containing the service information signals "idle signal β", "idle signal α" and "idle signal β", the IRS changes to ISS and sends, either:

–   an information block containing three "signal repetitions", if it is the slave station; or

–   one "signal repetition", if it is the master station,

until either "control signal 1" or "control signal 2" is received, taking into account the time limit mentioned in § 3.7.12.1.

3.7.11.6   The ISS changes to IRS after the reception of, either:

–   an information block containing three "signal repetitions" if it is the master station; or

–   one "signal repetition" if it is the slave station,

and sends either "control signal 1" or "control signal 2" depending on whether the preceding control signal was "control signal 2" or "control signal 1", respectively, after which the traffic flow starts in the appropriate direction.

3.7.12   **Time-out procedure**

3.7.12.1   When reception of information blocks or of control signals is continuously mutilated, both stations revert to the "rephase" condition after 32 cycles of continuous repetition, in accordance with § 3.8.

3.7.13.   **Answer-back procedure**

3.7.13.1   If the ISS is required to request terminal identification, the station sends the signals "↑" (combination No. 30) and "⊠" (combination No. 4) followed, if necessary, by one or more "idle signals β" to complete the information block.

3.7.13.2   On receipt of an information block containing the traffic information signal "⊠" (combination No. 4) with the traffic flow in the figure case condition, the IRS:

–   changes the direction of the traffic flow in accordance with § 3.7.11;

–   transmits the traffic information signals derived from the teleprinter answer-back code generator;

–   transmits, after completion of the answer-back code, or in the absence of an answer-back code, two information blocks of three "idle signals β";

–   changes the direction of the traffic flow in accordance with § 3.7.11, and reverts to IRS.

3.7.14   **End-of-communication procedure**

3.7.14.1   If the ISS is required to terminate the established circuit, it sends the "end-of-communication block" containing three "idle signals α", until the appropriate "control signal 1" or "control signal 2" has been received; however, the number of transmissions of the "end-of-communication block" is limited to four, after which the ISS reverts to the "stand-by" condition.

3.7.14.2   On receipt of the "end-of-communication block" the IRS sends the appropriate control signal indicating correct reception of this block, and reverts to the "stand-by" condition.

3.7.14.3   On receipt of the control signal that confirms the unmutilated reception of the "end-of-communication block", the ISS reverts to the "stand-by" condition.

3.7.14.4   If the IRS is required to terminate the established circuit, it has first to change over to the ISS condition, in accordance with § 3.7.11, before the termination can take place.

3.8   **Rephasing procedure**

3.8.1   If during the traffic flow, reception of information blocks or control signals is continuously mutilated, both stations change to the "rephase" condition after 32 cycles of continuous repetition. Rephasing is the automatic re-establishment of the previous circuit immediately following interruption of that circuit as a result of continuous repetition (see § 3.7.12).

NOTE 1 – Some coast stations do not provide for rephasing. Therefore, it should be possible to disable the rephasing procedure.

3.8.2   After changing to the "rephase" condition the master station immediately initiates the rephasing procedure. This procedure is the same as the phasing procedure; however, in the case of a 7-signal call identity, instead of "control signal 4" the rephasing slave station will transmit "control signal 5" after the reception of the appropriate "call signal" transmitted by the rephasing master station.

3.8.3   When "control signal 5" is received by the master station, automatic identification takes place along the same lines as laid down in § 3.6. However, on receipt of the "end-of-identification block", containing three "signal repetitions":

3.8.3.1   If, at the time of interruption, the slave station was in the IRS condition, it sends either:

–   "control signal 1" if the last correctly received block before the interruption occurred as an "information block 2"; or

–   "control signal 2" if the last correctly received block before the interruption occurred was an "information block 1".

3.8.3.2   If, at the time of interruption, the slave station was in the ISS condition, it sends "control signal 3", to initiate change-over to the IRS condition. When the change-over is completed, i.e. after correct reception of the block containing three "signal repetitions" by the master station, the master station sends either:

–   "control signal 1" if the last correctly received block before the interruption occurred was an "information block 2"; or

–   "control signal 2" if the last correctly received block before the interruption occurred was an "information block 1".

3.8.4   On receipt of "control signal 4", during the rephasing procedure the master station sends one "end-of-communication block" containing three "idle signals α" after which it continues with the rephasing attempt.

3.8.5   On receipt of each identification block, the slave station compares the received identification signals with the previously stored identity of the master station and:

–   if the signals are identical, the slave station continues with the procedure by sending the appropriate check-sum signal;

–   if the signals are not identical, the slave station initiates the "end-of-communication" procedure in accordance with § 3.7.14 and remains in the "rephase" condition.

3.8.6   On receipt of a block containing three "idle signals α", the slave station sends one "control signal 1" and remains in the "rephase" condition.

3.8.7   In the case of a 4-signal call identity, the rephasing master station:

–   upon receipt of two consecutive signals "control signal 1" or "control signal 2" resumes directly with the transmission of traffic information if the slave station was in the IRS condition, or initiates the change-over procedure in accordance with § 3.7.11.1 if the slave station was in the ISS condition;

–   upon receipt of two consecutive signals "control signal 3" proceeds directly with the change-over procedure in accordance with § 3.7.11.4 if the slave station was in the ISS condition.

3.8.8   In the case of a 4-signal call identity, the slave station on receipt of the appropriate "call signal" sends:

–   if, at the time of interruption, the slave station was in the IRS condition, either:

    –   "control signal 1" if it had correctly received "information block 2" before the interruption occurred; or

    –   "control signal 2" if it had correctly received "information block 1" before the interruption occurred;

–   if, at the time of interruption, the slave station was in the ISS condition, "control signal 3" to initiate change-over to the ISS condition.

3.8.9   If rephasing has not been accomplished within the time-out interval of 32 cycles, both stations revert to the "stand-by" condition and no further rephasing attempts are made.

3.9   Summary of service blocks and service information signals

3.9.1   Service blocks

X_1 - RQ - X_2 :   "Call block 1" containing the 1st and 2nd identification signals.

X_3 - X_4 - RQ :   "Call block 2" for a 4-signal call identity containing the 3rd and 4th identification signals.

RQ - X_3 - X_4 :   "Call block 2" for a 7-signal call identity containing the 3rd and 4th identification signals.

X_5 - X_6 - X_7 :   "Call block 3" for a 7-signal call identity containing the 5th, 6th and 7th identification signals.

Y_1 - α - Y_2 :   "Identification block 1" containing self-identification signals 1 and 2 and request for the 1st check-sum signal.

α - Y_3 - Y_4 :   "Identification block 2" containing self-identification signals 3 and 4 and request for the 2nd check-sum signal.

Y_5 - Y_6 - Y_7 :   "Identification block 3" containing self-identification signals 5, 6 and 7 and request for the 3rd check-sum signal.

RQ - RQ - RQ :   If occurring within the automatic identification procedure, indicates the end of that procedure and requests the appropriate control signal.

   During the traffic flow, indicates request for repetition of the last control signal or in the change-over procedure response to β - α - β.

β - α - β :   Block to change the direction of the traffic flow.

α - α - α :   Block to initiate the end-of-communication procedure.

3.9.2   Service information signals

CS1 :   Request for "information block 1" or "call signal" has been correctly received during phasing/rephasing (only in the case of a 4-signal call identity).

CS2 :   Request for "information block 2".

CS3 :   IRS requests change of traffic flow direction.

CS4 :   "Call signal" has been correctly received during phasing.

CS5 :   "Call signal" has been correctly received during rephasing.

RQ :   Request for retransmission of the last identification or information block or in the change-over procedure, response to β - α - β.

4   Characteristics, mode B (FEC)

4.1   General

The system operates in a synchronous mode, transmitting an uninterrupted stream of signals from a station sending in the collective B-mode (CBSS) to a number of stations receiving in the collective B-mode (CBRS), or from a station sending in the selective B-mode (SBSS) to one or more selected stations receiving in the selective B-mode (SBRS).

4.2   The sending station (CBSS and SBSS)

The sending station, both in collective and in selective B-mode, sends each signal twice: the first transmission (DX) of a specific signal is followed by the transmission of four other signals, after which the retransmission (RX) of the first signal takes place, allowing for time-diversity reception at 280 ms (4×70 ms) time space (see Fig. 2).

FIGURE 2

Time-diversity transmission
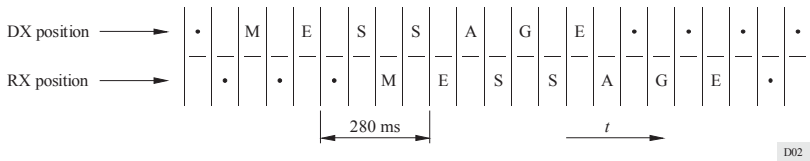
4.3 The receiving station (CBRS and SBRS)

The receiving station, both in collective and selective B-mode, checks both signals (DX and RX), and uses the unmutilated one. When both signals appear as unmutilated but different, then both signals should be considered as mutilated.

4.4 Phasing procedure

4.4.1 When no circuit is established, both stations are in the "stand-by" condition and no sending or receiving condition is assigned to either of the stations.

4.4.2 The station required to transmit information becomes the sending station and sends alternately "phasing signal 2" and "phasing signal 1", whereby "phasing signal 2" is transmitted in the DX position and "phasing signal 1" in the RX position. At least sixteen of these signal pairs should be transmitted.

4.4.3 On receipt of the signal sequence "phasing signal 1"-"phasing signal 2", or of the signal sequence "phasing signal 2"-"phasing signal 1", in which "phasing signal 2" determines the DX position and "phasing signal 1" determines the RX position, and at least two further phasing signals in the appropriate position, the station changes to the CBRS condition and offers continuous stop-polarity to the line output terminal until either the traffic information signal "←" (combination No. 27) or "≡" (combination No. 28) is received.

4.5 Selecting calling procedure (selective B-mode)

4.5.1 After the transmission of the required number of phasing signals, the SBSS sends the "call signal", which consists of six transmissions of a sequence, each consisting of the identification signals of the station to be selected followed by an "idle signal β". This transmission takes place using time-diversity in accordance with § 4.2.

4.5.2 The SBSS sends the "call signal" and all further information signals in a 3B/4Y ratio, i.e. inverted with respect to the information signals in Tables 1 and 2 and the identification signals in Table 3a.

4.5.3 The "call signal" contains either four, or seven identification signals as applicable. The identification signals are listed in Table 3a. The composition of these "call signals" should be in accordance with Recommendation ITU-R M.491.

4.5.4 Following unmutilated reception of one complete signal sequence representing its inverted identification signals, the CBRS changes to the SBRS condition and continues offering stop-polarity to the line output terminal until either the traffic information signal; "←" (combination No. 27) or "≡" (combination No. 28) is received.

4.5.5 The station in the SBRS condition accepts the subsequent information signals received with the 3B/4Y ratio, all other stations reverting to the "stand-by" condition.

4.6 Traffic flow

4.6.1 Immediately prior to the transmission of the first traffic signals the sending station transmits the information signals "←" (combination No. 27) and "≡" (combination No. 28), and starts transmitting traffic.

4.6.2   A CBSS sends, during breaks in the information flow, "phasing signals 1" and "phasing signals 2" in the RX and DX positions respectively. At least one sequence of four consecutive phasing signal pairs should occur for every 100 signals sent in the DX position during traffic flow.

4.6.3   A SBSS sends, during breaks in the information flow, "idle signals β".

4.6.4   On receipt of either the traffic combination signal "←" (combination No. 27) or "≡" (combination No. 28), the receiving station starts printing the received traffic information signals.

NOTE 1 – The term "printing" is used in § 4.6.4 and 4.6.5 to denote the transfer of traffic signals to the output device.

4.6.5   The receiving station checks both signals received in the DX and RX position:

–   printing an unmutilated DX or RX signal; or

–   printing a "Δ" (combination No. 31), or alternatively an "error character" (to be user-defined) if both DX and RX signals are mutilated or appear unmutilated but are different.

4.6.6   A receiving station reverts to the "stand-by" condition if, during a predetermined time, the percentage of mutilated signals received has reached a predetermined value.

4.6.7   **End-of-transmission**

4.6.7.1   A station sending in the B-mode (CBSS or SBSS) should terminate the transmission by sending at least 2 s of consecutive "idle signals α", immediately after the last transmitted traffic information signals after which the station reverts to the "stand-by" condition.

4.6.7.2   The receiving station reverts to the "stand-by" condition not less than 210 ms after receipt of at least two consecutive "idle signals α" in the DX position.

FIGURE 3

**Phasing procedure with automatic identification
in the case of a 7-signal call identity (mode A)**

D03
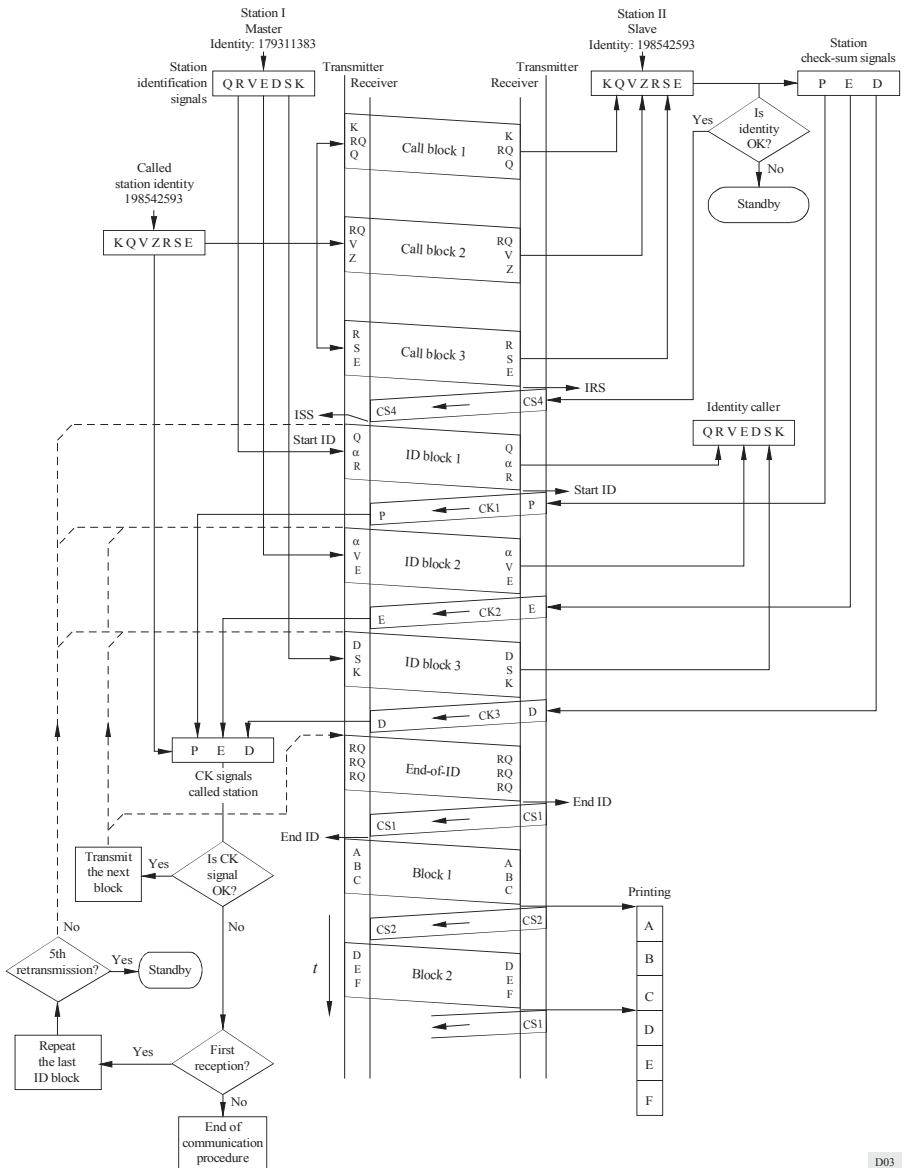
FIGURE 4

**Rephasing procedure with automatic identification in the case
of a 7-signal call identity (station II was ISS)**
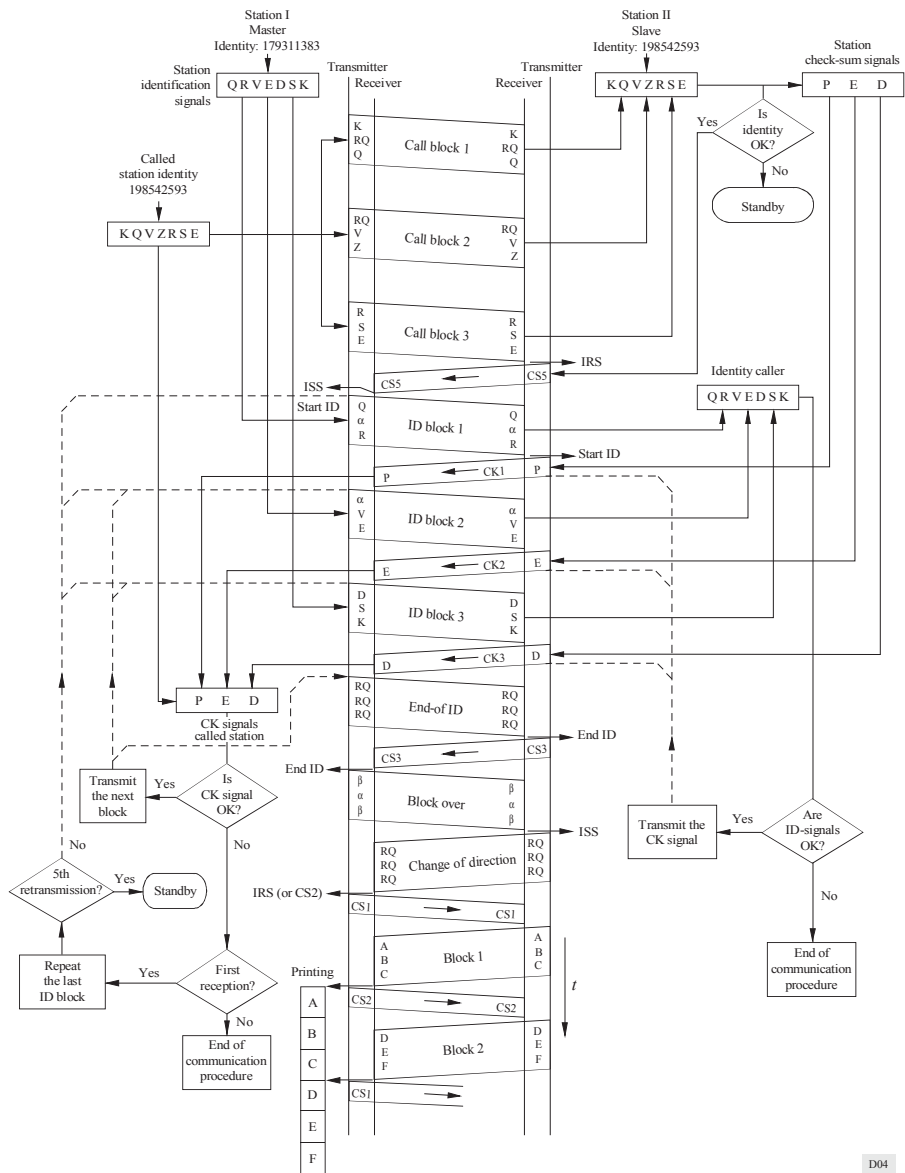
FIGURE 5

Traffic flow with change-over procedure and end-of-communication
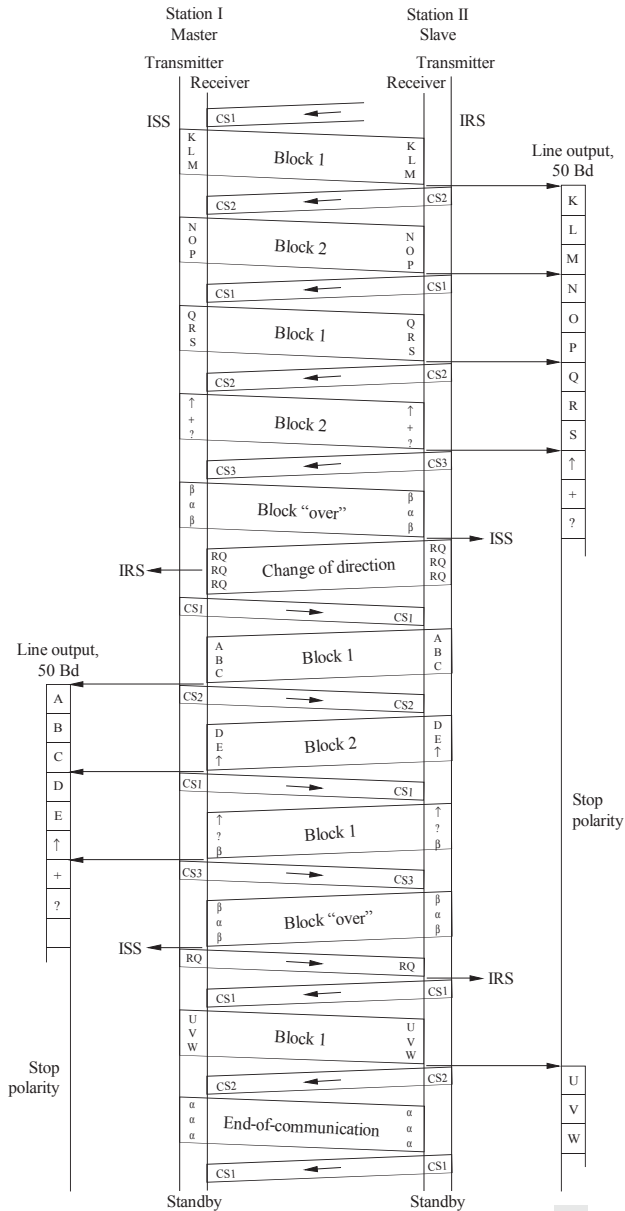
D05

FIGURE 6

**Phasing procedure with automatic identification in the condition
of mutilated reception in the case of a 7-signal call identity**
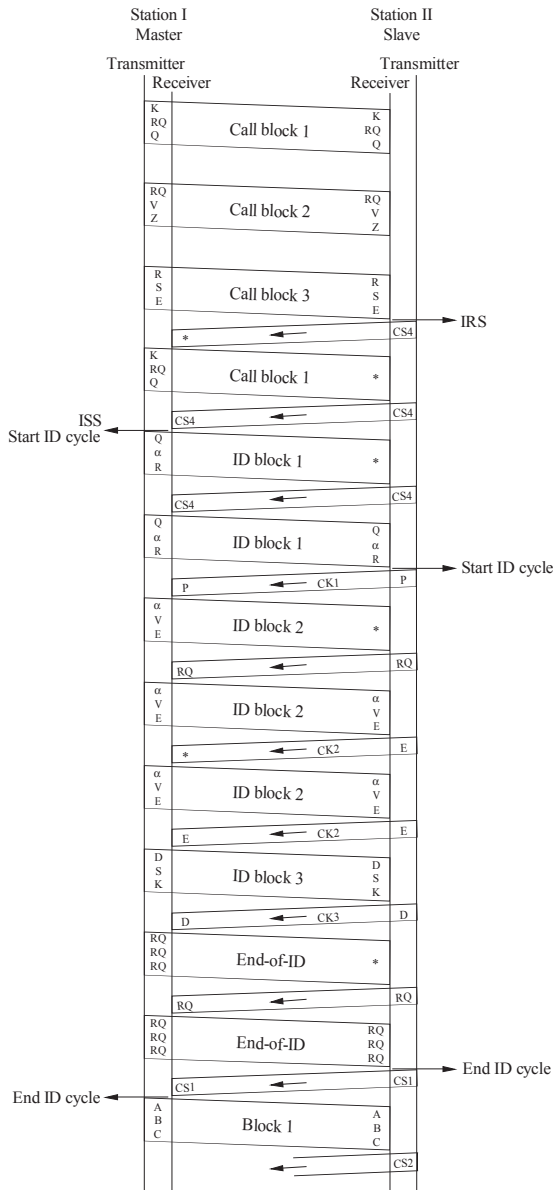
* Detected error

FIGURE 7

Traffic flow in the condition of mutilated reception
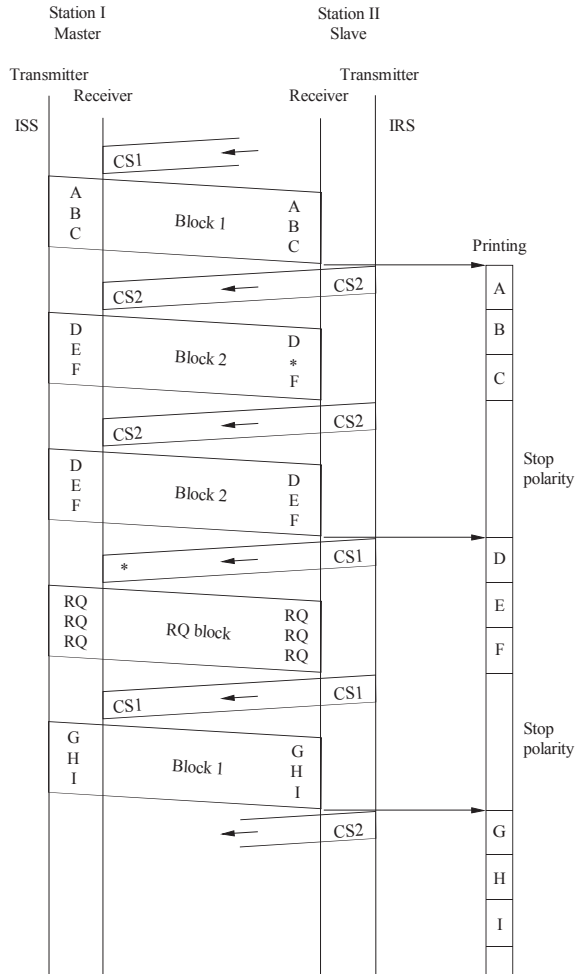
* Detected error

D07

FIGURE 8

Phasing procedure in the case of a 4-signal call identity
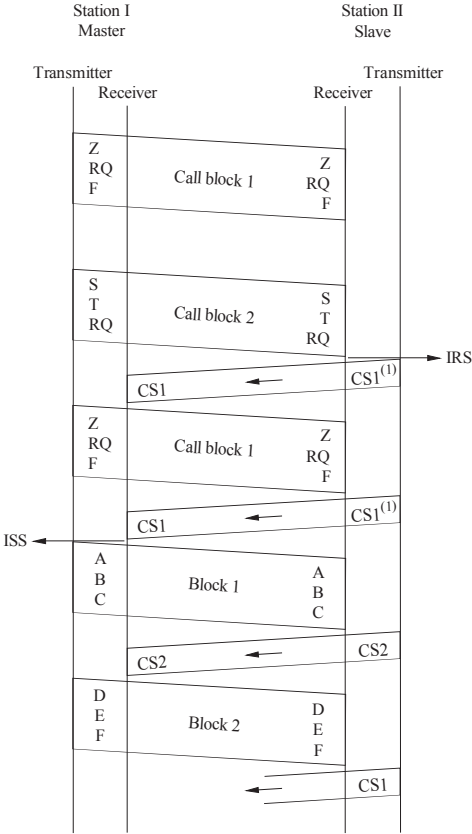
(1) With some equipment built in accordance with Recommendation ITU-R M.476 this could be CS2.

D08

FIGURE 9

**Phasing procedure in the condition of mutilated reception
in the case of a 4-signal call identity**

* Detected error
(1) With some equipment built in accordance with
    Recommendation ITU-R M.476 this could be CS2.

D09

FIGURE 10

Collective B-mode operation

1: phasing signal 1
2: phasing signal 2
* Detected error
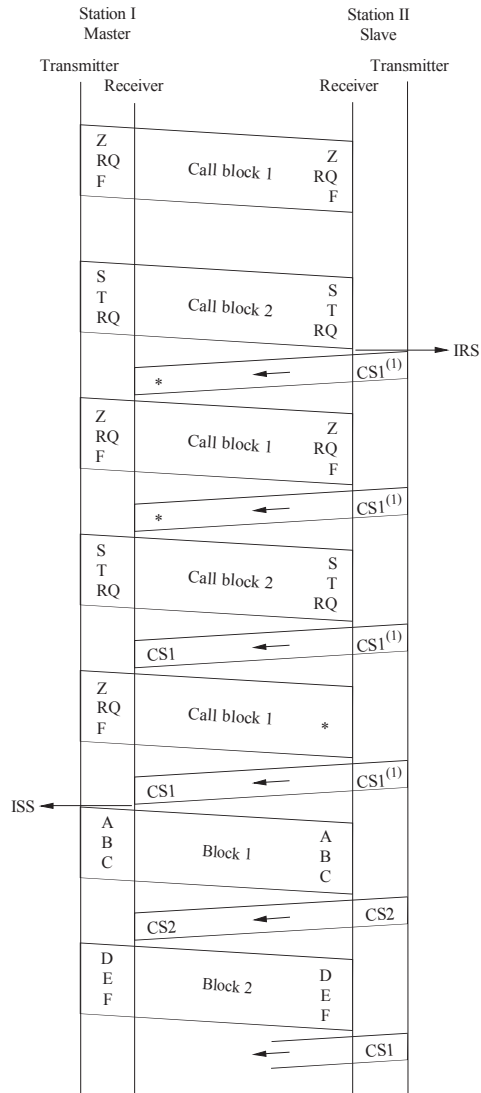
FIGURE 11

Selective B-mode operation in the case of a 4-signal call identity

Station I   Station II

Selective call No.: 67890

Z F S T

1: phasing signal 1

2: phasing signal 2

Overlined symbols (e.g. $\overline{M}$) are in the 3B/4Y ratio

FIGURE 12

Selective B-mode operation in the case of a 7-signal call identity

1: phasing signal 1

2: phasing signal 2

Overlined symbols (e.g. $\overline{M}$) are in the 3B/4Y ratio
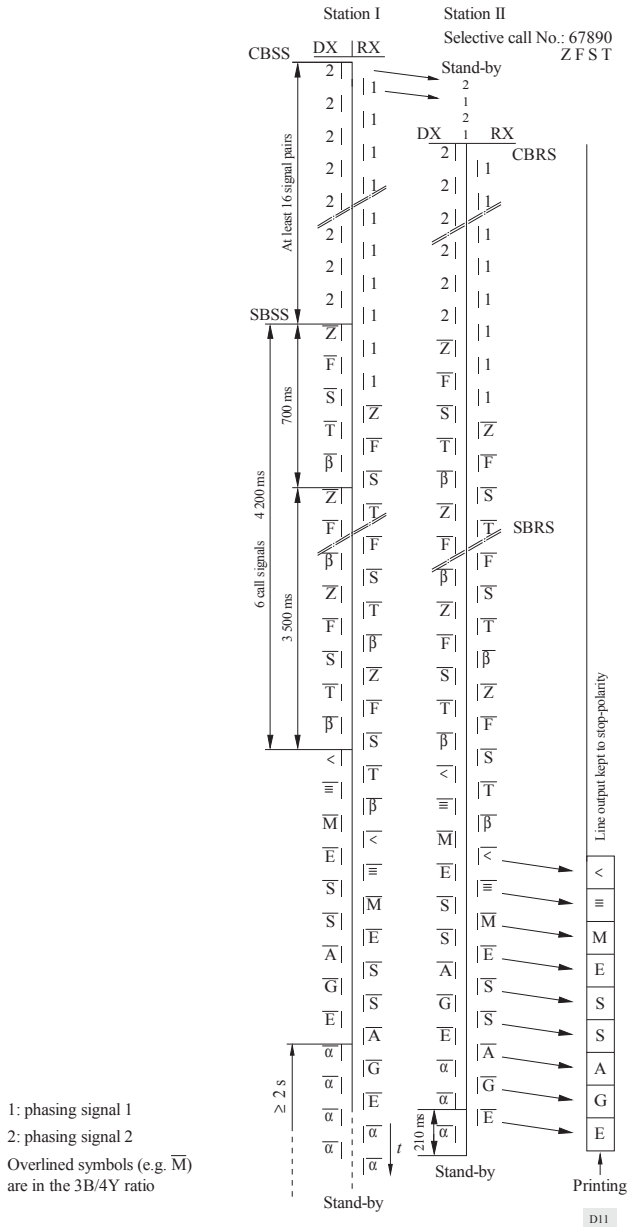
APPENDICES TO ANNEX 1

APPENDIX 1

SDL diagrams (mode A)

1 General

The specification and description language (SDL) is described in ITU-T Recommendation Z.100.

The following graphical symbols have been used*:

State

D13

– A "state" is a condition in which the action of a process is suspended awaiting an input.

External input

Internal input

D14

– An "input" is an incoming signal which is recognized by a process.

External output

Internal output

D15
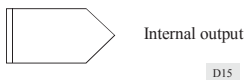
– An "output" is an action which generates a signal which in turn acts as an input elsewhere.

Decision

D16

_____
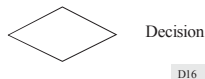
* *Note by the Secretariat:*

A "connector" is represented by the following graphical symbol:

$(n)_{x\text{-}y\,(z)}$

where:

n : connector reference
x : number of the sheet
y : number of the Appendix (omitted when it occurs in the same Appendix).
z : number of occurrences.

–   A "decision" is an action which asks a question to which the answer can be obtained at that instant and chooses one of several paths to continue the sequence.

Task

D17

–   A "task" is any action which is neither a decision nor an output.

2   Phasing procedure with automatic identification in the case of a 7-signal call identity (calling station)

2.1   The SDL diagrams are given in Appendix 2.

2.2   The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_0	128 cycles	02, 03, 04	1
n_1	128 cycles	00	1
n_2	32 cycles	05, 06, 07, 08	2, 3

3   Rephasing procedure with automatic identification in the case of a 4-signal call identity (calling station)

3.1   The SDL diagrams are given in Appendix 3.

3.2   The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_5	32 cycles	00, 02, 03, 04	1
		05, 06, 07, 08	2, 3
n_1	128 cycles		1
n_2	32 cycles	05, 06, 07, 08	2, 3

4   Phasing procedure without automatic identification in the case of a 4-signal call identity (calling station)

4.1   The SDL diagrams are given in Appendix 4.

4.2   The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_0	128 cycles	02, 03	1
n_1	128 cycles	00	1

5 **Rephasing procedure without automatic identification in the case of a 4-signal call identity (calling station)**

5.1 The SDL diagrams are given in Appendix 5.

5.2 The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_5	32 cycles	00, 02, 03	1
n_1	128 cycles		1

6 **Phasing procedure with automatic identification in the case of a 7-signal call identity (called station)**

6.1 The SDL diagrams are given in Appendix 6.

6.2 The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_2	32 cycles	05, 06, 07, 08	2, 3

7 **Rephasing procedure with automatic identification in the case of a 7-signal call identity (called station)**

7.1 The SDL diagrams are given in Appendix 7.

7.2 The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_5	32 cycles	00, 01, 02, 03, 04	1
		05, 06, 07, 08	2, 3
n_2	32 cycles	05, 06, 07, 08	2, 3

8 **Phasing procedure without automatic identification in the case of a 4-signal call identity (called station)**

8.1 The SDL diagrams are given in Appendix 8.

9 **Rephasing procedure without automatic identification in the case of a 4-signal call identity (called station)**

9.1 The SDL diagrams are given in Appendix 9.

9.2 The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_5	32 cycles	00, 01, 03	1

10   Traffic flow in the case of a 4-signal call identity and in the case of a 7-signal call identity (station is in the ISS position)

10.1   The SDL diagrams are given in Appendix 10.

10.2   The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_3	32 cycles	09, 10, 13	1, 3
n_4	4 cycles	11, 12	2
n_1	128 cycles	12	2
n_5	32 cycles	11, 12, 13, 14	2, 3

11   Traffic flow in the case of a 4-signal call identity and in the case of a 7-signal call identity (station is in the IRS position)

11.1   The SDL diagrams are given in Appendix 11.

11.2   The following supervisory counters are used in the diagrams:

Counter	Time-out	State	Sheet
n_3	32 cycles	09, 10, 11	1, 2
n_5	32 cycles	09, 10, 11, 12	1, 2

APPENDIX 2

**Phasing procedure with automatic identification in
the case of a 7-signal call identity (calling station)**

Sheet 1 (of 3)

t_1: call identity the same as the one before and $n_1 > 0$?
* Detected error, invalid signal or no signal at all

D18

Connector
reference
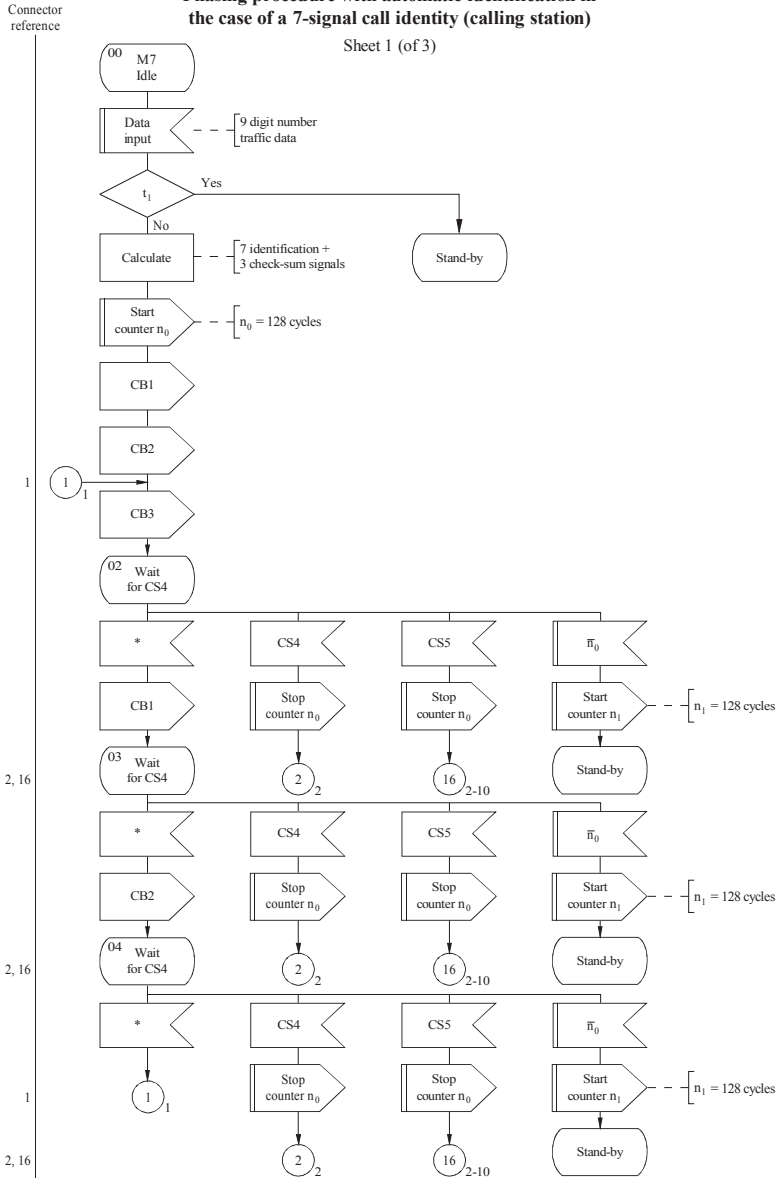
APPENDIX 2

Sheet 2 (of 3)
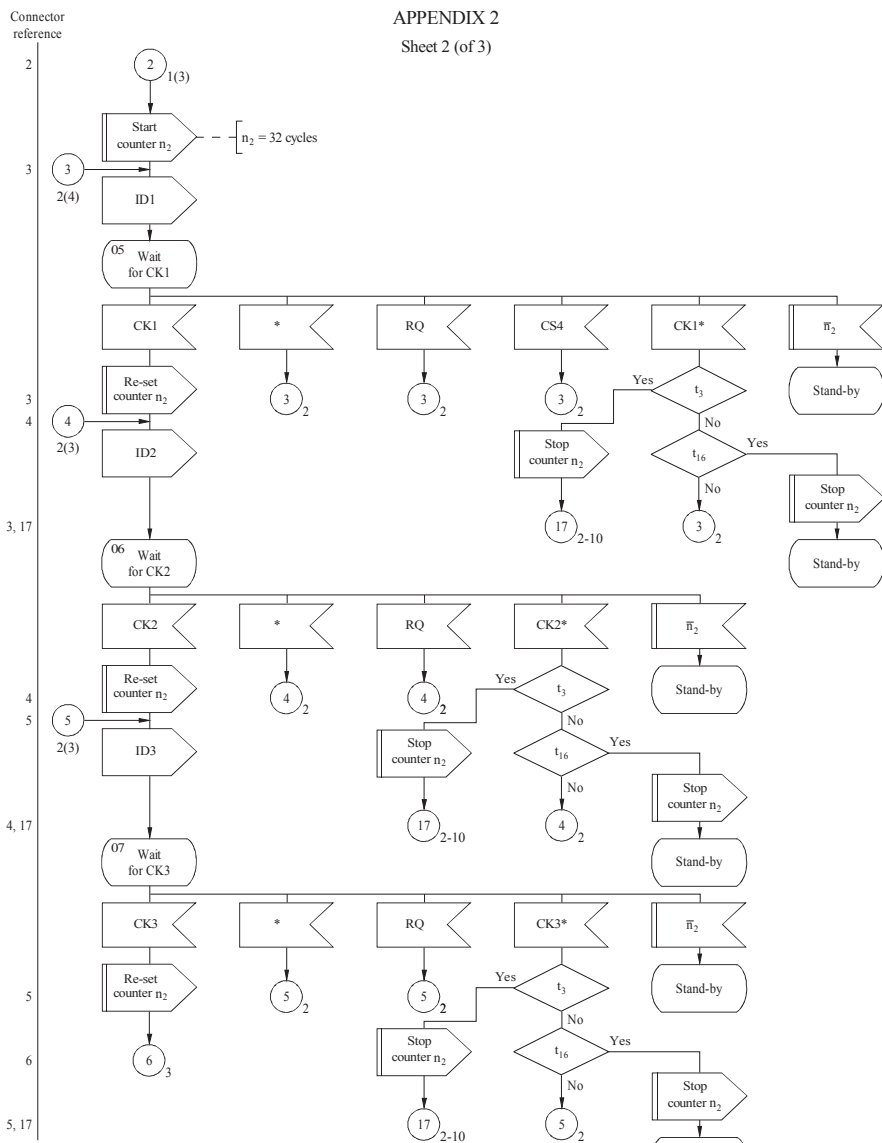
t$_{16}$: fourth reception of a wrong check-sum signal?

t$_3$: same wrong check-sum signal one cycle before?

CKn*: wrong check-sum signal

   * Detected error, invalid signal or no signal at all

D19

APPENDIX 2

Sheet 3 (of 3)

Connector
reference
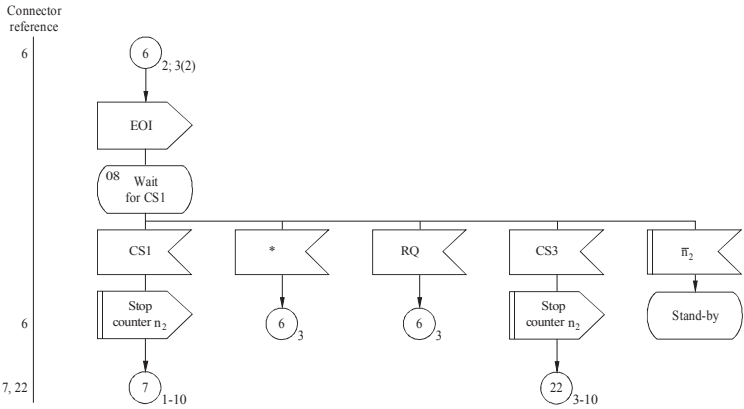
* Detected error, invalid signal or no signal at all

D20

APPENDIX 3

**Rephasing procedure with automatic identification in
the case of a 7-signal call identity
(calling station)**

Sheet 1 (of 3)
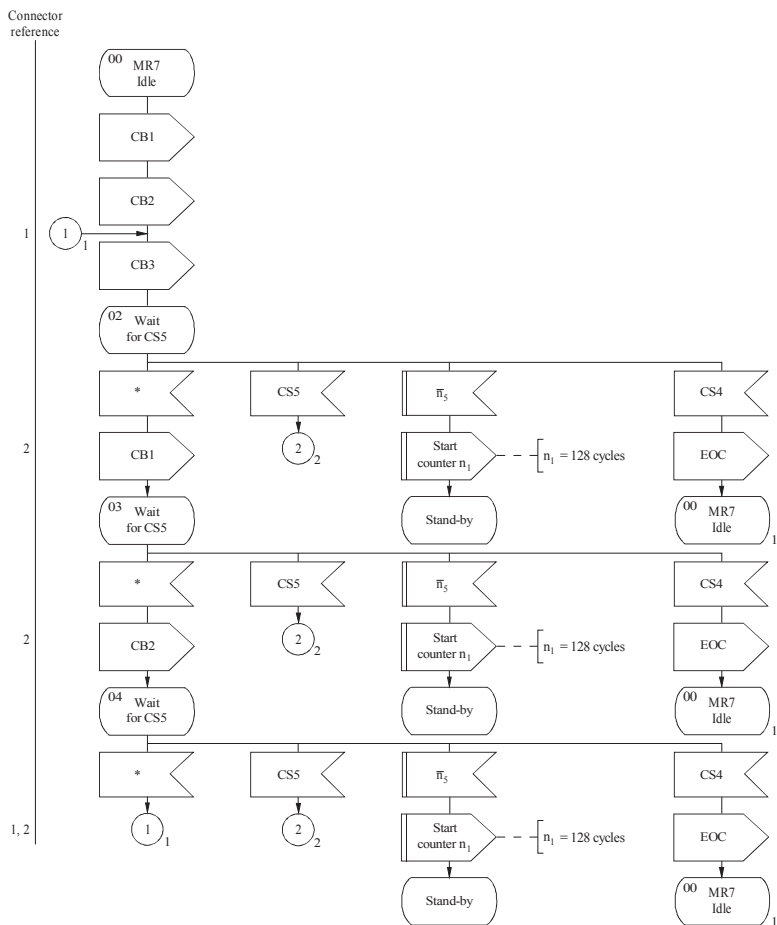
* Detected error, invalid signal or no signal at all

D21

APPENDIX 3

Sheet 2 (of 3)

Connector reference

t_{16} : fourth reception of a wrong check-sum signal?

t_3 : same wrong check-sum signal one cycle before?

CKn*: wrong check-sum signal

* Detected error, invalid signal or no signal at all

2 | 2 1(3)

Start counter n_2 — $n_2 = 32$ cycles

3 | 3 2(4)

ID1

05 Wait for CK1

CK1 | * | RQ | CS5 | CK1* | $\overline{n}_2$ | CS3

Re-set counter n_2 | | | | | Stand-by | Stop counter n_2

3 | 3 2 | 3 2 | 3 2 | t_3 Yes | |

4 | 4 2(3) | | | Stop counter n_2 | No | | 22 3-10

ID2 | | | | t_{16} Yes | |

22 | | | | 17 2-10 | Stop counter n_2 |

06 Wait for CK2 | | | | No |

3, 17 | | | | 3 2 No | $n_5 = 0$? |

| | | | 00 MR7 Idle 1 | Stand-by Yes

CK2 | * | RQ | CK2* | $\overline{n}_2$ | CS3

Re-set counter n_2 | | | t_3 Yes | Stand-by | Stop counter n_2

4 | 4 2 | 4 2 | No |

5 | 5 2(3) | | Stop counter n_2 | t_{16} Yes | 22 3-10

ID3 | | | No | Stop counter n_2 |

22 | | 17 2-10 | 4 2 No | $n_5 = 0$? |

07 Wait for CK3 | | | 00 MR7 Idle 1 | Stand-by Yes

4, 17 |

CK3 | * | RQ | CK3* | π_2 | CS3

Re-set counter n_2 | | | t_3 Yes | Stand-by | Stop counter n_2

5 | 5 2 | 5 2 | No |

6, 22 | 6 3 | | Stop counter n_2 | t_{16} Yes | 22 3-10

| | 17 2-10 | No | Stop counter n_2 |

5, 17 | | | 5 2 No | $n_5 = 0$? |

| | | 00 MR7 Idle 1 | Stand-by Yes

D22

APPENDIX 3

Sheet 3 (of 3)

Connector
reference

* Detected error, invalid signal or no signal at all

D23

APPENDIX 4

**Phasing procedure without automatic identification in
the case of a 4-signal call identity (calling station)**

Sheet 1 (of 1)

Connector
reference
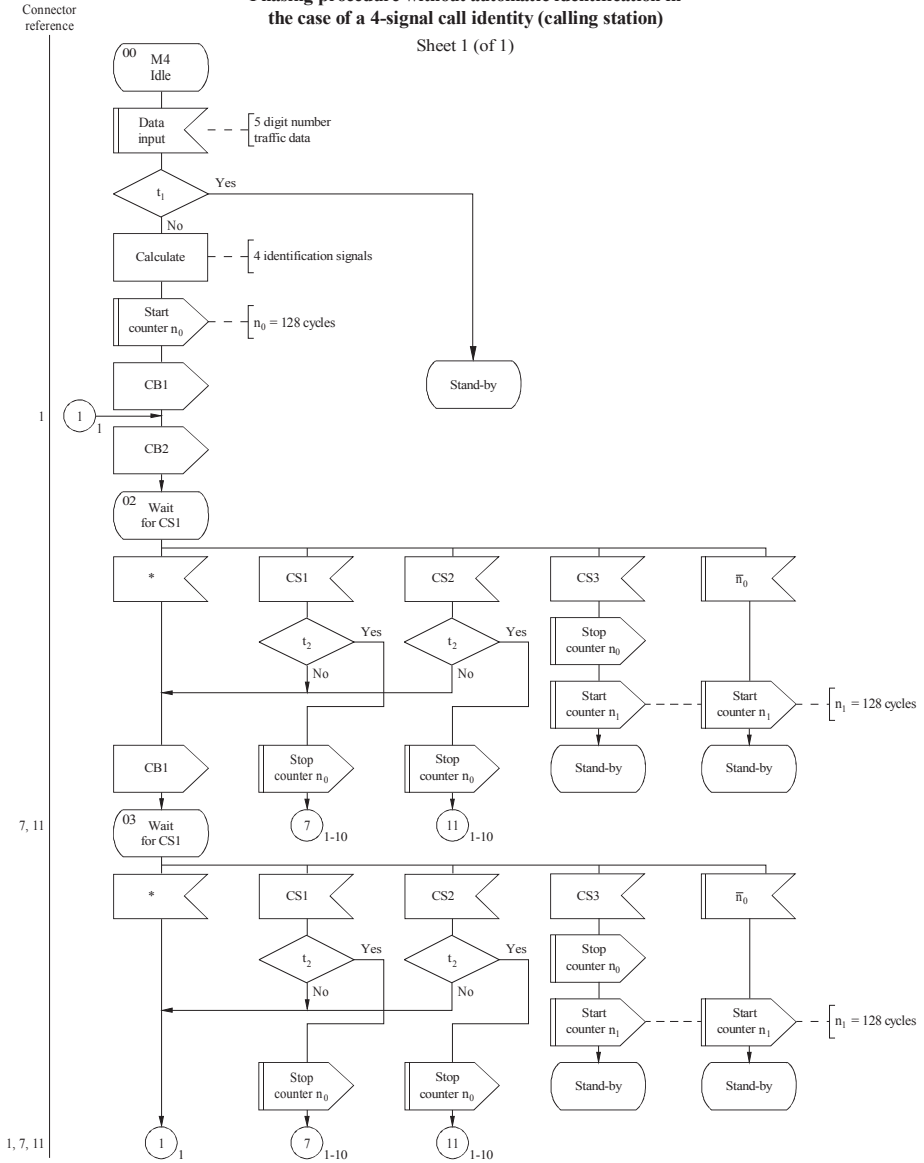
t_1 : call identity the same as the one before and $n_1 > 0$?
t_2 : same control signal one cycle before?
* Detected error, invalid signal or no signal at all

D24

Rec. ITU-R M.625-3

APPENDIX 5

**Rephasing procedure without automatic identification in
the case of a 4-signal call identity
(calling station)**

Sheet 1 (of 1)

Connector
reference
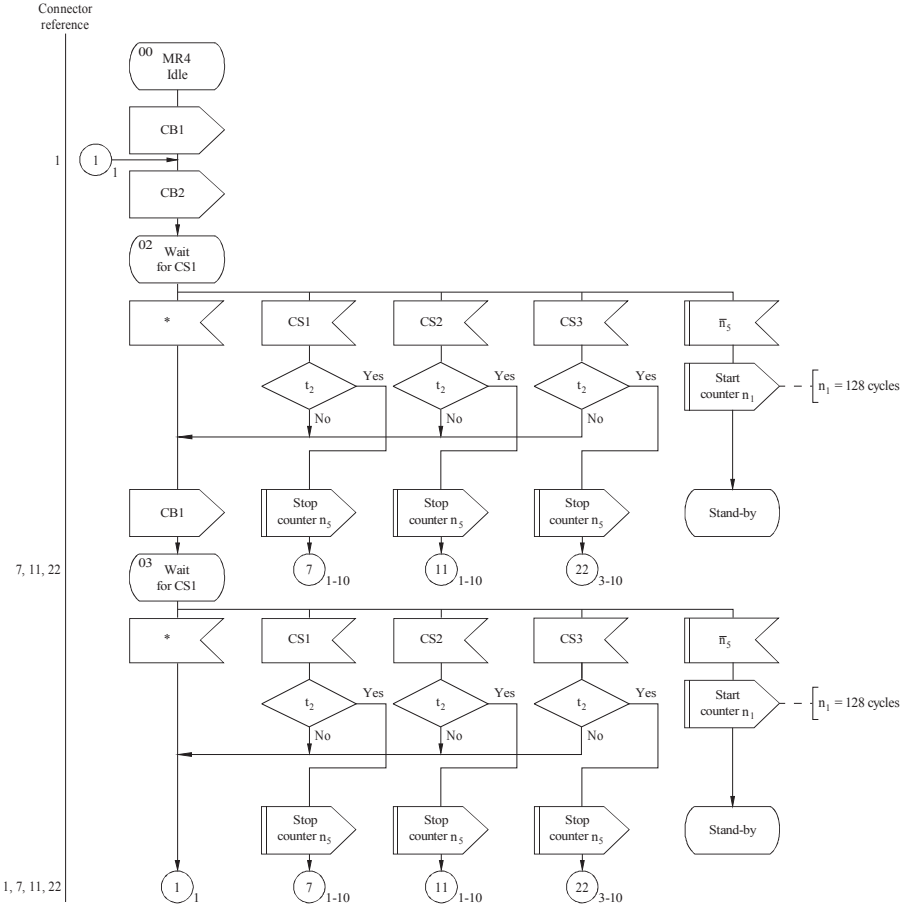
t_2: same control signal one cycle before?
 * Detected error, invalid signal or no signal at all

D25

APPENDIX 6

**Phasing procedure with automatic identification in
the case of a 7-signal call identity
(called station)**

Sheet 1 (of 3)

* Detected error, invalid signal or no signal at all

D26

APPENDIX 6

Sheet 2 (of 3)

Connector
reference

t_3: same ID-block one cycle before?

* Detected error, invalid signal or no signal at all

D27

APPENDIX 6

Sheet 3 (of 3)
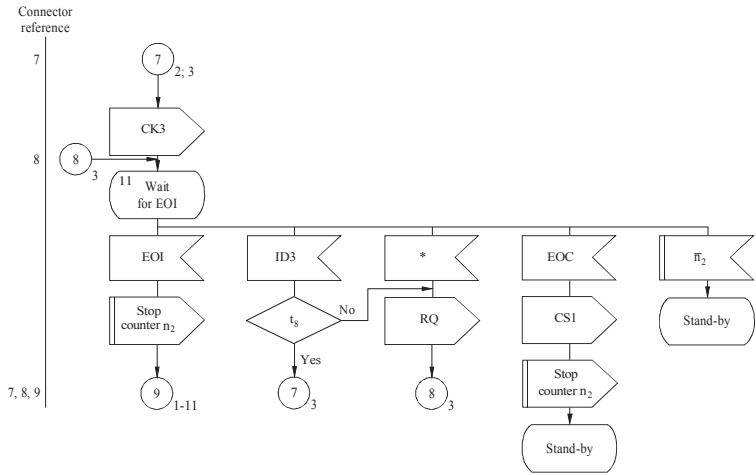
t_3: same ID-block one cycle before?

* Detected error, invalid signal or no signal at all

D28

APPENDIX 7

**Rephasing procedure with automatic identification in
the case of a 7-signal call identity
(called station)**

Sheet 1 (of 3)

* Detected error, invalid signal or no signal at all

APPENDIX 7

Sheet 2 (of 3)

Connector
reference

1

1

1(2)

Start
counter n_2 — — $n_2 = 32$ cycles

2

2

2

CS5

08 Wait
for ID1

ID1   ID1*   *   EOC $\bar{n}_2$

Re-set
counter n_2 2   CS1   Stand-by

2   2

3   3   2

CK1   Stop
counter n_2 Stop
counter n_2

4   4   2

09 Wait
for ID2   13   00 SR7
Idle

13   2-11   1

ID2   ID2*   *   ID1   EOC $\bar{n}_2$

Re-set
counter n_2 RQ   3   CS1   Stand-by

3   3   2

5   5   2

CK2   Stop
counter n_2 4   Stop
counter n_2

4   4   2

6   6   2

10 Wait
for ID3   13   00 SR7
Idle

13   2-11   1

ID3   ID3*   *   ID2   EOC $\bar{n}_2$

Stop
counter n_2 RQ   5   CS1   Stand-by

5   5   2

6, 7   7   6

7   3   6   2

Stop
counter n_2 Stop
counter n_2

13   13   00 SR7
Idle

13   2-11   1
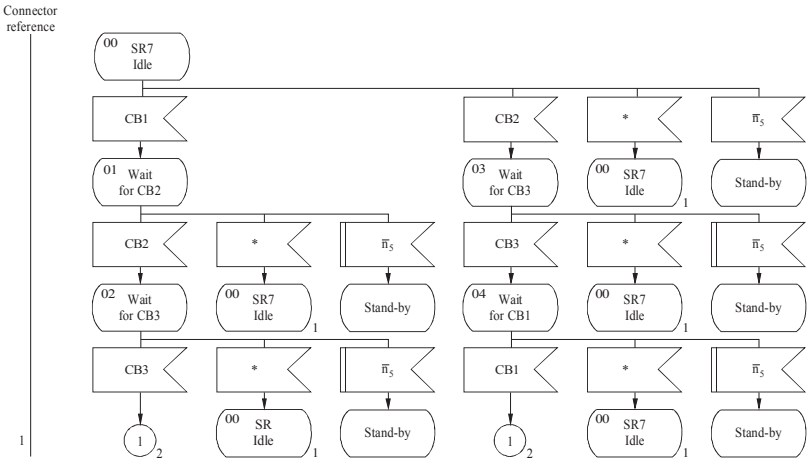
IDn* : wrong identification signal(s)

* Detected error, invalid signal or no signal at all

D30

APPENDIX 7

Sheet 3 (of 3)
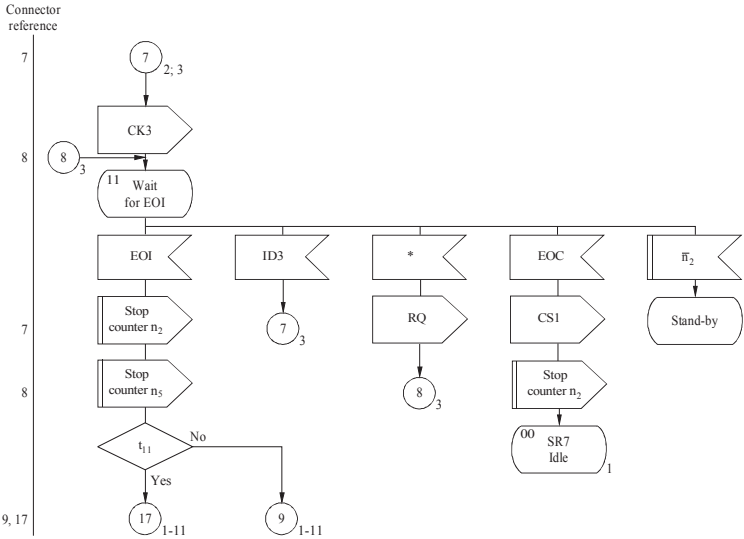
Connector
reference

7 ⑦ 2; 3

CK3

8 ⑧ 3

11 Wait
for EOI

| EOI | ID3 | * | EOC | $\overline{n}_2$ |

| Stop counter n_2 | ⑦ 3 | RQ | CS1 | Stand-by |

7

| Stop counter n_5 | | ⑧ 3 | Stop counter n_2 |

8

t_{11} No

00 SR7
Idle 1

Yes

9, 17 ⑰ 1-11 ⑨ 1-11

t_{11}: block 2 was the last received block at the
moment the interruption occurred?

* Detected error, invalid signal or no signal at all

D31

APPENDIX 8

**Phasing procedure without automatic identification in
the case of a 4-signal call identity
(called station)**

Sheet 1 (of 1)

Connector
reference

```
        ┌──────┐
        │00  S4│
        │  Idle│
        └──────┘
    ┌──────┐          ┌──────┐          ┌──────┐
    │ CB1  ◁          │ CB2  ◁          │  *   ◁
    └──────┘          └──────┘          └──────┘
    ┌──────┐          ┌──────┐          ┌──────────┐
    │01 Wait│         │03 Wait│         │ Stand-by │
    │for CB2│         │for CB1│         └──────────┘
    └──────┘          └──────┘
 ┌──────┐ ┌──────┐ ┌──────┐   ┌──────┐ ┌──────┐
 │CB2(7)◁ │ CB2  ◁ │  *   ◁   │ CB1  ◁ │  *   ◁
 └──────┘ └──────┘ └──────┘   └──────┘ └──────┘
   ( 0 )    ( 9 )  ┌──────────┐ ( 9 )  ┌──────────┐
    1-6      1-11  │ Stand-by │  1-11  │ Stand-by │
                   └──────────┘        └──────────┘
```

0, 9
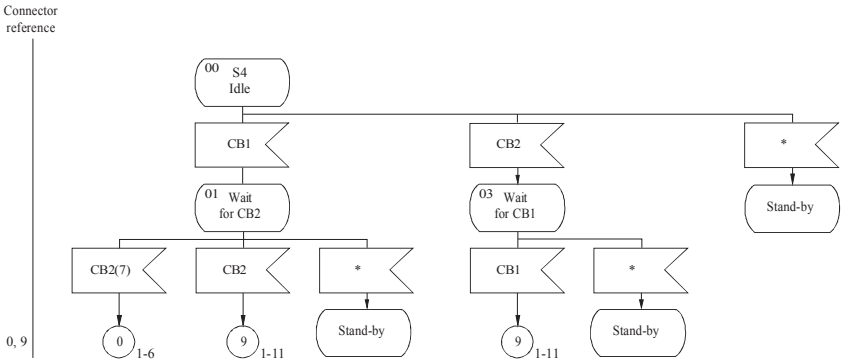
* Detected error, invalid signal or no signal at all   D32

APPENDIX 9

**Rephasing procedure with automatic identification in
the case of a 4-signal call identity
(called station)**

Sheet 1 (of 1)
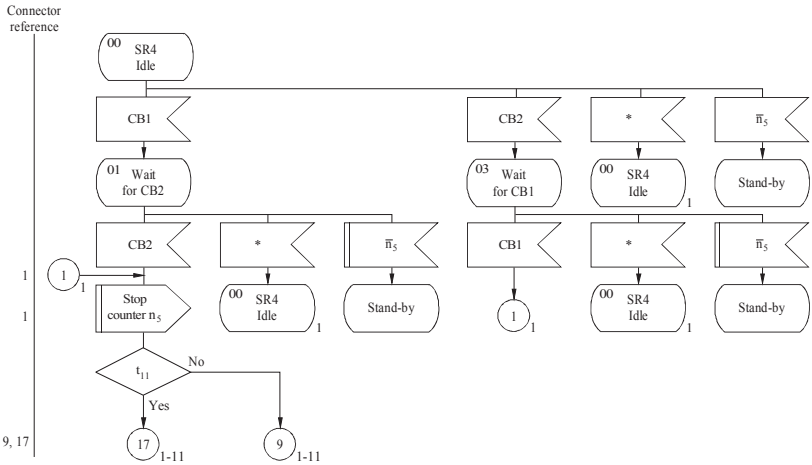
t_{11}: block 2 was the last received block at the
moment the interruption occurred?

* Detected error, invalid signal or no signal at all

APPENDIX 10

Traffic flow in the case of a 4-signal call identity and in the case of a 7-signal call identity (station is in the ISS position)

Sheet 1 (of 3)
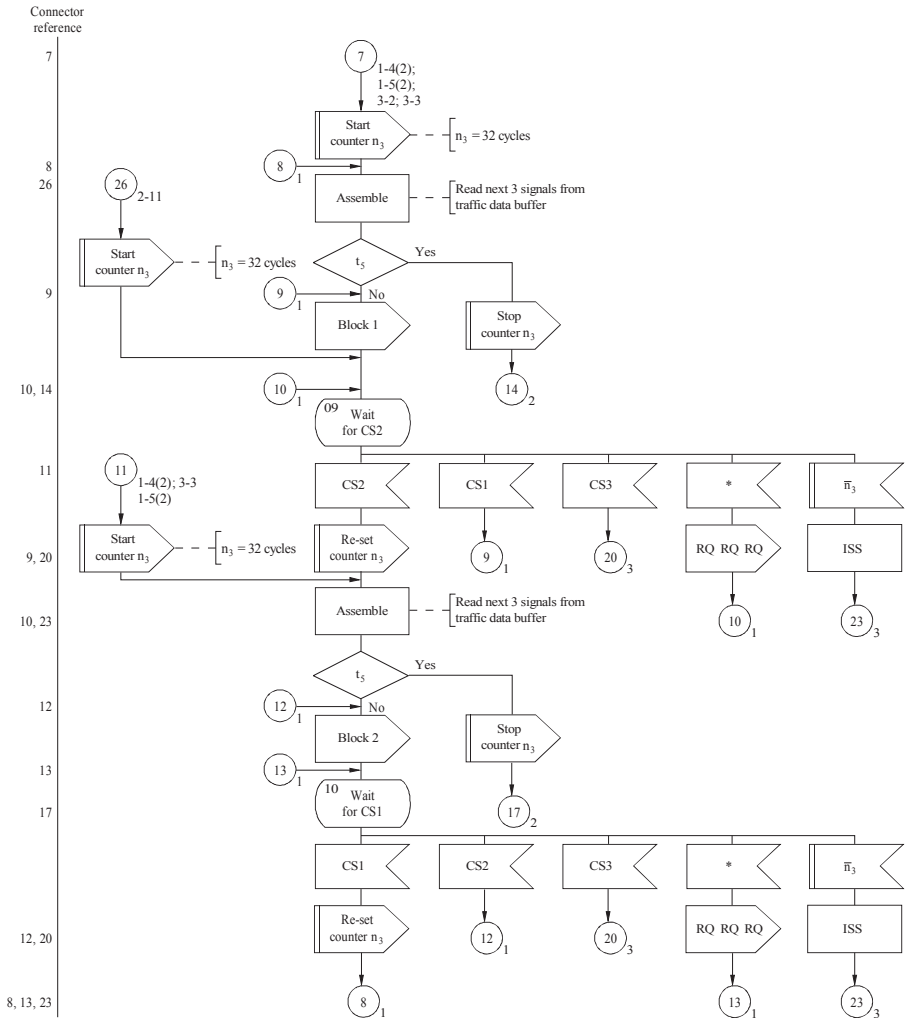
t_5 : data block contains message "end-of-communication"?

ISS: notice: station is ISS at the moment the interruption occurred

* Detected error, invalid signal or no signal at all

D34

APPENDIX 10

Sheet 2 (of 3)
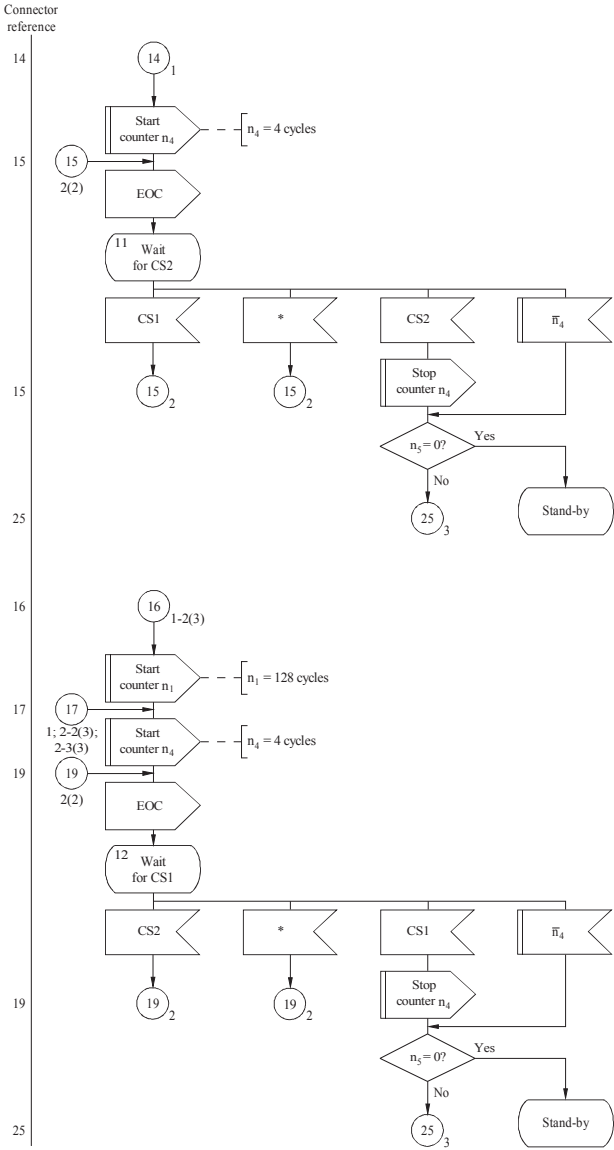
* Detected error, invalid signal or no signal at all

D35

APPENDIX 10

Sheet 3 (of 3)

Connector
reference
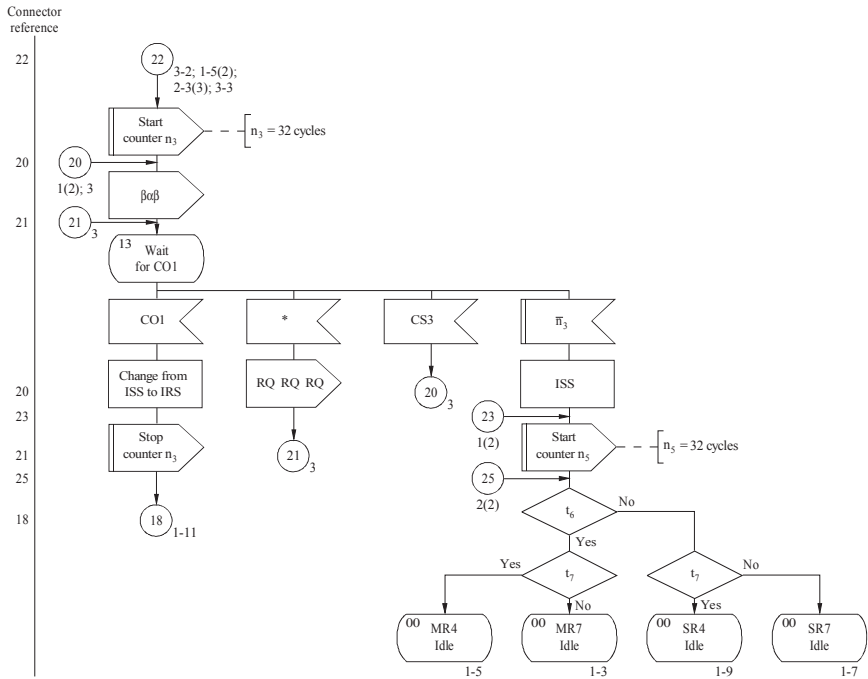
t_6 : station is master station?

t_7 : station working in the case of
a 4-position call identity?

ISS : notice: station is ISS at the moment
the interruption occurred

CO1: if ISS is:
– master then "RQ RQ RQ"
– slave then "RQ"

* Detected error, invalid signal or no signal at all

D36

APPENDIX 11

**Traffic flow in the case of a 4-signal call identity and in the
case of a 7-signal call identity (station is in the IRS position)**

Sheet 1 (of 2)

Connector
reference

18

18 3-10

9   t_{12} Yes   9   1-8(2); 1-6;
                          1-9; 3-6; 3-7

No

17   17 1

10   10 1

Start
counter n_3 — $n_3 = 32$ cycles

Assemble   — Appropriate
             control signal

t_{13} Yes

11   11   No

13   1(2)   CS1   13 2

12   Wait
     for block 1

Block 1   *   RQ-BL   EOC $\overline{n}_3$

11, 17   17 1; 1-9; 3-7 t_{14} Yes   11 1   11 1   CS2   IRS2

Start   Re-set
counter n_3 — $n_3 = 32$ cycles   counter n_3 No   13 2   Stop
13, 14   counter n_3 14 2

Assemble — Appropriate control signal

$n_5 = 0$?   Yes

16   t_{13} Yes   No

12   12   No   Stand-by

13   1(2)   CS2   13 2   16 2

13   Wait
     for block 2

Block 2   *   RQ-BL   EOC $\overline{n}_3$

12   t_{15} Yes   12 1   12 1   CS1   IRS1

Re-set
13, 14   counter n_3 No   13 2   Stop
                                       counter n_3 14 2

10   10 1

$n_5 = 0$?   Yes

No

16   Stand-by

16 2

t_{12} : block 2 was the last received block?

t_{13} : the emitting control signal is CS3?

t_{14} : block 1 with or without the previous block 2
       contains the sequence "+?"?

t_{15} : block 2 with or without the previous block 1
       contains the sequence "+?"?

IRS1: notice: station is IRS at the moment the
      interruption occurred, last received block 1

IRS2: notice: station is IRS at the moment the
      interruption occurred, last received block 2

 * Detected error, invalid signal or no signal at all

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APPENDIX 11

Sheet 2 (of 2)

Connector
reference

13

13 — 1(4); 2(2); 2-7(3)

CS3

14 Wait for βαβ

βαβ   *   RQ RQ RQ $\bar{\pi}_3$

13 — CO2   13 2   13 2   ISS

14 — Change from ISS to IRS   14 1(2)   Start counter n_5 — $n_5 = 32$ cycles

16 — Stop counter n_3 16 1(2) t_6 No

     Yes

26 — 26 1-10   Yes t_7 No t_7 No   Yes

00 MR4 Idle   00 MR7 Idle   00 SR4 Idle   00 SR7 Idle

1-5   1-3   1-9   1-7
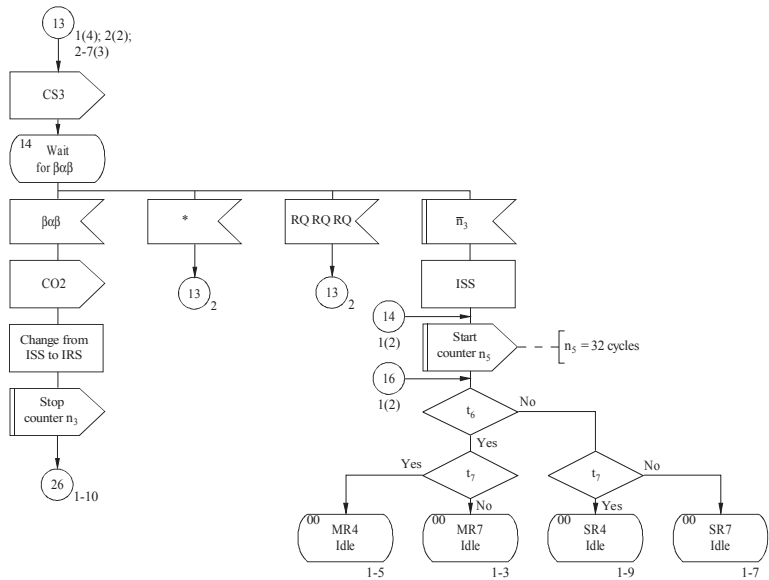
t_6 : station is master station?

t_7 : station working in the case of a 4-signal call identity?

CO2: if IRS is:
— master then "RQ"
— slave then "RQ RQ RQ"

* Detected error, invalid signal or no signal at all

D38

APPENDIX 12

**Phasing procedure with automatic identification
in the case of a 7-signal call identity (calling station) and traffic flow if the station
is in the ISS position (state overview diagram)**

Sheet 1 (of 8)

State number	State description	Sheet reference	Counters running	Supervisory counters
00	M7 idle	1-2	n_1	n_0 = 128 cycles
02	Wait for CS4	1-2	n_0	n_1 = 128 cycles
03	Wait for CS4	1-2	n_0	n_2 = 32 cycles
04	Wait for CS4	1-2	n_0	n_3 = 32 cycles
05	Wait for CK1	2-2	n_2	n_4 = 4 cycles
06	Wait for CK2	2-2	n_2	
07	Wait for CK3	2-2	n_2	
08	Wait for CS1	3-2	n_2	
09	Wait for CS2	1-10	n_3	
10	Wait for CS1	1-10	n_3	
11	Wait for CS2	2-10	n_4	
12	Wait for CS1	2-10	n_1, n_4	
13	Wait for change-over	3-10	n_3	

D39

APPENDIX 12

**Rephasing procedure with automatic identification
in the case of a 7-signal call identity (calling station) and traffic flow if the station
is in the ISS position (state overview diagram)**

Sheet 2 (of 8)
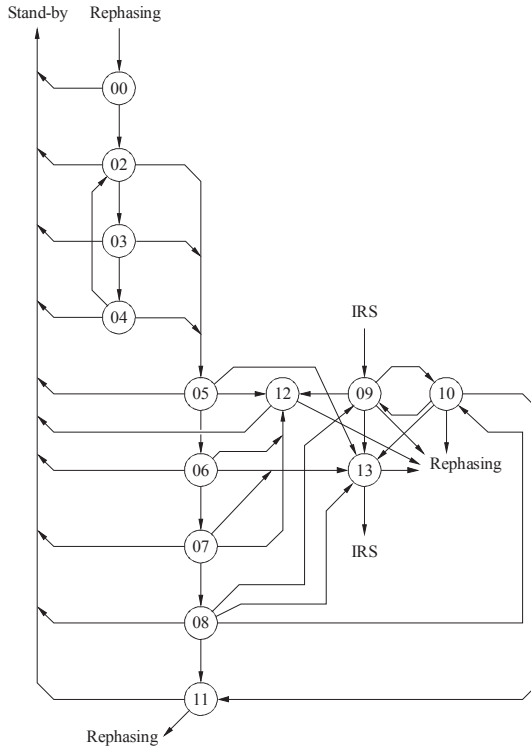
State number	State description	Sheet reference	Counters running	Supervisory counters
00	MR7 idle	1-3	n_5	$n_1 = 128$ cycles
02	Wait for CS5	1-3	n_5	$n_2 = 32$ cycles
03	Wait for CS5	1-3	n_5	$n_3 = 32$ cycles
04	Wait for CS5	1-3	n_5	$n_4 = 4$ cycles
05	Wait for CK1	2-3	n_2, n_5	$n_5 = 32$ cycles
06	Wait for CK2	2-3	n_2, n_5	
07	Wait for CK3	2-3	n_2, n_5	
08	Wait for CS1	3-3	n_2, n_5	
09	Wait for CS2	1-10	n_3, n_5	
10	Wait for CS1	1-10	n_3, n_5	
11	Wait for CS2	2-10	n_4, n_5	
12	Wait for CS1	2-10	n_1, n_4, n_5	
13	Wait for change-over	3-10	n_3, n_5	

D40

APPENDIX 12

**Phasing procedure without automatic identification
in the case of a 4-signal call identity (calling station) and traffic flow if the station
is in the ISS position (state overview diagram)**

Sheet 3 (of 8)
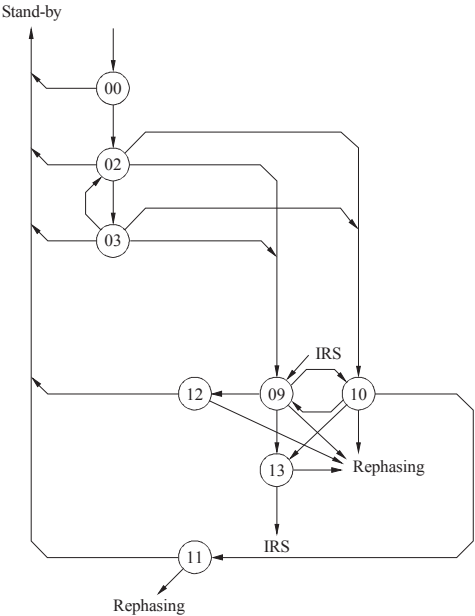
Stand-by

00

02

03

IRS

12   09   10

13   Rephasing

IRS

11

Rephasing

State number	State description	Sheet reference	Counters running	Supervisory counters
00	M4 idle	1- 4	n_1	n_0 = 128 cycles
02	Wait for CS1	1- 4	n_0	n_1 = 128 cycles
03	Wait for CS1	1- 4	n_0	n_3 = 32 cycles
09	Wait for CS2	1-10	n_3	n_4 = 4 cycles
10	Wait for CS1	1-10	n_3	
11	Wait for CS2	2-10	n_4	
12	Wait for CS1	2-10	n_1, n_4	
13	Wait for change-over	3-10	n_3	

D41

APPENDIX 12

**Rephasing procedure without automatic identification
in the case of a 4-signal call identity (calling station) and traffic flow if the station
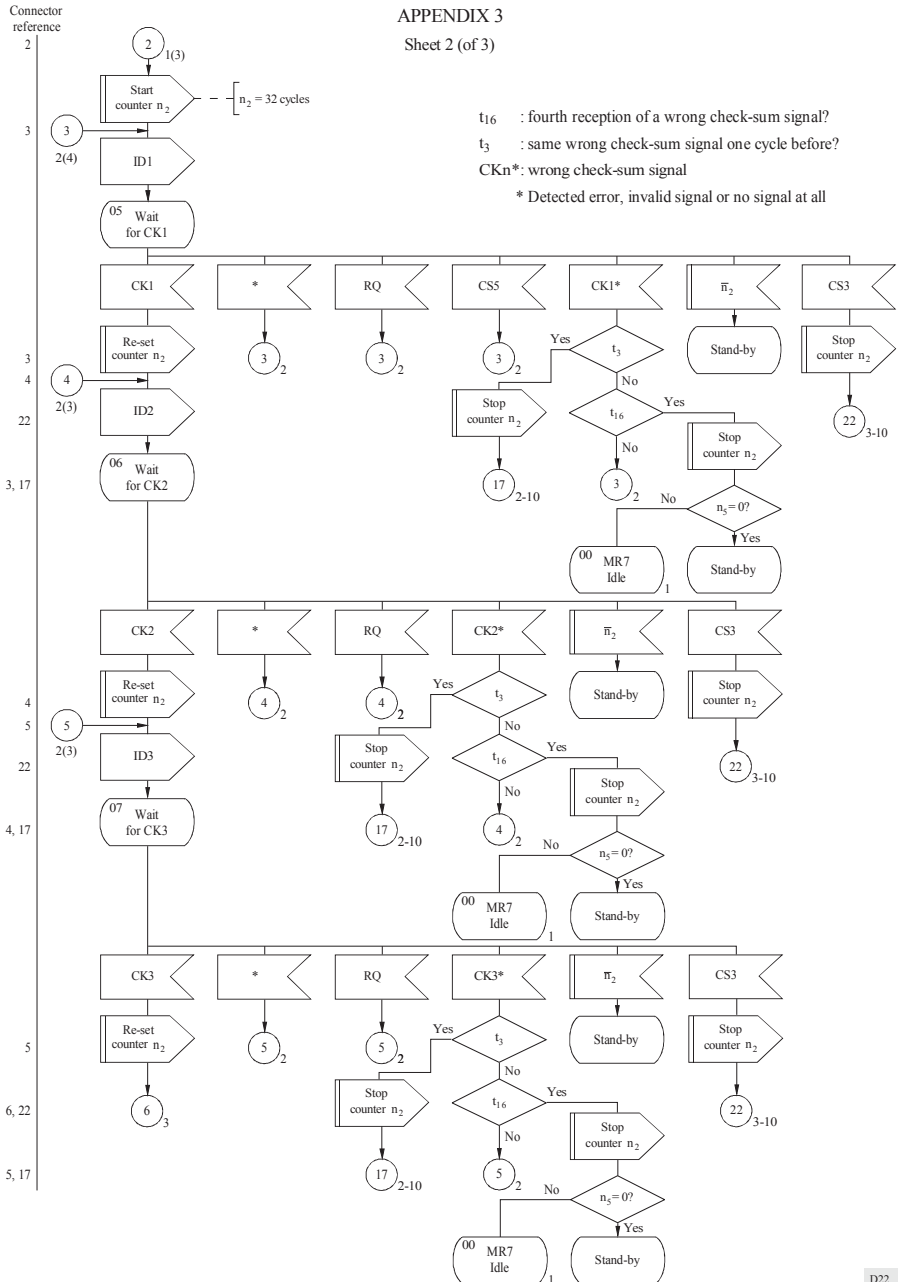is in the ISS position (state overview diagram)**

Sheet 4 (of 8)
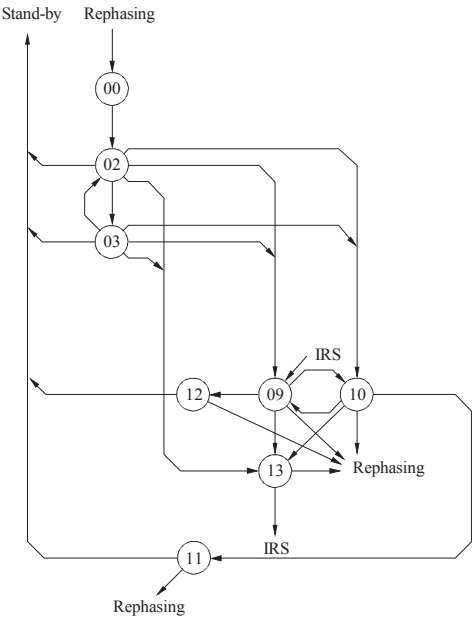
State number	State description	Sheet reference	Counters running	Supervisory counters
00	M4 idle	1-5	n_5	$n_1 = 128$ cycles
02	Wait for CS1	1-5	n_5	$n_3 = 32$ cycles
03	Wait for CS1	1-5	n_5	$n_4 = 4$ cycles
09	Wait for CS2	1-10	n_3	$n_5 = 32$ cycles
10	Wait for CS1	1-10	n_3	
11	Wait for CS2	2-10	n_4	
12	Wait for CS1	2-10	n_1, n_4	
13	Wait for change-over	3-10	n_3	

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APPENDIX 12

**Phasing procedure with automatic identification
in the case of a 7-signal call identity (called station) and traffic flow if the station
is in the IRS position (state overview diagram)**

Sheet 5 (of 8)
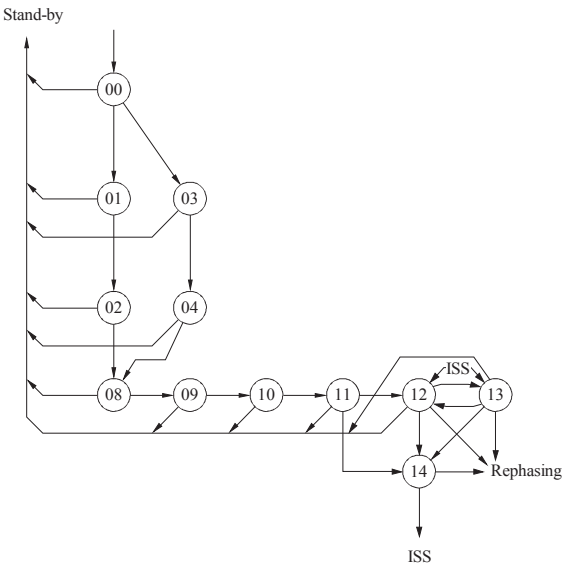
State number	State description	Sheet reference	Counters running	Supervisory counters
00	S7 idle	1-6		n_2 = 32 cycles
01	Wait for CB2	1-6		n_3 = 32 cycles
02	Wait for CB3	1-6		
03	Wait for CB3	1-6		
04	Wait for CB1	1-6		
08	Wait for ID1	2-6	n_2	
09	Wait for ID2	2-6	n_2	
10	Wait for ID3	2-6	n_2	
11	Wait for EOI	3-6	n_2	
12	Wait for block 1	1-11	n_3	
13	Wait for block 2	1-11	n_3	
14	Wait for βαβ	2-11	n_3	

D43

APPENDIX 12

**Rephasing procedure with automatic identification
in the case of a 7-signal call identity (called station) and traffic flow if the station
is in the IRS position (state overview diagram)**

Sheet 6 (of 8)
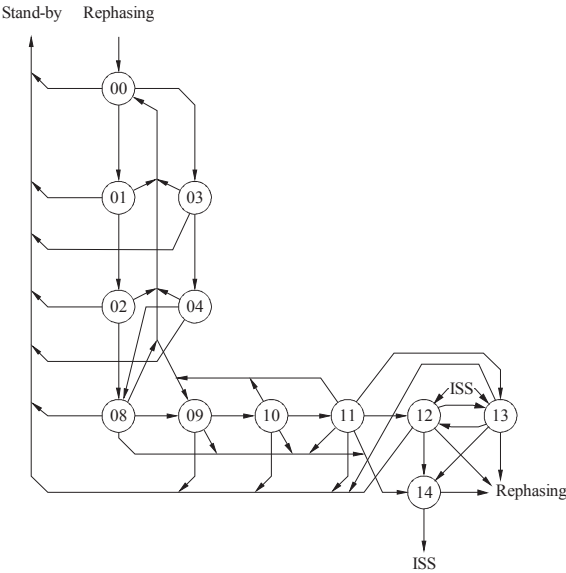
State number	State description	Sheet reference	Counters running	Supervisory counters
00	SR7 idle	1-7	n_5	n_2 = 32 cycles
01	Wait for CB2	1-7	n_5	n_3 = 32 cycles
02	Wait for CB3	1-7	n_5	n_5 = 32 cycles
03	Wait for CB3	1-7	n_5	
04	Wait for CB1	1-7	n_5	
08	Wait for ID1	2-7	n_2, n_5	
09	Wait for ID2	2-7	n_2, n_5	
10	Wait for ID3	2-7	n_2, n_5	
11	Wait for EOI	3-7	n_2, n_5	
12	Wait for block 1	1-11	n_3, n_5	
13	Wait for block 2	1-11	n_3, n_5	
14	Wait for $\beta\alpha\beta$	2-11	n_3, n_5	D44

APPENDIX 12

**Phasing procedure without automatic identification
in the case of a 4-signal call identity (called station) and traffic flow if the station
is in the IRS position (state overview diagram)**

Sheet 7 (of 8)
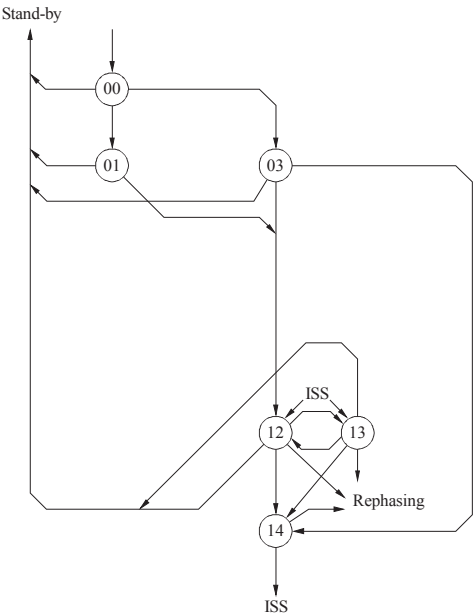
State number	State description	Sheet reference	Counters running	Supervisory counters
00	S4 idle	1-8		$n_3 = 32$ cycles
01	Wait for CB2	1-8		
03	Wait for CB1	1-8		
12	Wait for block 1	1-11	n_3	
13	Wait for block 2	1-11	n_3	
14	Wait for βαβ	2-11	n_3	D45

APPENDIX 12

**Rephasing procedure without automatic identification
in the case of a 4-signal call identity (called station) and traffic flow if the station
is in the IRS position (state overview diagram)**

Sheet 8 (of 8)
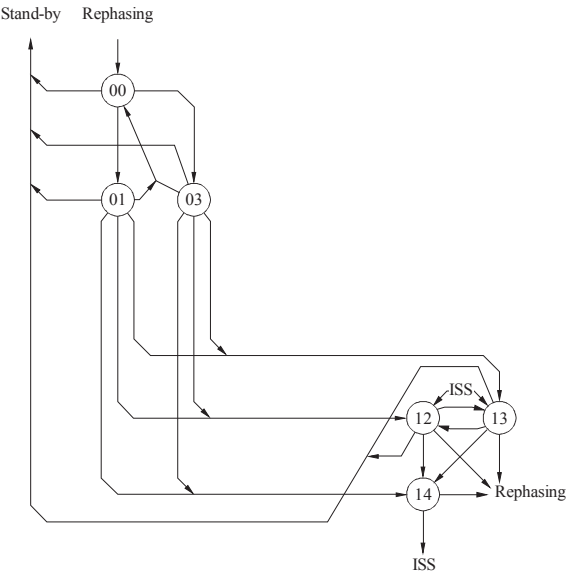
State number	State description	Sheet reference	Counters running	Supervisory counters
00	SR4 idle	1-9	n_5	n_2 = 32 cycles
01	Wait for CB2	1-9	n_5	n_3 = 32 cycles
03	Wait for CB1	1-9	n_5	n_5 = 32 cycles
12	Wait for block 1	1-11	n_3, n_5	
13	Wait for block 2	1-11	n_3, n_5	
14	Wait for $\beta\alpha\beta$	2-11	n_3, n_5	D46

RECOMMENDATION ITU-R M.633-4[*]

Transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through a satellite system in the 406 MHz band

(1986-1990-2000-2004-2010)

Scope

This Recommendation provides transmission characteristics of a satellite emergency position-indicating radio beacon system (satellite EPIRBs) operating in the 406 MHz band.

The ITU Radiocommunication Assembly,

considering

a)   that satellite EPIRBs can be used for distress alerting in the maritime, land and aeronautical environments;

b)   that satellite EPIRBs with common characteristics may be employed in diverse operating environments;

c)   that satellite EPIRBs are one of the prime alerting means in the Global Maritime Distress and Safety System (GMDSS) of the International Maritime Organization (IMO);

d)   that all ships to which Chapter IV of the International Convention for the Safety of Life at Sea (SOLAS), 1974, (as amended in 1988) applies, are required by Regulation IV/7.1.6 to carry a satellite EPIRB from 1 August 1993;

e)   that SOLAS Regulation IV/7.1.6 provides for the carriage of a satellite EPIRB operating in the 406 MHz band;

f)   that all aeroplanes and helicopters for which Parts I, II and III of Annex 6 of the Convention on International Civil Aviation apply, are required to carry at least one satellite EPIRB operating in the 406 MHz band (referred to as Emergency Locator Transmitter (ELT) in the ICAO documentation),

noting

a)   the current and planned availability of operational Cospas-Sarsat satellites in orbit;

b)   the current and projected availability of the Cospas-Sarsat ground system,

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[*]   This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Mobile Satellite Organization (IMSO) and the Cospas-Sarsat Secretariat.

recommends

1 that the transmission characteristics and data formats for a satellite EPIRB operating through a satellite system in the 406 MHz band should be in accordance with Cospas-Sarsat Document C/S T.001 (Issue 3, Revision 10, October 2009 titled Specification for 406 MHz Cospas-Sarsat Distress Beacons).

NOTE 1 – A copy of document C/S T.001 (Issue 3, Revision 10, October 2009) can be obtained free of charge from the Cospas-Sarsat Secretariat (mail@cospas.sarsat.int) or the Cospas-Sarsat website (http://www.cospas-sarsat.org/).

RECOMMENDATION ITU-R S.672-4*

**Satellite antenna radiation pattern for use as
a design objective in the fixed-satellite service
employing geostationary satellites**

(1990-1992-1993-1995-1997)

The ITU Radiocommunication Assembly,

considering

a)   that the use of space-station antennas with the best available radiation patterns will lead to the most efficient use of the radio-frequency spectrum and the geostationary orbit;

b)   that both single feed elliptical (or circular) and multiple feed shaped beam antennas are used on operational space stations;

c)   that although improvements are being made in the design of space-station antennas, further information is still required before a reference radiation pattern can be adopted for coordination purposes;

d)   that the adoption of a design objective radiation pattern for space-station antennas will encourage the fabrication and use of orbit-efficient antennas;

e)   that it is only necessary to specify space-station antenna radiation characteristics in directions of potential interference for coordination purposes;

f)   that for wide applicability the mathematical expressions should be as simple as possible consistent with effective predictions;

g)   that nevertheless, the expressions should account for the characteristics of practical antenna systems and be adaptable to emerging technologies;

h)   that measurement difficulties lead to inaccuracies in the modelling of spacecraft antennas at large off-axis angles;

j)   that the size constraints of launch vehicles lead to limitations in the D/λ values of spacecraft antennas, particularly at lower frequencies such as the 6/4 GHz band;

k)   that space-station antenna pattern parameters such as reference point, coverage area, equivalent peak gain, that may be used to define a space-station reference antenna pattern, are found in Annex 1;

l)   that two computer programs have been developed to generate coverage contours (see Annex 2),

_____

* Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

recommends

1   that for single feed circular or elliptical beam spacecraft antennas in the fixed-satellite service (FSS), the following radiation pattern should be used as a design objective, outside the coverage area:

$$G(\psi) = G_m - 3\,(\psi/\psi_b)^\alpha \quad \text{dBi} \qquad \text{for} \qquad \psi_b \le \psi \le a\,\psi_b \tag{1}$$

$$G(\psi) = G_m + L_N + 20\log z \quad \text{dBi} \qquad \text{for} \quad a\,\psi_b < \psi \le 0.5b\,\psi_b \tag{2a}$$

$$G(\psi) = G_m + L_N \quad \text{dBi} \qquad \text{for } 0.5b\,\psi_b < \psi \le b\,\psi_b \tag{2b}$$

$$G(\psi) = X - 25\log\psi \quad \text{dBi} \qquad \text{for} \qquad b\,\psi_b < \psi \le Y \tag{3}$$

$$G(\psi) = L_F \quad \text{dBi} \qquad \text{for} \qquad Y < \psi \le 90° \tag{4a}$$

$$G(\psi) = L_B \quad \text{dBi} \qquad \text{for} \qquad 90° < \psi \le 180° \tag{4b}$$

where:

$$X = G_m + L_N + 25\log(b\,\psi_b) \qquad \text{and} \qquad Y = b\,\psi_b\, 10^{0.04(G_m + L_N - L_F)}$$

$G(\psi)$:   gain at the angle ψ from the main beam direction (dBi)

G_m: maximum gain in the main lobe (dBi)

ψ_b: one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)

L_N: near-in-side-lobe level in dB relative to the peak gain required by the system design

$L_F = 0$ dBi far side-lobe level (dBi)

z: (major axis/minor axis) for the radiated beam

L_B: $15 + L_N + 0.25\,G_m + 5\log z$ dBi or 0 dBi whichever is higher.

NOTE 1 – Patterns applicable to elliptical beams require experimental verification. The values of *a* in Table 1 are provisional.

TABLE 1

L_N (dB)	a	b	α
–20	$2.58\ \sqrt{(1 - \log z)}$	6.32	2
–25	$2.58\ \sqrt{(1 - 0.8\log z)}$	6.32	2
–30	–	6.32	–

The numeric values of *a*, *b*, and α for $L_N = -20$ dB and –25 dB side-lobe levels are given in Table 1. The values of *a* and α for $L_N = -30$ dB require further study. Administrations are invited to provide data to enable the values of *a* and α for $L_N = -30$ dB to be determined;

2   that for multiple-feed, shaped beam, spacecraft antennas in the FSS, the radiation pattern to be used as a design objective shall be selected from the following formulae depending upon the class of antenna and the range of the scan ratio.

Definition of class of antennas

– Definition of class A antennas:

Class A antennas are those with the boresight location within the coverage area.

– Definition of class B antennas:

Class B antennas are those with the boresight location outside the coverage areas for one or more of the beams.

Definition of scan ratio

There are two definitions of the scan ratio:

The scan ratio δ in § 2.1 is defined as the angular distance between the centre of coverage (defined as the centre of the minimum area ellipse) and a point on the edge-of-coverage, divided by the beamwidth of the component beam.

Scan ratio S used in § 2.2 and 2.3 is defined as the angular distance between the antenna boresight and a point on the edge-of-coverage, divided by the beamwidth of the component beam.

In the initial determination of which *recommends* is applicable to a specific class A antenna, the δ scan ratio definition should be used;

2.1 for class A antennas with scan ratio values $\delta \leq 3.5$:

$$G_{dBi}(\Delta\psi) = \begin{cases} G_{ep} + 0.256 - 13.065\left(\dfrac{\Delta\psi}{Q\,\psi_0} + 0.5\right)^2 & \text{for} \quad 0 \leq \dfrac{\Delta\psi}{\psi_0} \leq 0.8904\,Q \\[3mm] G_{ep} - 25 & \text{for } 0.8904\,Q < \dfrac{\Delta\psi}{\psi_0} \leq 1.9244\,Q \\[3mm] G_{ep} - 25 + 20\log\left(\dfrac{1.9244\,Q\,\psi_0}{\Delta\psi}\right) & \text{for } 1.9244\,Q < \dfrac{\Delta\psi}{\psi_0} \leq 18/\psi_0 \end{cases}$$

where:

$\Delta\psi$: angle (degrees) from the convex coverage contour to a point outside the coverage region in a direction normal to the sides of the contour

G_{ep} : equivalent peak gain (dBi)

$= G_e + 3.0$

ψ_0 : the half-power beamwidth of component beams (degrees)

$= 72\,(\lambda/D)$

λ : wavelength (m)

D : physical diameter of the reflector (m)

$$Q = 10^{\left(\dfrac{0.000075\,(\delta - 1/2)^2}{[(F/D_p)^2 + 0.02)]^2}\right)}$$

δ : scan ratio as defined in § 2

F/D_p : ratio of the reflector focal length F to parent parabola diameter D_p

$D_p = 2(d + h)$

d: projected aperture diameter of the offset paraboloid

h: offset height to the edge of the reflector;

2.2   that for class A antennas with scan ratio values $S \geq 5$:

$$G_{dBi}(\Delta\psi) = \begin{cases} G_e - B\left[\left(1 + \dfrac{\Delta\psi}{\psi_b}\right)^2 - 1\right] & \text{for} & 0° \leq \Delta\psi \leq C\,\psi_b \\[2mm] G_e - 22 & \text{for} & C\,\psi_b < \Delta\psi \leq (C + 4.5)\,\psi_b \\[2mm] G_e - 22 + 20\log_{10}\left[\dfrac{(C + 4.5)\,\psi_b}{\Delta\psi}\right] & \text{for} & (C + 4.5)\,\psi_b < \Delta\psi \leq 18° \end{cases}$$

where:

$\Delta\psi$: angle (degrees) from the convex coverage contour in a direction normal to the sides of the contour

G_e: gain at the edge-of-coverage (dBi)

$B = B_0 - (S - 1.25)\,\Delta B$ for $S \geq 5$

$B_0 = 2.05 + 0.5\,(F/D - 1) + 0.0025\,D/\lambda$

$\Delta B = 1.65\,(D/\lambda)^{-0.55}$

ψ_b: beamlet radius

$= 36\,\lambda/D$

λ: wavelength (m)

D: physical diameter of the reflector (m)

$C = \sqrt{1 + \dfrac{22}{B}} - 1$

S: scan ratio as defined in § 2

F/D: ratio of focal length over the physical diameter of the antenna;

2.3   that for class B antennas, which only use scan ratio S (for $S \geq 0$):

$$G_{dBi}(\Delta\psi) = \begin{cases} G_e - B\left[\left(1 + \dfrac{\Delta\psi}{\psi_b}\right)^2 - 1\right] & \text{for} & 0° \leq \Delta\psi \leq C\,\psi_b \\[2mm] G_e - 17 + 18.7012\log_{10}\left(\cos\left[\dfrac{\Delta\psi - C\,\psi_b}{\psi_b}\right]\right) & \text{for} & C\,\psi_b < \Delta\psi \leq (C+1)\,\psi_b \\[2mm] G_e - 22 & \text{for} & (C+1)\,\psi_b < \Delta\psi \leq (C+4.5)\,\psi_b \\[2mm] G_e - 22 + 20\log_{10}\left[\dfrac{(C+4.5)\psi_b}{\Delta\psi}\right] & \text{for} & (C+4.5)\,\psi_b < \Delta\psi \leq 18° \end{cases}$$

where:

$\Delta\psi$: angle (degrees) from the convex coverage contour in a direction normal to the sides of the contour

G_e: gain at the edge-of-coverage (dBi)

$B = B_0 - (S - 1.25)\,\Delta B$ for $S \geq 0$

$B_0 = 2.05 + 0.5\,(F/D - 1) + 0.0025\,D/\lambda$

$\Delta B = 1.65\,(D/\lambda)^{-0.55}$

ψ_b: beamlet radius

$$= 36\ \lambda/D$$

λ : wavelength (m)

D : physical diameter of the reflector (m)

$$C = \sqrt{1 + \frac{17}{B}} - 1$$

S : scan ratio as defined in § 2

F/D : ratio of focal length over the physical diameter of the antenna;

2.4 that for class A antennas with scan ratio values $\delta > 3.5$ and $S < 5$, the design objective is still under study. In particular, studies are required on the extension of the equations given in § 2.1 and 2.2 into this region. One possible method of extending the design objective into this region is described in Annex 1. For the definition of scan ratios δ and S and their application, see § 2;

2.5 that the following Notes shall be considered part of § 2.1 and 2.2:

NOTE 1 – The coverage area shall be defined as the contour constructed from the polygon points surrounding the service area, using the method given in Annex 2.

NOTE 2 – For the cuts, where the −3 dB gain contour is outside of the constructed coverage contour, the design objective pattern should originate from the −3 dB contour.

NOTE 3 – This Recommendation should be applied only in the direction of an interference sensitive system. That is, it need not be applied in directions where the potential for interference to other networks does not exist (e.g. off the edge of the Earth, unpopulated ocean regions). 10% of the cuts may exceed the design objective pattern.

NOTE 4 – This Recommendation does not apply to dual frequency band antennas. Antennas using the reflector induced phase error for beam broadening belong to this category and require further study.

ANNEX 1

Satellite antenna patterns in the fixed-satellite service

1   Satellite antenna reference radiation patterns

1.1   Single feed circular beams

The radiation pattern of the satellite antenna is important in the region of the main lobe as well as the farther side lobes. Thus, the possible patterns commencing at the −3 dB contour of the main lobe are divided into four regions. These are illustrated in Fig. 1.

Difficulties arise, however, in attempting to apply the postulated pattern to a non-circular beam. Administrations are therefore requested to submit measured radiation patterns for antennas with other than simple circular beams.

FIGURE 1

Radiation pattern envelope functions
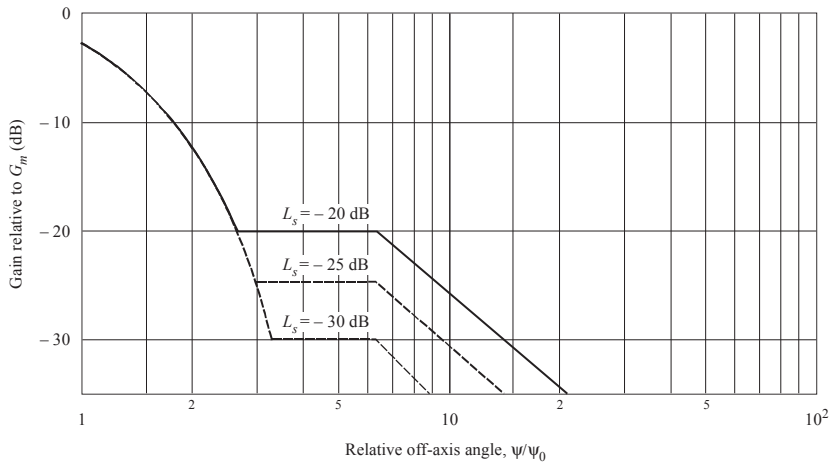
$$G(\psi) = G_m - 3\,(\psi/\psi_0)^2 \qquad\qquad \text{dBi} \qquad\qquad \text{for} \qquad \psi_0 \le \psi \le a\,\psi_0 \qquad (I)$$

$$G(\psi) = G_m + L_s \qquad\qquad\qquad\quad \text{dBi} \qquad\qquad \text{for} \qquad a\,\psi_0 < \psi \le b\,\psi_0 \qquad (II)$$

$$G(\psi) = G_m + L_s + 20 - 25\log(\psi/\psi_0) \quad \text{dBi} \qquad\qquad \text{for} \qquad b\,\psi_0 < \psi \le \psi_1 \qquad (III)$$

$$G(\psi) = 0 \qquad\qquad\qquad\qquad\qquad \text{dBi} \qquad\qquad \text{for} \qquad \psi_1 < \psi \qquad (IV)$$

where:

$G(\psi)$:　gain at the angle (ψ) from the axis (dBi)

G_m:　　maximum gain in the main lobe (dBi)

ψ_0:　　one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)

ψ_1:　　value of (ψ) when $G(\psi)$ in equation (III) is equal to 0 dBi

L_s:　　the required near-in-side-lobe level (dB) relative to peak gain

a, b:　　the numeric values are given below:

L_s	a	b
− 20	2.58	6.32
− 25	2.88	6.32
− 30	3.16	6.32

0672-01

1.2　Single feed elliptical beams

The functions in Fig. 1 define a maximum envelope for the first side lobes at a level of −20 dB relative to peak gain and this pattern applies to antennas of fairly simple designs. However, in the interest of a better utilization of the orbit capacity, it may be desirable to reduce this level to −30 dB and to use antennas of more sophisticated design. The pattern adopted by the World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service, Geneva, 1977 (WARC BS-77) for broadcasting satellite antennas meets this requirement and is now being achieved and

should therefore apply in that case. Additional studies may be desirable to ascertain the feasibility of achieving these reduced side-lobe levels in common practice, particularly with respect to the 6/4 GHz bands.

1.3   Multiple feed shaped beams

A similar pattern applicable to shaped beams must be based on analysis of several shaped beams and also on theoretical considerations. Additional parameters must be specified, such as the diameter of the elemental beamlet and the level of the first side lobe. In addition the cross-section and means of measuring angles form part of the pattern definition.

The important consideration in producing such a reference is the discrimination to be achieved from the edge of coverage of all types of antenna, including the most complex shaped beam antenna, as a function of angular separation of the coverage areas as seen from the orbit. The radiation pattern of a shaped beam antenna is unique and it is mainly determined by the following operational and technical factors:

–   shape of the coverage area;

–   satellite longitude;

–   maximum antenna aperture;

–   feed design and illumination taper;

–   normalized reflector aperture diameter (D/λ);

–   focal length to aperture diameter ratio (F/D);

–   number of frequency re-use and independent beam ports;

–   number of feed elements utilized;

–   bandwidths;

–   polarization orthogonality requirements;

–   total angular coverage region provided;

–   stability of feed element phase and amplitude excitations;

–   reconfigurability requirements;

–   number of orbital positions from which beam coverages must be provided;

–   reflector surface tolerances achieved;

–   beam pointing (i.e. derived from satellite or independent beam positioning via earth-based tracking beacons);

–   component beam degradations due to scan aberrations that are related to the specific reflector or antenna configuration (i.e. single reflector, dual reflector, shaped reflector systems without a focal axis, direct radiating array, etc.).

In view of this, there may be some difficulties in developing a single reference radiation pattern for shaped beam antennas.

The reference pattern of Fig. 1 is unsatisfactory for shaped beam antennas, since a key parameter to the reference pattern is ψ_0, the –3 dB half-beamwidth, whereas the beam centre of a shaped beam is ill-defined and largely irrelevant to the out-of-beam response. A simple reference pattern consisting of four segments, as illustrated in Fig. 2 might be more satisfactory for the basis of a reference pattern. The slope of the skirt of this pattern would be a function of the angular distance outside the average contour.

FIGURE 2

Possible form of reference radiation pattern

Δψ: off-axis angle relative to edge of coverage
     (assumed to be equivalent to the –3 dB contour)

ψ: off-axis angle relative to reference point
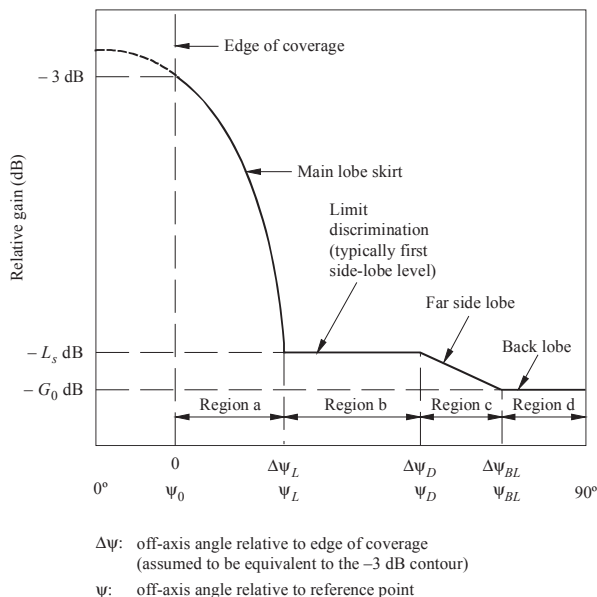
0672-02

The particular direction in which to measure this angular distance is also a parameter which needs definition. One method is to measure this angle orthogonally from the constant gain contour which corresponds most closely to the coverage area. Difficulties arise with this method where portions of the gain contours are concave such as occurs with crescent-shaped patterns. For this type of pattern, the orthogonal direction away from a contour could intersect the coverage area again. From an antenna design standpoint, the difficulty in achieving good discrimination in the concave portion of a pattern increases with the degree of concavity. An alternative method which could circumvent these problems is to circumscribe the coverage area by a contour which has no concavity and then measure the angles orthogonally from this contour; this contour being considered as edge of coverage. Other methods of defining the direction of measurement are possible, e.g. the centre of a circumscribing ellipse could be used as a reference point (see § 2.1 and 2.2), but an unambiguous definition is needed for any reference pattern.

Once the direction is defined, the radiation pattern can be separated into four regions of interest:

Region a: Main lobe skirt (edge of coverage to angle of limit discrimination)

This region is assumed to cover what is considered to be adjacent coverage regions. The required isolation between satellite networks would be obtained from a combination of satellite antenna discrimination and orbital separation.

A simple function which could be applied to this region could be in a form similar to that given in equation (I) of Fig. 1.

Region b: Non-adjacent coverage region

This region begins where the radiation pattern yields sufficient discrimination to allow nearly co-located satellites to serve non-adjacent areas ($\Delta\psi_L$ in Fig. 2). The limit discrimination (L_s) may be between -20 and -30 dB.

Region c: Far side-lobe region

Region d: Back-lobe region

Each of these regions covers the higher order side lobes and is applicable to very widely spaced service areas and, in those frequency bands used bidirectionally, to parts of the orbit. In the latter case, care must be exercised when considering very large off-axis angles since unpredictable reflections from the spacecraft bus and spill-over from the main reflector might have significant effect. A minimum gain envelope of 0 dBi is suggested pending more information (Region d in Fig. 2).

2   Shaped beam radiation pattern models

For shaped beam modelling purposes, prior to the actual design of an antenna, a simplified reference pattern might be used. Two models which can generate such patterns and their associated parameters are presented below. Both models are suitable for computer-aided interference studies and, in conjunction with satellite centred maps, for manual application. The models form the basis of a recommended pattern or patterns. However, it would be advisable to only apply the resultant pattern "profiles" in the direction of an interference sensitive system. That is, they should not be applied in directions where the potential for interference to other networks does not exist (i.e. off the edge of the Earth, unpopulated ocean regions, etc.).

2.1   Representation of coverage area

Various methods have been proposed in the past for the service area representation of FSS antennas. In one method, the angular distance outside the coverage area is measured in a direction normal to the service area geography (constant gain contour) as seen from the satellite. In practice, the gain contour is designed to fit the service area as closely as possible and therefore the difference between using the service area and the constant gain contour is expected to be very small. However, difficulties will arise with this method in certain cases where portions of gain contours are concave such as with crescent shaped patterns. For such patterns, the orthogonal direction away from the contour could intersect the coverage area again thereby causing ambiguity (see Fig. 3a)). Another difficulty with this representation is that for a given location outside the coverage area, there could be more than one point on the service area at which the line joining the observation location to the point on the service area is normal to the service area contour at that point (see Fig. 3a)).

However, a method has been developed which circumvents the difficulties cited above using angular measurements normal to the coverage area and patterns containing concavities. This method involves a number of graphical constructions and is described in a set of step-by-step procedures in Annex 2.

In addition, these step-by-step procedures can be simplified by use of a convex-only coverage contour. To produce a convex-only coverage contour, the same procedure as described in Annex 2 is undertaken, except that only convex corners, i.e. those in which the circle lies inside the coverage contour are considered. The resultant coverage contour is illustrated in Fig. 3b).

Another way of representing the shaped beam patterns is by circumscribing the actual coverage area by a minimum area ellipse. The angular distance is measured from the edge of the ellipse in a direction normal to the periphery of the ellipse. This has the advantage that it is relatively easy to write highly efficient computer programs to define such an angular measurement procedure. However, this representation tends to considerably overestimate the area defined by the actual service area.

Another method is a hybrid approach which gives an unambiguous definition for representing the shaped beam coverage area. In this method a minimum area ellipse circumscribing the geographic coverage is used to define the centre of coverage area. The centre of coverage area does not necessarily represent the beam centre and is used only to define the axis of pattern cuts. Once the centre of coverage area is defined, the minimum area ellipse has no further significance.

A convex polygon is then used to define the coverage area boundary. The number of sides forming the polygon are determined based on the criteria that it should circumscribe the coverage area as closely as possible and should be of convex shape. A typical example is shown in Fig. 3c) for the service area representation. The angular directions are radial from the centre of the coverage area.

For an observation location outside the coverage area, the direction of applying the template and the angular distances are unambiguously defined with reference to the centre of coverage area. However, this method tends to underestimate the angular spacing between the gain contours outside the coverage area when the angle of the radial with respect to the coverage contour significantly departs from normal.

In summary, it would appear that the most acceptable method, both in accuracy and ease of construction, is the use of the convex-only coverage contour with the angular distances measured along directions normal to the sides of the contour, as shown in Fig. 3b).

2.2   Equivalent peak gain

In situations where it is not necessary to tailor the beam to compensate for the variation in propagation conditions across the service area, the minimum coverage area gain achieved at the coverage area contour is considered to be 3 dB less than the equivalent peak gain (G_{ep}). In practice the actual peak gain may be higher or lower than the equivalent peak gain and may not necessarily occur on-axis.

In some situations there could be a large variation of propagation conditions over the service area or service requirements may warrant special beam tailoring within the service area. In these cases the minimum required relative gain (relative to the average gain on the coverage area contour) at each polygon vertex is computed and linear interpolation based on the azimuth from the beam axis may then be used to determine the relative gain at intermediate azimuths. Under this scenario the gain at the coverage area contour is direction dependent.

Note that for a shaped beam, the gain variation within the coverage area is not related to the roll-off of gain beyond the edge of coverage. The antenna performance within the coverage area, including the gain, is not related to the interference introduced into adjacent systems. The gain variation within the coverage area, therefore, need not be characterized in shaped beam reference patterns.

FIGURE 3

Different representation of coverage area

a)

b) Measurement of the angle, $\Delta\psi$, from the (convex) coverage contour

c)

0672-03
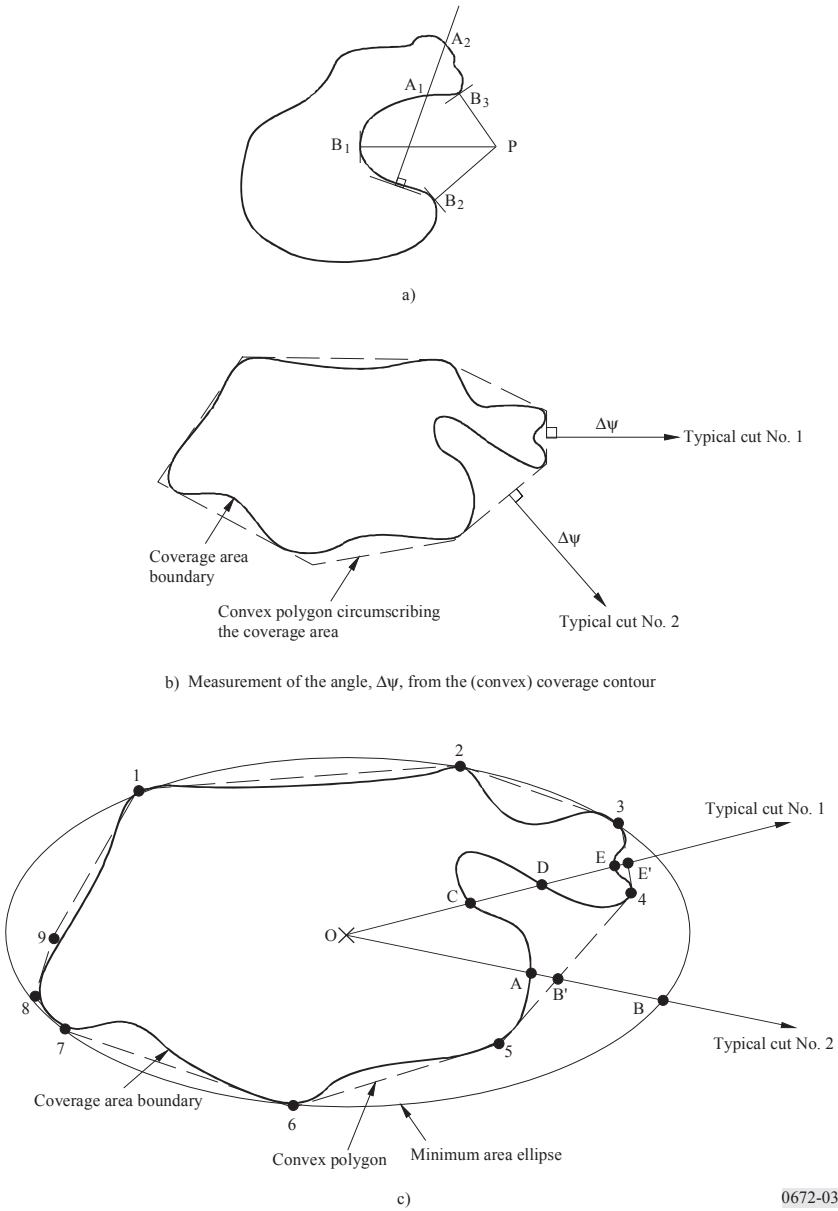
2.3   Elemental beamlet size

The side-lobe levels are determined by the aperture illumination function. Considering an illumination function of the form:

$$f(x) = \cos^N\left(\frac{\pi}{2} \cdot x\right) \qquad |x| \leq 1 \tag{5}$$

which is zero at the aperture edge for $N > 0$. The elemental beamlet radius, as a function of the side-lobe level (dB) and the D/λ ratio, is, over the range of interest, approximately given by:

$$\psi_b = (16.56 - 0.775\, L_s)\, \lambda/D \qquad \text{degrees} \tag{6}$$

where L_s is the relative level of the first side lobe (dB).

This expression illustrates the trade-off between antenna diameter, side-lobe level and steepness of the main lobe skirt regions. It is derived by curve fitting the results obtained from calculations for different side-lobe levels. This relationship has been used as a starting point in the models described below.

2.4   Development of co-polar pattern models

Generalized co-polar patterns for future shaped beam antennas based on measurements on several operational shaped beam antennas (Brazilsat, Anik-C, Anik-E, TDRSS, Intelsat-V, G-Star, Intelsat-VI, Intelsat-VII, Cobra) and on theoretical considerations are given in this section.

Previous modelling did not appear to quantify the beam broadening effects. The following models include two separate approaches which deal with these effects, which are essential to predicting shaped beam antenna performance accurately.

2.4.1   First model

The shaped beam pattern given in this section is in terms of the primary as well as the secondary parameters. The primary parameters are the beamlet size, coverage area width in the direction of interest and the peak side-lobe level. Secondary parameters are the blockage parameter, surface deviation and the number of beamwidths scanned. The effect of secondary parameters on the antenna radiation is to broaden the main beam and increase the side-lobe level. Although the dominant parameter in the beam broadening is the number of beamwidths scanned, the effects of the other two parameters are given here for completeness. However, the effect of blockage on side-lobe level should not be overlooked. Though it is true that, due to practical limitations, even for a satellite antenna design which calls for maintaining the blockage free criteria, there is normally a small amount of edge blockage. In particular, edge blockage is quite likely to occur for linear dual-polarization antennas employing a common aperture as is the case of dual gridded reflectors used for Anik-E, G-Star, Anik-C, Brazilsat, etc. This is because of the required separation between the foci of the two overlapped reflectors for the isolation requirements and for the volume needed for accommodating two sets of horns.

In the far side-lobe regions there is very little measured information available on which to base a model. Reflections from the spacecraft structure, feed array spill-over, and direct radiation from the feed cluster can introduce uncertainties at large off-axis angles and may invalidate theoretical

projections. Measurement in this region is also extremely difficult and therefore further study is required to gain confidence in the model in this region. In the interim, a minimum gain plateau of 0 dBi is suggested.

It should be noted that the suggested pattern is only intended to apply in directions where side-lobe levels are of concern. In uncritical directions, e.g. towards ocean regions or beyond the limb of the Earth or in any direction in which interference is not of concern, this pattern need not be a representative model.

General co-polar Model 1

The following three-segment model representing the envelope of a satellite shaped beam antenna radiation pattern outside of the coverage area, is proposed:

Main lobe skirt region:

$$G_{dBi}(\Delta\psi) = G_{ep} + U - 4V\left(\frac{\Delta\psi}{Q\psi_0} + 0.5\right)^2 \qquad \text{for} \qquad 0 \le \Delta\psi \le W \cdot Q \cdot \psi_0$$

Near-in side-lobe region:

$$G_{dBi}(\Delta\psi) = G_{ep} + SL \qquad \text{for } W \cdot Q \cdot \psi_0 \le \Delta\psi \le Z \cdot Q \cdot \psi_0$$

Far side-lobe region:

$$G_{dBi}(\Delta\psi) = G_{ep} + SL + 20\log(Z \cdot Q \cdot \psi_0 / \Delta\psi) \qquad \text{for} \qquad Z \le \Delta\psi \le 18$$

where:

$\Delta\psi$: angle from the edge of coverage (degrees)

$G_{dBi}(\Delta\psi)$: gain at $\Delta\psi$ (dBi)

G_{ep} : equivalent peak gain

$\qquad G_{ep} = G_e + 3.0$ (dBi)

ψ_0 : half-power diameter of the beamlet (degrees)

$\qquad \psi_0 \approx (33.12 - 1.55\,SL)\,\lambda/D$

$\qquad \lambda$: wavelength (m)

$\qquad D$: diameter of the reflector (m)

SL : side-lobe level relative to the peak (dB)

$\quad U = 10\log A,\ V = 4.3429\,B$ are the main beam parameters

$\qquad B = [\ln(0.5/10^{0.1SL})] / [[(16.30 - 3.345\,SL) / (16.56 - 0.775\,SL)]^2 - 1]$

$\qquad A = 0.5\exp(B)$

$\quad W = (-0.26 - 2.57\,SL) / (33.12 - 1.55\,SL)$

$\quad Z = (77.18 - 2.445\,SL) / (33.12 - 1.55\,SL)$

$\quad Q$: beam broadening factor due to the secondary effects:

$$Q = \exp[(8\pi^2(\varepsilon/\lambda)^2] \cdot [\eta_i(\Delta)]^{-0.5} \cdot 10^{\left(\frac{0.000075(\delta - 1/2)^2}{[(F/D_p)^2 + 0.02]^2}\right)} \tag{7}$$

The variables in equation (7) are defined as:

ε : r.m.s. surface error

Δ : blockage parameter (square root of the ratio between the area blocked and the aperture area)

δ :   number of beamwidths scanned away from the axial direction

$= \theta_0/\psi_0$

θ_0 :   angular separation between the centre of coverage, defined as the centre of the minimum area ellipse, to the edge of the coverage area

$$\eta_i(\Delta) = 1 - \Delta^2 \qquad\qquad \text{for central blockage}$$

$$= [1 - [1 - A(1 - \Delta)^2]\,\Delta^2]^2 \qquad \text{for edge blockage} \qquad (8)$$

A in equation (8) is the pedestal height in the primary illumination function $(1 - Ar^2)$ on the reflector and r is the normalized distance from the centre in the aperture plane of the reflector ($r = 1$ at the edge). F/D_p in equation (7) is the ratio of the focal length to the parent parabola diameter. For a practical satellite antenna design this ratio varies between 0.35 and 0.45.

The far-out side-lobe gain depends on the feed-array spillover, reflection and diffraction effects from the spacecraft structure. These effects depend on individual designs and are therefore difficult to generalize.

As given in equation (7), the beam broadening factor Q depends on the r.m.s. surface error ε, the blockage parameter Δ, number of beams scanned δ, and F/D_p ratio. In practice, however, the effect of ε and Δ on beam broadening is normally small and can be neglected. Thus, equation (7) can be simplified to:

$$Q = 10^{\left(\dfrac{0.000075\,(\delta - 1/2)^2}{[(F/D_p)^2 + 0.02]^2} \right)} \qquad (9)$$

where:

$D_p = 2(d + h)$

d :   projected aperture diameter of the offset paraboloid

h :   offset height to the edge of the reflector.

Equation (9) clearly demonstrates the dependence of beam broadening on number of beams scanned and the satellite antenna F/D_p ratio. This expression is valid for δ as high as nine beamwidths, which is more than sufficient for global coverage even at 14/11 GHz band; for service areas as large as Canada, United States or China the value of δ is generally one to two beams at 6/4 GHz band and about four beams at 14/11 GHz band, in the application of this model. Thus, for most of the systems the value of Q is normally less than 1.1. That is, the beam broadening effect is generally about 10% of the width of the elemental beamlet of the shaped-beam antenna.

Neglecting the main beam broadening due to blockage and reflector surface error, and assuming a worst-case value of 0.35 for F/D_p ratio of the reflector, the beam broadening factor Q can be simplified as:

$$Q = 10^{0.0037\,(\delta - 1/2)^2}$$

In the 6/4 GHz band, a −25 dB side-lobe level can be achieved with little difficulty using a multi-horn solid reflector antenna of about 2 m in diameter, consistent with a PAM-D type launch. To achieve 30 dB discrimination, a larger antenna diameter could be required if a sizeable angular

range is to be protected or controlled. In the 14/11 GHz fixed-satellite bands, 30 dB discrimination can generally be achieved with the 2 m antenna and the use of a more elaborate feed design.

The above equations for the reference pattern are dependent upon the scan angle of the component beam at the edge of coverage in the direction of each individual cut for which the pattern is to be applied. For a reference pattern to be used as a design objective, a simple pattern with minimum parametric dependence is desirable. Hence, a value or values of Q which cover typically satellite coverages should be selected and incorporated in the above equations.

A steeper main beam fall-off rate can be achieved for a typical domestic satellite service area as compared to very large regional coverage areas; and conversely a reference pattern satisfying a regional coverage will be too relaxed for domestic satellite coverages.

Therefore it is proposed to simplify Model 1 into the following two cases for the FSS antennas. For these cases a –25 dB side-lobe plateau level is assumed.

a) **Small coverage regions** ($\delta < 3.5$)

Most of the domestic satellite coverage areas fall under this category. The beam broadening factor Q is taken as 1.10 to represent reference patterns of modest scan degradations for small coverage regions as:

$$G_{dBi}(\Delta\psi) = \begin{cases} G_{ep} + 0.256 - \dfrac{10.797}{\psi_0^2}\,(\Delta\psi + 0.55\,\psi_0)^2 & \text{for} \qquad 0 \leq \Delta\psi \leq 0.9794\,\psi_0 \\[2mm] G_{ep} - 25 & \text{for } 0.9794\,\psi_0 < \Delta\psi \leq 2.1168\,\psi_0 \\[2mm] G_{ep} - 25 + 20\log(2.1168\,\psi_0/\Delta\psi) & \text{for } 2.1168\,\psi_0 < \Delta\psi \leq 18 \end{cases}$$

b) **Wide coverage regions** ($\delta > 3.5$)

Examples for wide coverage regions are the hemi-beam and global coverages of INTELSAT and INMARSAT. In order to represent the pattern degradation due to large scan, a value of 1.3 is taken for the Q factor. The reference patterns applicable to these coverages ($\delta > 3.5$) are defined as:

$$G_{dBi}(\Delta\psi) = \begin{cases} G_{ep} + 0.256 - \dfrac{7.73}{\psi_0^2}\,(\Delta\psi + 0.65\,\psi_0)^2 & \text{for} \qquad 0 \leq \Delta\psi \leq 1.1575\,\psi_0 \\[2mm] G_{ep} - 25 & \text{for } 1.1575\,\psi_0 < \Delta\psi \leq 2.5017\,\psi_0 \\[2mm] G_{ep} - 25 + 20\log(2.5017\,\psi_0/\Delta\psi) & \text{for } 2.5017\,\psi_0 < \Delta\psi \leq 18 \end{cases}$$

2.4.2 Second model

There will be many difficulties in providing a relatively simple pattern that could be applied to a range of different satellite antennas without prejudice to any particular design or system. With this thought the template presented here by Model 2 does not intend to describe a single unique envelope, but a general shape. The template may be considered not only for a single antenna application, but as an overall representation of a family of templates describing antennas suitable for many different applications.

In the development of the model, an attempt has been made to take full account of the beam broadening that results from component beams scanned away from boresight of a shaped-beam antenna. A careful attempt has been made to encompass the effects of interference and mutual

coupling between adjacent beamlets surrounding the component beamlet under consideration. To avoid complexity in the formulation, two additional adjacent beamlets along the direction of scan of the component beamlets have been considered. The variation in beam broadening with F/D ratio has also been taken into account, the results have been tested over the range $0.70 \leq F/D \leq 1.3$ and modelled for an average scan plane between the elevation plane and azimuth plane. If the modelling had been done for the azimuth plane only, sharper characteristics than predicted might be expected. Other assumptions made in the model are as follows:

–   the boundary of the component beams corresponding to the individual array elements has been assumed to correspond to the ideal –3 dB contour of the shaped coverage beam;

–   the component beamlet radius, ψ_b, is given by equation (6) and corresponds to an aperture edge taper of –4 dB;

–   the value of B which controls the main beam region, is directly modelled as a function of the scan angle of the component beam, the antenna diameter D and the F/D ratio of the antenna reflector.

The value of F/D used in this model is the ratio of focal length to the physical diameter of the reflector. The model is valid for reflector diameters up to 120 λ, beam scanning of up to 13 beam widths and has shown good correlation to some 34 pattern cuts taken from four different antennas.

Recognizing that at some future date it may be desirable to impose a tighter control on antenna performance, this model provides two simple improvement factors, K_1 and K_2, to modify the overall pattern generated at present.

General co-polar Model 2

The equations to the various regions and the corresponding off-axis gain values are described below. Those gain values are measured normal to the coverage area at each point and this technique is allied to the definition of coverage area described in Annex 2.

At present, the values of K_1 and K_2 should be taken as unity, $K_1 = K_2 = 1$.

The equations used in this model are normalized to a first side lobe (L_s) of –20 dB. Ultimately, the particular value of the first side-lobe level chosen for the given application would be substituted.

a)   The main lobe skirt region: $(0° \leq \Delta\psi < C\psi_b)$

In this region the gain function is given by:

$$G\,(\Delta\psi) \;=\; G_e \;-\; K_1 B \left[\left(1 + \frac{\Delta\psi}{\psi_b} \right)^2 - 1 \right] \qquad\qquad \text{dBi} \qquad\qquad (10)$$

where:

$\qquad G\,(\Delta\psi)$:   reference pattern gain (dBi)

$\qquad\qquad G_e$:   gain at the edge of coverage (dBi)

$\qquad\qquad \Delta\psi$:   angle (degrees) from the (convex) coverage contour in a direction normal to the sides of the contour

$\qquad\qquad \psi_b = 32\,\lambda/D$ is the beamlet radius (degrees) (corresponding to $L_s = -20$ dB in equation (6))

$\qquad\qquad B = B_0 \;-\; (S \;-\; 1.25)\,\Delta B \qquad\qquad$ for $S \;\geq\; 1.25$ and

$$B = B_0 \qquad\qquad\qquad \text{for } S < 1.25$$

$$B_0 = 2.05 + 0.5\,(F/D - 1) + 0.0025\,D/\lambda$$

$$\Delta B = 1.65\,(D/\lambda)^{-0.55}.$$

Equations for both the elevation and azimuth planes are given here in order to maintain generality.

azimuth plane: $\quad B_0 = 2.15 + T$

elevation plane: $\quad B_0 = 1.95 + T$

$$\text{where } T = 0.5\,(F/D - 1) + 0.0025\,D/\lambda$$

azimuth plane: $\quad \Delta B = 1.3\,(D/\lambda)^{-0.55}$

elevation plane: $\quad \Delta B = 2.0\,(D/\lambda)^{-0.55}$

D: physical antenna diameter (m)

λ: wavelength (m)

S: angular displacement A between the antenna boresight and the point of the edge-of-coverage, in half-power beamwidths of the component beam, as shown in Fig. 4, i.e. $S_1 = A_1 / 2\psi_b$ and $S_2 = A_2 / 2\psi_b$

$$C = \sqrt{1 + \frac{(20\,K_2 - 3)}{K_1\,B}} - 1$$

and corresponds to the limit where $G(\Delta\psi)$ corresponds to a $-20\,K_2$ (dB) level with respect to equivalent peak gain G_{ep}, i.e. $G(\Delta\psi) = G_e + 3 - 20\,K_2$.

b) **Near side-lobe region:** $C\psi_b \le \Delta\psi < (C + 0.5)\,\psi_b$

This region has been kept deliberately very narrow for the following reasons. High first lobes of the order of -20 dB occur only in some planes and are followed by monotonically decreasing side lobes. In regions where beam broadening occurs, the first side lobe merges with the main lobe which has already been modelled by B for the beam skirt. Hence it is necessary to keep this region very narrow in order not to over-estimate the level of radiation. (For class B antennas this region has been slightly broadened and the gain function modified.) The gain function in this region is constant and is given by:

$$G(\Delta\psi) = G_e + 3 - 20\,K_2 \tag{11}$$

c) **Intermediate side-lobe region:** $(C + 0.5)\,\psi_b \le \Delta\psi < (C + 4.5)\,\psi_b$

This region is characterized by monotonically decreasing side lobes. Typically, the envelope decreases by about 10 dB over a width of $4\,\psi_b$. Hence this region is given by:

$$G(\Delta\psi) = G_e + 3 - 20\,K_2 + 2.5\left[(C + 0.5) - \frac{\Delta\psi}{\psi_b}\right] \qquad \text{dBi} \tag{12}$$

The above expression decreases from $G_e + 3 - 20\,K_2$ at $(C + 0.5)\,\psi_b$ to $G_e + 3 - 10 - 20\,K_2$ at $(C + 4.5)\,\psi_b$.

d) **Wide-angle side-lobe region:** $(C + 4.5)\,\psi_b \le \Delta\psi < (C + 4.5)\,\psi_b\,D,$

$$\text{where } D = 10^{[(G_e - 27)\,/\,20]}$$

This corresponds to the region which is dominated by the edge diffraction from the reflector and it decreases by about 6 dB per octave. This region is then described by:

$$G(\Delta\psi) = G_e + 3 - 10 - 20\,K_2 + 20\log\left[\frac{(C + 4.5)\,\psi_b}{\Delta\psi}\right] \qquad \text{dBi} \qquad (13)$$

In this region $G(\Delta\psi)$ decreases from $G_e + 3 - 10 - 20\,K_2$ at $(C + 4.5)\,\psi_b$ to $G_e + 3 - 16 - 20\,K_2$ at $2\,(C + 4.5)\,\psi_b$. The upper limit corresponds to where $G(\Delta\psi) = 3$ dBi.

FIGURE 4

A schematic of a coverage zone
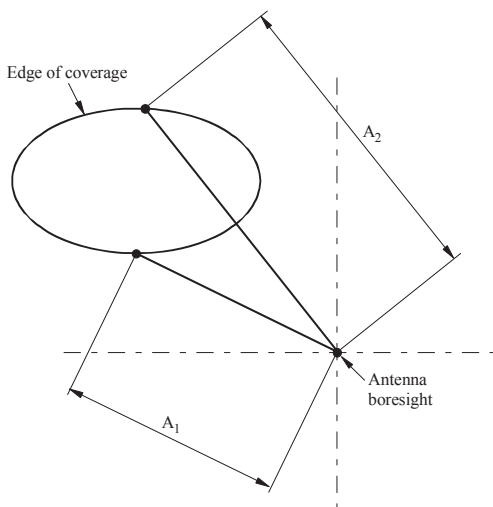
a) Boresight outside the coverage zone
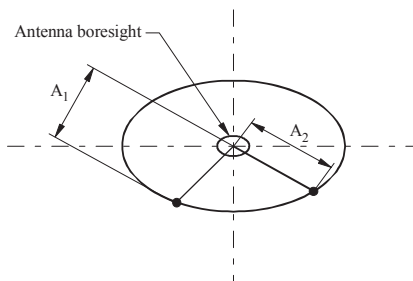
b) Boresight inside the coverage zone

A_1, A_2: angular deviation (degrees) of the two points on the edge of
coverage from the antenna boresight

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e) **Far-out side-lobe region:** $(C + 4.5)\, \psi_b\, D \leq \Delta\psi \leq 90$,

$$\text{where } D = 10^{[(G_e - 27)/20]}$$

$$G(\Delta\psi) = 3 \qquad \text{dBi} \tag{14}$$

These regions are depicted in Fig. 5.

Different regions in the proposed model 2

L_s: first side-lobe level
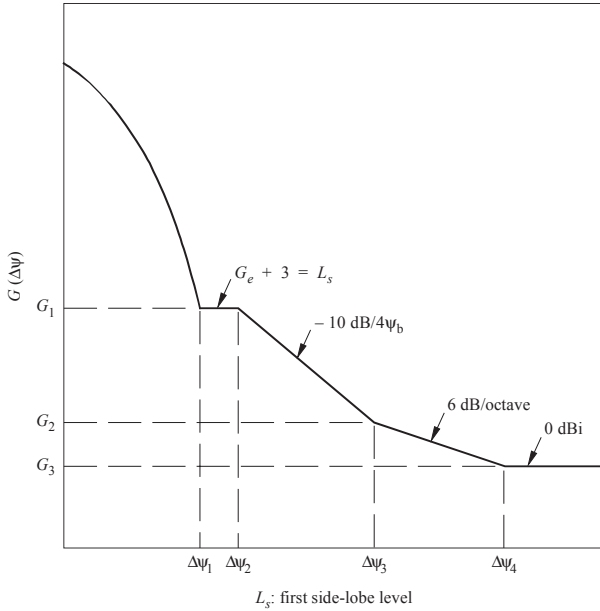
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The model can also be extended to the case of simple circular beams, elliptical beams and to shaped-reflector antennas. These cases are covered by adjustment to the value of B in the above general model:

– for simple circular and elliptical beams B is modified to a value, $B = 3.25$

– for shaped-reflectors the following parameters are modified to:

$$B = \begin{cases} 1.3 & \text{for } 0.5 \leq S \leq 0.75 \\ 1.56 - 0.34\,S & \text{for } 0.75 < S \leq 2.75 \\ 0.62 & \text{for } S > 2.75 \end{cases}$$

where:

S: (angular displacement from the centre of coverage) / $2\psi_b$

$$\psi_b = 40 \; \lambda/D$$

$$K_2 = 1.25$$

It should be noted that the values proposed for shaped-reflector antennas correspond to available information on simple antenna configurations. This new technology is rapidly developing and therefore these values should be considered tentative. Furthermore, additional study may be needed to verify the achievable side-lobe plateau levels.

Use of improvement factors K_1 and K_2

The improvement factors K_1 and K_2 are not intended to express any physical process in the model, but are simple constants to make adjustments to the overall shape of the antenna pattern without changing its substance.

Increasing the value of K_1 from its present value of 1, will lead to an increase in the sharpness of the main beam roll-off.

Parameter K_2 can be used to adjust the levels of the side-lobe plateau region by increasing K_2 from its value of unity.

2.5 Shaped beam pattern roll-off characteristics

The main beam roll-off characteristics of shaped beam antennas depend primarily on the antenna size. The angular distance $\Delta\psi_L$ from the edge of coverage area to the point where the gain has decreased by 22 dB (relative to edge gain) is a useful parameter for orbit planning purposes: it is related to the antenna size as:

$$\Delta\psi_L \; = \; C \, (\lambda/D)$$

For central beams with little or no shaping, the value of C is 64 for -25 dB peak side-lobe level. However, for scanned beams C is typically in the range 64 to 80 depending on the extent of main beam broadening.

2.6 Reference pattern for intermediate scan ratios

recommends 2.1 and 2.2 have two reference patterns for the satellite antennas in the FSS, one for small coverage areas with scan ratios less than 3.5 and the other for wide coverage areas with scan ratios greater than 5.0. However, the radiation patterns for intermediate scan ratios ($3.5 < \delta < 5.0$) of satellite antennas have not been defined.

In order to fully utilize the Recommendation the radiation pattern for antennas with intermediate scan ratios between 3.5 and 5.0 should be defined. One approach would be to redefine either of the two models to cover the other region. However, as an interim solution it is proposed to connect the two models with a reference pattern defined by parameters similar to those used in *recommends* 2.1 and 2.2.

Based on this approach a new reference pattern, which is applicable only to Class A antennas, has been developed which satisfies the existing patterns for the small coverage and the wide coverage areas at $\delta = 3.5$ and $\delta = 5.0$ respectively. It is defined as a function of the beam-broadening factor Q_i

which is the ratio of upper limits of the main beam fall-off regions of the shaped beam ($\delta > 1/2$) and the pencil beam ($\delta = 1/2$). For intermediate scan ratios in the range $3.5 < \delta < 5.0$, the value of Q_i is interpolated as:

$$Q_i = Q + \left(\frac{C}{1.7808} - Q \right) \left(\frac{\delta - 3.5}{1.5} \right)$$

where:

$$Q = 10^{\left(\frac{0.000075 \, (\delta - 1/2)^2}{[(F/D_p)^2 + 0.02]^2} \right)}$$

$$C = \sqrt{1 + \frac{22}{B}} - 1$$

$$B = 2.05 + 0.5 \, (F/D - 1) + 0.0025 \, D/\lambda - (\delta - 1.25) \, 1.65 \, (D/\lambda)^{-0.55}$$

The reference pattern for intermediate scan ratios ($3.5 < \delta < 5.0$) is defined as:

$$G_{dBi} \, (\Delta\psi) = \begin{cases} G_{ep} + 0.256 - 13.065 \left(\dfrac{\Delta\psi}{Q_i \, \psi_0} + 0.5 \right)^2 & \text{for} \quad 0 \leq \dfrac{\Delta\psi}{\psi_0} \leq 0.8904 \, Q_i \\[3mm] G_{ep} - 25 & \text{for} \ 0.8904 \, Q_i < \dfrac{\Delta\psi}{\psi_0} \leq 1.9244 \, Q_i \\[3mm] G_{ep} - 25 + 20 \log \left(\dfrac{1.9244 \, Q_i}{\Delta\psi} \right) & \text{for} \ 1.9244 \, Q_i < \dfrac{\Delta\psi}{\psi_0} \leq \dfrac{18}{\psi_0} \end{cases}$$

The variables in the above equations have been defined in *recommends* 2.1 and 2.2.

Figure 6 shows an example of the new reference pattern for $\delta = 4.25$ and for two different values of D/λ.

FIGURE 6

**Proposed reference patterns for intermediate scan ratios
(3.5 < δ < 5.0)**
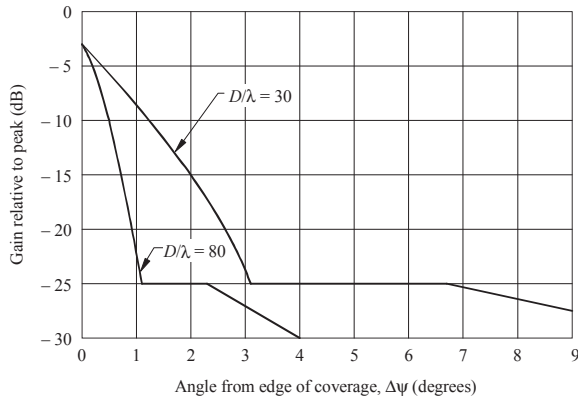
D/λ : parameter of the curves
$\delta = 1.25$
$F/D = 1, \ F/D_p = 0.35$

0672-06

Further study is needed to validate this model for the intermediate scan ratio region.

ANNEX 2

1 Defining coverage area contours and gain contours about the coverage area

1.1 Defining coverage area contours

A coverage area can be defined by a series of geographic points as seen from the satellite. The number of points needed to reasonably define the coverage area is a function of the complexity of the area. These points can be displaced to account for antenna pointing tolerances and variations due to service arc considerations. A polygon is formed by connecting the adjacent points. A coverage area contour is constructed about this polygon by observing two criteria:

– the radius of the curvature of the coverage area contour should be $\geq \psi_b$;

– the separation between straight segments of the coverage area contour should be $> 2\psi_b$ (see Fig. 7).

If the coverage polygon can be included in a circle of radius ψ_b, this circle is the coverage area contour. The centre of this circle is the centre of a minimum radius circle which will just encompass the coverage area contour. If the coverage polygon cannot be included in a circle of radius ψ_b, then proceed as follows:

Step 1: For all interior coverage polygon angles $< 180°$, construct a circle of radius ψ_b with its centre at a distance (ψ_b) on the internal bisector of the angle. If all angles are less than $180°$ (no concavities) Steps 2 and 4 which follow are eliminated.

Step 2: a) For all interior angles $> 180°$, construct a circle of radius ψ_b which is tangent to the lines connected to the coverage point whose centre is on the exterior bisector of the angle.

    b) If this circle is not wholly outside the coverage polygon, then construct a circle of radius ψ_b which is tangent to the coverage polygon at its two nearest points and wholly outside the coverage polygon.

Step 3: Construct straight line segments which are tangent to the portions of the circles of Steps 1 and 2 which are closest to, but outside the coverage polygon.

Step 4: If the interior distance between any two straight line segments from Step 3 is less than $2\psi_b$, the controlling points on the coverage polygon should be adjusted such that reapplying Steps 1 through 3 results in an interior distance between the two straight line segments equal to $2\psi_b$.

An example of this construction technique is shown in Fig. 7.

FIGURE 7

Construction of a coverage area contour

Step 1

Step 2a)

ψ_b

Step 2a) fails

Step 2b)

Coverage polygon

Coverage area contour
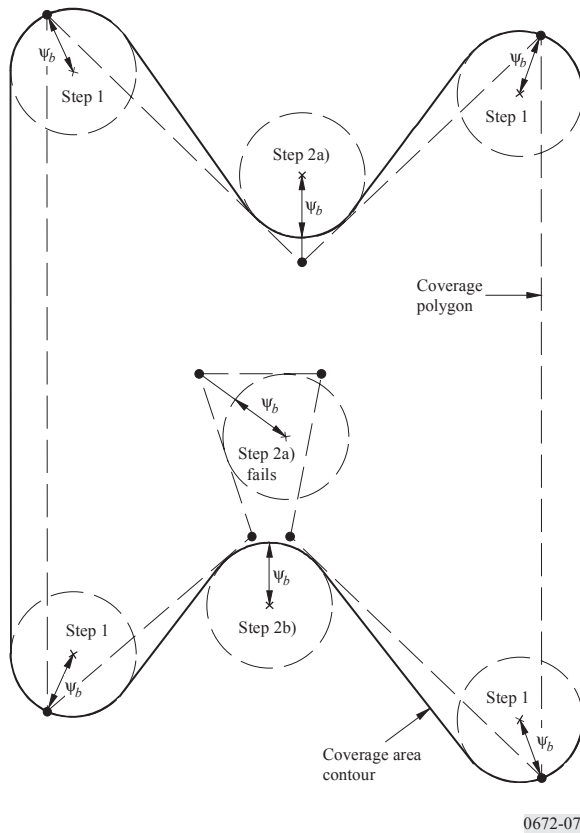
0672-07

1.2 Gain contours about the coverage area contours

As also noted in Annex 1, difficulties arise where the coverage area contour exhibits concavities. Using a $\Delta\psi$ measured normal to the coverage area contour will result in intersections of the normals and could result in intersections with the coverage area contour.

In order to circumvent this problem, as well as others, a two step process is proposed. If there are no concavities in the coverage contours, the following Step 2 is eliminated.

Step 1: For each $\Delta\psi$, construct a contour such that the angular distance between this contour and the coverage area contour is never less than $\Delta\psi$.

This can be done by constructing arcs of $\Delta\psi$ dimension from points on the coverage area contour. The outer envelope of these arcs is the resultant gain contour.

Where the coverage area contour is straight or convex, this condition is satisfied by measuring normal to the coverage area contour. No intersections of normals will occur for this case.

Using the process described in Step 1 circumvents these construction problems in areas of concavity. However, from a realistic standpoint some problem areas remain. As noted in Annex 1, side-lobe control in regions of concavity can become more difficult as the degree of concavity increases, the pattern cross-section tends to broaden and using the Step 1 process, discontinuities in the slope of the gain contour can exist.

It would appear reasonable to postulate that gain contours should have radii of curvature which are never less than ($\psi_b + \Delta\psi$) as viewed from inside and outside the gain contour. This condition is satisfied by the Step 1 process where the coverage area contour is straight or convex, but not in areas of concavity in the coverage area contour. The focal points for radii of curvature where the coverage area contour is straight or convex are within the gain contour. In areas of concavity, the use of Step 1 can result in radii of curvature as viewed from outside the gain contour which are less than ($\psi_b + \Delta\psi$).

Figure 8 shows an example of the Step 1 process in an area of concavity. Semi-circular segments are used for the coverage area contour for construction convenience. Note the slope discontinuity.

To account for the problems enumerated above and to eliminate any slope discontinuity, a Step 2 is proposed where the concavities exist.

FIGURE 8

**Gain contours from Step 1 in a concave coverage
area contour**
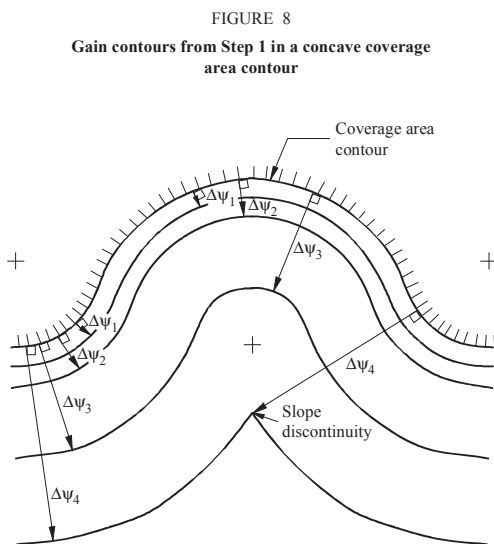
0672-08

Step 2: In areas of the gain contour determined by Step 1 where the radius of curvature as viewed from outside this contour is less than ($\psi_b + \Delta\psi$) this portion of the gain contour should be replaced by a contour having a radius equal to ($\psi_b + \Delta\psi$).

Figure 9 shows an example of the Step 2 process applied to concavity of Fig. 8. For purposes of illustration, values of the relative gain contours are shown, assuming ψ_b as shown and a value of $B = 3$ dB.

This method of construction has no ambiguities and results in contours in areas of concavities which might reasonably be expected. However, difficulties occur in generating software to implement the method, and furthermore it is not entirely appropriate for small coverage areas. Further work will continue to refine the method.

To find the gain values at specific points without developing contours the following process is used.

Gain values at points which are not near an area of concavity can be found by determining the angle $\Delta\psi$ measured normal to the coverage area contour and computing the gain from the appropriate equation: (10), (11), (12), (13) or (14). The gain at a point in concavity can be determined as follows.

First a simple test is applied. Draw a straight line across the coverage concavity so that it touches the coverage edge at two points without crossing it anywhere. Draw normals to the coverage contour at the tangential points. If the point under consideration lies outside the coverage area between the two normals, the antenna discrimination at that point may be affected by the coverage concavity. It is then necessary to proceed as follows:

Determine the smallest angle $\Delta\psi$ between the point under consideration and the coverage area contour. Construct a circle with radius ($\psi_b + \Delta\psi$), whose circumference contains the point, in such a way that its angular distance from any point on the coverage area contour is maximized when the circle lies entirely outside the coverage area; call this maximum angular distance $\Delta\psi'$. The value of $\Delta\psi'$ may be any angle between 0 and $\Delta\psi$; it cannot be greater than but may be equal to $\Delta\psi$. The antenna discrimination for the point under consideration is then obtained from equations (10), (11), (12), (13) or (14) as appropriate using $\Delta\psi'$ instead of $\Delta\psi$.

Two computer programs for generating the coverage area contours based on the above method have been developed and are available at the Radiocommunication Bureau.

FIGURE 9

**Construction of gain contours in a concave coverage area
contour – Step 1 plus Step 2**

Coverage area contour

$$G(\Delta\psi) = -3\left[\left(1 + \frac{\Delta\psi}{\psi_b}\right)^2 - 1\right] \text{ dB}$$

$r = \psi_b + \Delta\psi$

$r_0 = 1.9\,\psi_b$

r_0: radius of curvature of coverage contour concavity

r: radius of curvature
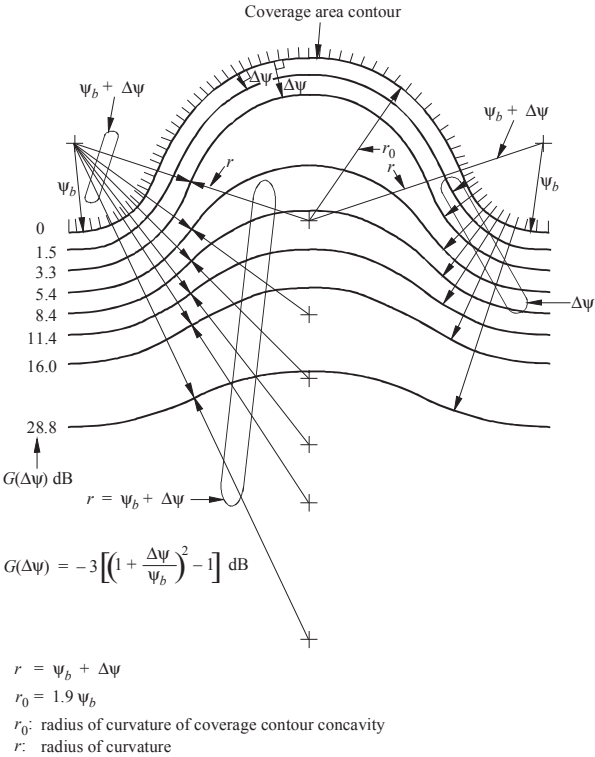
0672-09

RECOMMENDATION ITU-R M.690-1*

TECHNICAL CHARACTERISTICS OF EMERGENCY POSITION-INDICATING RADIO BEACONS (EPIRBs) OPERATING ON THE CARRIER FREQUENCIES OF 121.5 MHz AND 243 MHz

(Question ITU-R 31/8)

(1990-1995)

Summary

This Recommendation contains technical characteristics to which emergency position-indicating radio beacons (EPIRBs) intended to operate on the carrier frequency of 121.5 MHz and 243 MHz should conform.

Additional characteristics for EPIRBs intended for carriage on aircraft are specified in relevant annexes to the Convention on International Civil Aviation.

The ITU Radiocommunication Assembly,

considering

a)   that the Radio Regulations define the purpose of emergency position-indicating radio beacon (EPIRB) signals;

b)   that administrations authorizing the use of EPIRBs operating on carrier frequencies of 121.5 MHz and 243 MHz should ensure that such EPIRBs comply with relevant ITU-R Recommendations and the standards and recommended practices of ICAO,

recommends

1   that the technical characteristics of EPIRBs operating on the carrier frequencies of 121.5 MHz and 243 MHz should be in accordance with Annex 1.

ANNEX 1

Technical characteristics of emergency position-indicating radio beacons (EPIRBs) operating on the carrier frequencies of 121.5 MHz and 243 MHz

EPIRBs operating on the carrier frequencies of 121.5 MHz and 243 MHz should fulfil the following conditions (see Note 1):

a)   emission in normal antenna conditions and positions should be vertically polarized and be essentially omnidirectional in the horizontal plane;

b)   carrier frequencies should be amplitude-modulated (minimum duty cycle of 33%), with a minimum depth of modulation of 0.85;

c)   the emission should consist of a characteristic audio-frequency signal obtained by amplitude modulation of the carrier frequencies with a downward audio-frequency sweep within a range of not less than 700 between 1 600 Hz and 300 Hz and with a sweep repetition rate of two to four times per second;

_____

*   This Recommendation should be brought to the attention of the International Civil Aviation Organization (ICAO) and the COSPAS-SARSAT Secretariat.

d)   the emission should include a clearly defined carrier frequency distinct from the modulation sideband components; in particular, at least 30% of the power should be contained at all times within:

± 30 Hz of the carrier frequency on 121.5 MHz;

± 60 Hz of the carrier frequency on 243 MHz;

e)   the class of emission should be A3X; however, any type of modulation which satisfies the requirements laid down in b), c) and d) above may be used, provided it does not impair the precise locating of the radio beacon.

NOTE 1 – Additional characteristics for EPIRBs aboard aircraft are specified in the relevant annexes to the Convention on International Civil Aviation.

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RECOMMENDATION ITU-R P.838-3

Specific attenuation model for rain for use in prediction methods

(Question ITU-R 201/3)

(1992-1999-2003-2005)

The ITU Radiocommunication Assembly,

considering

a) that there is a need to calculate the attenuation due to rain from a knowledge of rain rates,

recommends

1 that the following procedure be used.

The specific attenuation γ_R (dB/km) is obtained from the rain rate R (mm/h) using the power-law relationship:

$$\gamma_R = kR^{\alpha} \tag{1}$$

Values for the coefficients k and α are determined as functions of frequency, f (GHz), in the range from 1 to 1 000 GHz, from the following equations, which have been developed from curve-fitting to power-law coefficients derived from scattering calculations:

$$\log_{10} k = \sum_{j=1}^{4} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_k \log_{10} f + c_k \tag{2}$$

$$\alpha = \sum_{j=1}^{5} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_\alpha \log_{10} f + c_\alpha \tag{3}$$

where:

f: frequency (GHz)

k: either k_H or k_V

α: either α_H or α_V.

Values for the constants for the coefficient k_H for horizontal polarization are given in Table 1 and for the coefficient k_V for vertical polarization in Table 2. Table 3 gives the values for the constants for the coefficient α_H for horizontal polarization, and Table 4 gives the values for the constants for the coefficient α_V for vertical polarization.

TABLE 1

Coefficients for k_H

j	a_j	b_j	c_j	m_k	c_k
1	−5.33980	−0.10008	1.13098		
2	−0.35351	1.26970	0.45400	−0.18961	0.71147
3	−0.23789	0.86036	0.15354		
4	−0.94158	0.64552	0.16817		

TABLE 2

Coefficients for k_V

j	a_j	b_j	c_j	m_k	c_k
1	−3.80595	0.56934	0.81061		
2	−3.44965	−0.22911	0.51059	−0.16398	0.63297
3	−0.39902	0.73042	0.11899		
4	0.50167	1.07319	0.27195		

TABLE 3

Coefficients for α_H

j	a_j	b_j	c_j	m_α	c_α
1	−0.14318	1.82442	−0.55187		
2	0.29591	0.77564	0.19822		
3	0.32177	0.63773	0.13164	0.67849	−1.95537
4	−5.37610	−0.96230	1.47828		
5	16.1721	−3.29980	3.43990		

TABLE 4

Coefficients for α_V

j	a_j	b_j	c_j	m_α	c_α
1	−0.07771	2.33840	−0.76284		
2	0.56727	0.95545	0.54039		
3	−0.20238	1.14520	0.26809	−0.053739	0.83433
4	−48.2991	0.791669	0.116226		
5	48.5833	0.791459	0.116479		

For linear and circular polarization, and for all path geometries, the coefficients in equation (1) can be calculated from the values given by equations (2) and (3) using the following equations:

$$k = [k_H + k_V + (k_H - k_V)\cos^2 \theta \cos 2\tau]/2 \tag{4}$$

$$\alpha = [k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2 \theta \cos 2\tau]/2k \tag{5}$$

where θ is the path elevation angle and τ is the polarization tilt angle relative to the horizontal ($\tau = 45°$ for circular polarization).

For quick reference, the coefficients k and α are shown graphically in Figs. 1 to 4, and Table 5 lists numerical values for the coefficients at given frequencies.

FIGURE 1

k coefficient for horizontal polarization

Frequency (GHz)

0838-01

FIGURE 2

α coefficient for horizontal polarization

0838-02
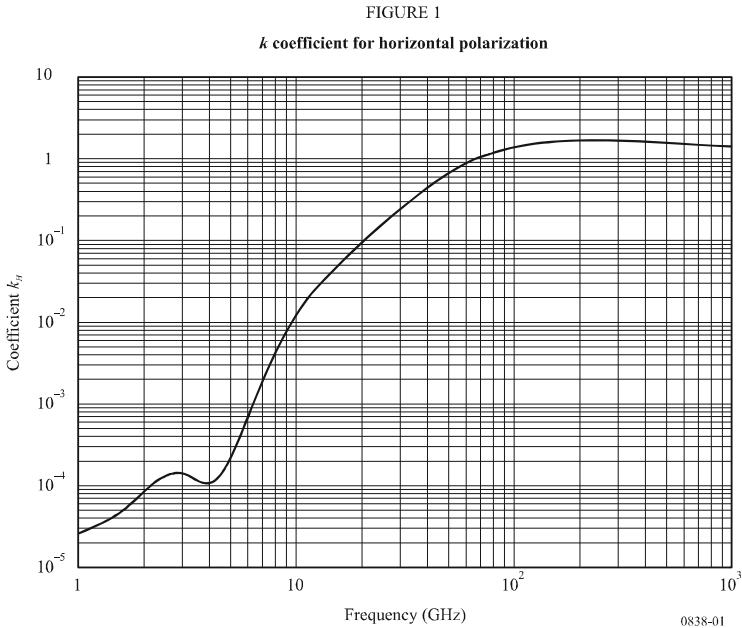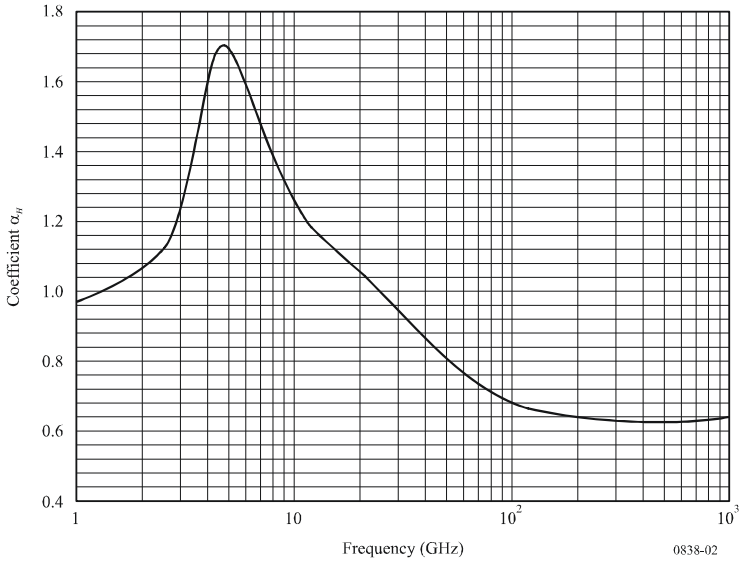
FIGURE 3

k coefficient for vertical polarization

0838-03

FIGURE 4

α coefficient for vertical polarization

0838-04
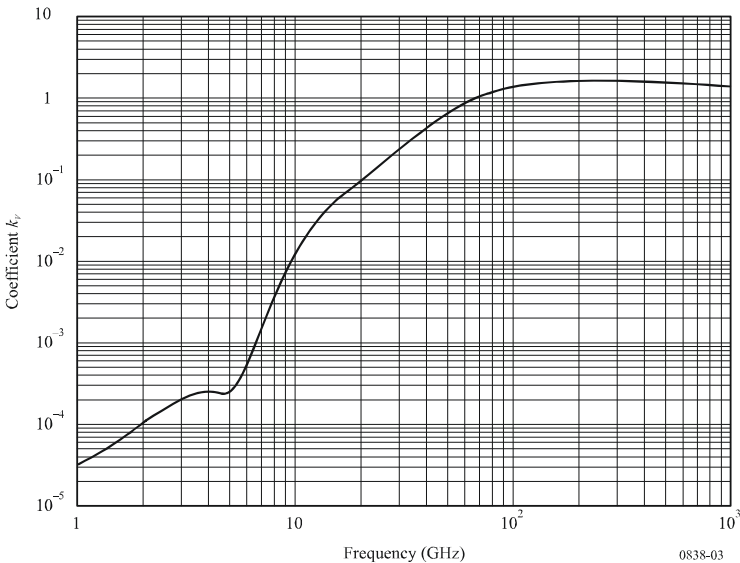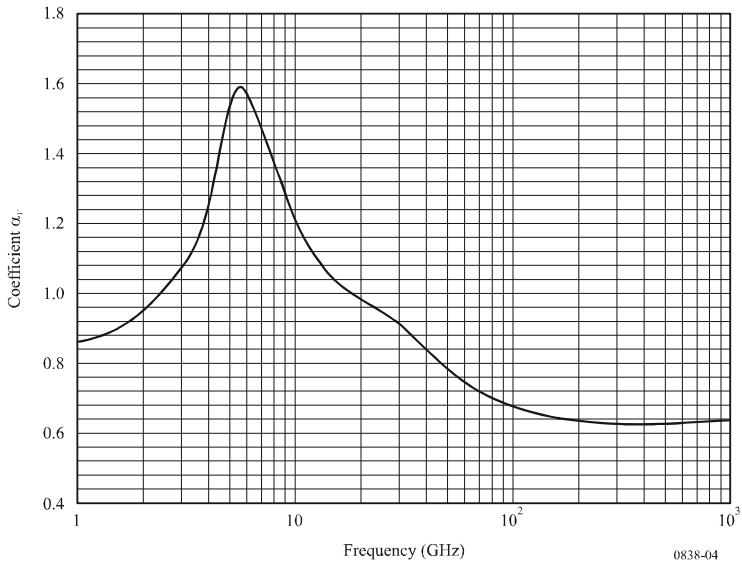
TABLE 5

**Frequency-dependent coefficients for estimating specific rain attenuation
using equations (4), (5) and (1)**

Frequency (GHz)	k_H	α_H	k_V	α_V
1	0.0000259	0.9691	0.0000308	0.8592
1.5	0.0000443	1.0185	0.0000574	0.8957
2	0.0000847	1.0664	0.0000998	0.9490
2.5	0.0001321	1.1209	0.0001464	1.0085
3	0.0001390	1.2322	0.0001942	1.0688
3.5	0.0001155	1.4189	0.0002346	1.1387
4	0.0001071	1.6009	0.0002461	1.2476
4.5	0.0001340	1.6948	0.0002347	1.3987
5	0.0002162	1.6969	0.0002428	1.5317
5.5	0.0003909	1.6499	0.0003115	1.5882
6	0.0007056	1.5900	0.0004878	1.5728
7	0.001915	1.4810	0.001425	1.4745
8	0.004115	1.3905	0.003450	1.3797
9	0.007535	1.3155	0.006691	1.2895
10	0.01217	1.2571	0.01129	1.2156

TABLE 5 (*continued*)

Frequency (GHz)	k_H	α_H	k_V	α_V
11	0.01772	1.2140	0.01731	1.1617
12	0.02386	1.1825	0.02455	1.1216
13	0.03041	1.1586	0.03266	1.0901
14	0.03738	1.1396	0.04126	1.0646
15	0.04481	1.1233	0.05008	1.0440
16	0.05282	1.1086	0.05899	1.0273
17	0.06146	1.0949	0.06797	1.0137
18	0.07078	1.0818	0.07708	1.0025
19	0.08084	1.0691	0.08642	0.9930
20	0.09164	1.0568	0.09611	0.9847
21	0.1032	1.0447	0.1063	0.9771
22	0.1155	1.0329	0.1170	0.9700
23	0.1286	1.0214	0.1284	0.9630
24	0.1425	1.0101	0.1404	0.9561
25	0.1571	0.9991	0.1533	0.9491
26	0.1724	0.9884	0.1669	0.9421
27	0.1884	0.9780	0.1813	0.9349
28	0.2051	0.9679	0.1964	0.9277
29	0.2224	0.9580	0.2124	0.9203
30	0.2403	0.9485	0.2291	0.9129
31	0.2588	0.9392	0.2465	0.9055
32	0.2778	0.9302	0.2646	0.8981
33	0.2972	0.9214	0.2833	0.8907
34	0.3171	0.9129	0.3026	0.8834
35	0.3374	0.9047	0.3224	0.8761
36	0.3580	0.8967	0.3427	0.8690
37	0.3789	0.8890	0.3633	0.8621
38	0.4001	0.8816	0.3844	0.8552
39	0.4215	0.8743	0.4058	0.8486
40	0.4431	0.8673	0.4274	0.8421
41	0.4647	0.8605	0.4492	0.8357
42	0.4865	0.8539	0.4712	0.8296
43	0.5084	0.8476	0.4932	0.8236
44	0.5302	0.8414	0.5153	0.8179
45	0.5521	0.8355	0.5375	0.8123
46	0.5738	0.8297	0.5596	0.8069
47	0.5956	0.8241	0.5817	0.8017
48	0.6172	0.8187	0.6037	0.7967

TABLE 5 (*continued*)

Frequency (GHz)	k_H	α_H	k_V	α_V
49	0.6386	0.8134	0.6255	0.7918
50	0.6600	0.8084	0.6472	0.7871
51	0.6811	0.8034	0.6687	0.7826
52	0.7020	0.7987	0.6901	0.7783
53	0.7228	0.7941	0.7112	0.7741
54	0.7433	0.7896	0.7321	0.7700
55	0.7635	0.7853	0.7527	0.7661
56	0.7835	0.7811	0.7730	0.7623
57	0.8032	0.7771	0.7931	0.7587
58	0.8226	0.7731	0.8129	0.7552
59	0.8418	0.7693	0.8324	0.7518
60	0.8606	0.7656	0.8515	0.7486
61	0.8791	0.7621	0.8704	0.7454
62	0.8974	0.7586	0.8889	0.7424
63	0.9153	0.7552	0.9071	0.7395
64	0.9328	0.7520	0.9250	0.7366
65	0.9501	0.7488	0.9425	0.7339
66	0.9670	0.7458	0.9598	0.7313
67	0.9836	0.7428	0.9767	0.7287
68	0.9999	0.7400	0.9932	0.7262
69	1.0159	0.7372	1.0094	0.7238
70	1.0315	0.7345	1.0253	0.7215
71	1.0468	0.7318	1.0409	0.7193
72	1.0618	0.7293	1.0561	0.7171
73	1.0764	0.7268	1.0711	0.7150
74	1.0908	0.7244	1.0857	0.7130
75	1.1048	0.7221	1.1000	0.7110
76	1.1185	0.7199	1.1139	0.7091
77	1.1320	0.7177	1.1276	0.7073
78	1.1451	0.7156	1.1410	0.7055
79	1.1579	0.7135	1.1541	0.7038
80	1.1704	0.7115	1.1668	0.7021
81	1.1827	0.7096	1.1793	0.7004
82	1.1946	0.7077	1.1915	0.6988
83	1.2063	0.7058	1.2034	0.6973
84	1.2177	0.7040	1.2151	0.6958
85	1.2289	0.7023	1.2265	0.6943
86	1.2398	0.7006	1.2376	0.6929

TABLE 5 (*end*)

Frequency (GHz)	k_H	α_H	k_V	α_V
87	1.2504	0.6990	1.2484	0.6915
88	1.2607	0.6974	1.2590	0.6902
89	1.2708	0.6959	1.2694	0.6889
90	1.2807	0.6944	1.2795	0.6876
91	1.2903	0.6929	1.2893	0.6864
92	1.2997	0.6915	1.2989	0.6852
93	1.3089	0.6901	1.3083	0.6840
94	1.3179	0.6888	1.3175	0.6828
95	1.3266	0.6875	1.3265	0.6817
96	1.3351	0.6862	1.3352	0.6806
97	1.3434	0.6850	1.3437	0.6796
98	1.3515	0.6838	1.3520	0.6785
99	1.3594	0.6826	1.3601	0.6775
100	1.3671	0.6815	1.3680	0.6765
120	1.4866	0.6640	1.4911	0.6609
150	1.5823	0.6494	1.5896	0.6466
200	1.6378	0.6382	1.6443	0.6343
300	1.6286	0.6296	1.6286	0.6262
400	1.5860	0.6262	1.5820	0.6256
500	1.5418	0.6253	1.5366	0.6272
600	1.5013	0.6262	1.4967	0.6293
700	1.4654	0.6284	1.4622	0.6315
800	1.4335	0.6315	1.4321	0.6334
900	1.4050	0.6353	1.4056	0.6351
1 000	1.3795	0.6396	1.3822	0.6365

RECOMMENDATION ITU-R M.1084-4*, **

Interim solutions for improved efficiency in the use of the band 156-174 MHz by stations in the maritime mobile service

(Question ITU-R 96/8)

(1994-1995-1997-1998-2001)

The ITU Radiocommunication Assembly,

considering

a) that Recommendation No. 318 (Mob-87) of the World Administrative Radio Conference for the mobile services (Geneva, 1987) (WARC Mob-87) seeks the most appropriate means to improve efficiency in the use of the RR Appendix 18 VHF frequency spectrum for maritime mobile communications;

b) that a common international system is essential for maritime communications to ensure the safety of life at sea;

c) that the greatest long-term benefits in spectrum efficiency will be gained by using the latest digital or narrow-band transmission techniques;

d) that the introduction of new technology or replanning of frequency bands will be a significant exercise involving a long period of transition;

e) that any new equipment needs to be compatible or be able to co-exist with existing equipment conforming to Recommendation ITU-R M.489 already in widespread use;

f) that the introduction of new technology should not interrupt the continuous availability of RR Appendix 18 maritime mobile distress and safety communications in the VHF bands for all users;

g) that congestion in the VHF maritime mobile band has become a serious problem in some parts of the world and is continuing to grow;

h) that because of this need administrations may decide to take measures to solve their local congestion problem;

j) that RR Appendix 18 makes provision for administrations having an urgent need to reduce local congestion to apply 12.5 kHz channel interleaving on a non-interference basis to 25 kHz channels;

k) that the implementation of 12.5 kHz channels would require a standard channel numbering plan;

l) that administrations are planning to implement single frequency operation of two frequency channels as a means of alleviating current congestion;

---

* This Recommendation should be brought to the attention of the International Maritime Organization (IMO).

** *Note by the Secretariat:* Only Tables 1 and 3 of Annex 4 to this Recommendation are considered incorporated by reference.

m)   that these interim solutions are used by the standard universal automatic identification system developed in accordance with Recommendation ITU-R M.1371 to meet IMO vessel carriage requirements,

recommends

1   that administrations having an urgent need to resolve congestion, should implement single frequency operation of two frequency channels as an interim expedient measure;

2   that, for administrations having an urgent need to resolve congestion, changing to 12.5 kHz analogue frequency modulation (FM) as an interim expedient would be a simple approach to improving spectrum utilization but could have an impact on current operations, especially where it involved international shipping using 25 kHz channel spacing;

3   that administrations, when employing 12.5 kHz analogue FM channels as an interim measure, should avoid distress and safety channels and channels affecting the safety of international shipping;

4   that the interim arrangements referred to in *recommends* 2 and 3 should not prejudice the implementation of the longer term solution resulting from the ongoing studies which may result in the use of advanced technologies and channelling of bandwidth other than 12.5 kHz;

5   that the interim arrangements referred to in *recommends* 2 and 3 shall not prejudice the implementation of a single international system for distress and safety communications by the international community in the longer term;

6   that administrations intending to resolve current congestion problems through the use of narrow-band channels should consider Annex 2 as a guide to migration from 25 kHz channels to narrower bands;

7   that administrations intending to resolve current congestion problems through the use of narrow-band channels should use equipment conforming to the technical parameters given at Annex 1, whilst taking into account the provisions of RR Appendix 18;

8   that administrations implementing interleaved narrow-band channels at 12.5 kHz offset spacing on an interim basis should consider Annex 3 as an example of a possible implementation method (different example methods are available with other characteristics than those described in Annex 3);

9   that administrations implementing narrow-band channels at 12.5 kHz should consider Annex 4 for numbering the new channels;

10   that administrations implementing single frequency operation of two frequency channels should consider Annex 4, Section 3, for numbering the channels;

11   that administrations should, as far as possible, look to the implementation of the latest digital or narrow-band techniques to meet future operational requirements and achieve the efficient use of the band 156-174 MHz.

ANNEX 1

Technical characteristics for equipment designed to operate
in channels spaced by 12.5 kHz

Use of equipment implementing these parameters listed below (see Note 1) should only be in accordance with the provisions of RR Appendix 18:

–   the frequency tolerance for coast and ship station transmitters should not exceed 5 parts in 10^6;

–   the frequency deviation should not exceed ±2.5 kHz.

NOTE 1 – For information, other characteristics are based on European Telecommunications Standard (ETS) 300 086 published by the European Telecommunications Standards Institute (ETSI).

ANNEX 2

Migration to narrow-band channels in the maritime mobile service

1   Introduction

This Annex considers how in future the maritime-mobile service might migrate to narrow-band channels spaced at 5 kHz or 6.25 kHz apart, using linear or digital modulation. Consideration is given to migration from 25 kHz channel spacing as used at present, and from 12.5 kHz if the latter was to be implemented as an interim measure by some administrations.

2   Implications of migration to narrow-band channels

2.1   Migration

The most practicable and least disruptive method of migrating from 25 kHz or 12.5 kHz to 5 kHz or 6.25 kHz would be by interleaving the narrow-band channels with the wider ones and a similar technique can be used in all cases. However because the linear and digital modulation techniques using 5 kHz and/or 6.25 kHz are incompatible with current FM equipment, dual mode or additional equipment would be required during the change-over period.

2.2   Interleaving

2.2.1   Interleaving with 25 kHz channels

Figures 1 and 2 illustrate how 5 kHz and 6.25 kHz channels could be interleaved with the existing 25 kHz ones. During the change-over period, coast stations and ships would be required to equip with narrow-band equipment and move to the new narrow-band channels as they became available. The numbers of new narrow-band channels would be gradually increased during the transition period with the number of 25 kHz channels available correspondingly decreasing.

On a specified date all remaining 25 kHz channels would be withdrawn to be replaced by new ones.

The migration from 25 kHz channels is fairly straightforward but some realignment of channel or band edges is likely to be required.

FIGURE 1

Migration from 25 kHz to 5 kHz channelling
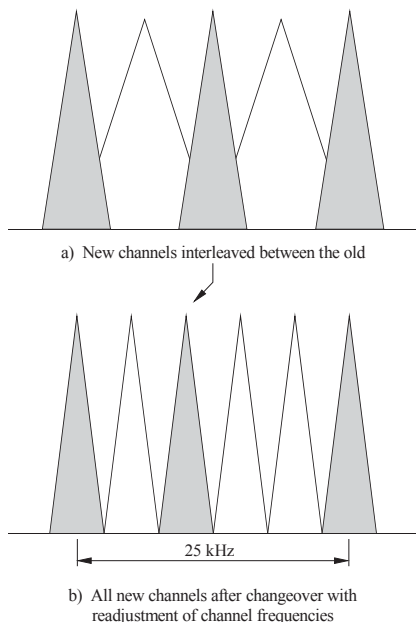
FIGURE 2

Migration from 25 kHz to 6.25 kHz channelling

a) New channels interleaved between the old

a) New channels interleaved between the old

25 kHz

25 kHz

b) All new channels after changeover with readjustment of channel frequencies

b) All new channels after changeover
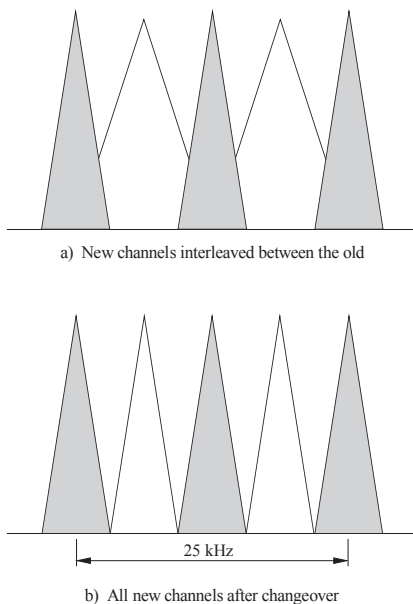
1084-01

2.2.2   Interleaving with 12.5 kHz channels

Figures 3 and 4 show that the principle for interleaving 5 kHz or 6.25 kHz channels with any interim 12.5 kHz channels is exactly the same as for 25 kHz. However, the final transition is made more complicated in the case of 5 kHz as the channel initially interleaved on the centre of the 25 kHz band would have to be moved by 2.5 kHz.

2.2.3   Interleaving with 25 kHz and 12.5 kHz channels

If some administrations were to move to 12.5 kHz channel spacing as an interim measure, and if the 12.5 kHz channels were interleaved with the 25 kHz channels, future migration to 5 kHz or 6.25 kHz channels would be significantly more complicated. As shown in Fig. 5, the new 5 kHz or 6.25 kHz channel would overlap one or other of the wider bandwidth channels.

FIGURE 3

Migration from 12.5 kHz to 5 kHz channelling
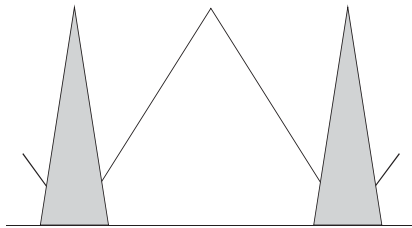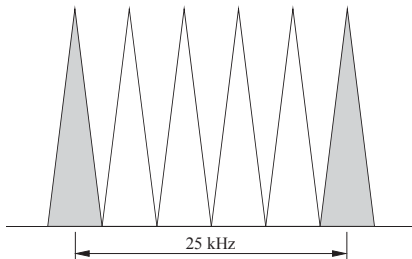
FIGURE 4

Migration from 12.5 kHz to 6.25 kHz channelling

a) New channels interleaved between the old

a) New channels interleaved between the old
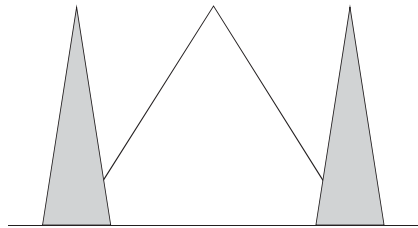
25 kHz

25 kHz

b) All new channels after changeover
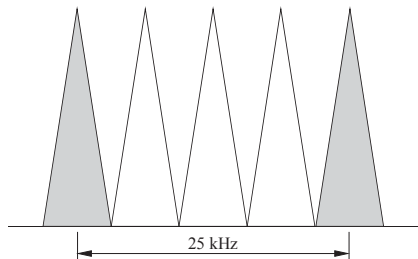
b) All new channels after changeover

1084-03

FIGURE 5

**Inserting a new channel, 5 or 6.25 kHz, on top of 12.5 kHz channels already interleaved
between 25 kHz channels, increases the overlap of transmissions.
Two alternative cases are shown**
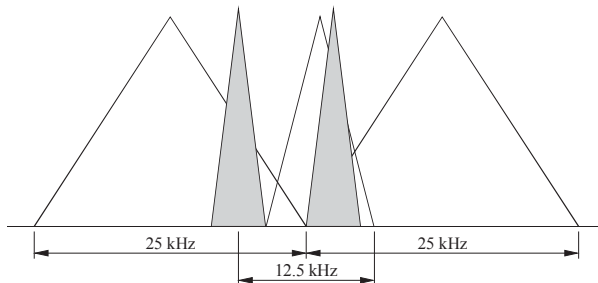
25 kHz

12.5 kHz

25 kHz

1084-05

3   Interference

The interleaving process has to be done so as to minimize mutual interference. Some measurements of the interference and co-channel performance between interleaved linear modulation and 12.5 kHz FM have been made. No similar published information has been identified for narrow-band digital speech. It is however reasonable to assume that interleaving 5 kHz or 6.25 kHz channels between 25 kHz channels will lead to less interference and better co-channel performance than between 12.5 kHz channels.

4   Conclusions

The migration path to either 5 kHz or 6.25 kHz channels would be similar. However, a direct transition from 25 kHz rather than via an interim step of 12.5 kHz would be simpler in that:

–   it would require less channel planning and realignment of centre frequencies;

–   it would avoid channel overlap if 12.5 kHz channels were interleaved, as an interim measure, with 25 kHz ones; and

–   the interference potential is likely to be less.

Clearly interleaving of channels will need to be carefully planned and the use of frequency planning tools will be important. Further field measurements and studies will be needed to provide the necessary information.

ANNEX 3

An example method for implementing interleaved narrow-band channels at 12.5 kHz offset spacing

This method could be used when 12.5 kHz operation is included along with digital selective-calling (DSC) operation (see Note 1) and 25 kHz in a single equipment.

NOTE 1 – DSC operation in this implementation is in full accordance with Recommendations ITU-R M.493, ITU-R M.541, ITU-R M.821 and ITU-R M.825.

1   Receiver performance

1.1   The sensitivity should be equal to or less than 0.3 µV for a 12 dB signal plus noise plus distortion to noise plus distortion (SINAD) ratio at the output of the receiver for a 1 kHz narrow band frequence modulation (NBFM) modulation tone at 2 kHz peak deviation.

1.2   Adjacent channel rejection should be at least 70 dB for a 12.5 kHz spaced adjacent channel.

1.3   The spurious response and out-of-band rejection ratio should be at least 75 dB.

1.4   The radio-frequency intermodulation rejection ratio should be at least 75 dB.

1.5   The power of any conducted spurious emission, measured at the antenna terminals, should not exceed 2.0 nW at any discrete frequency.

1.6   The effective radiated power (e.r.p.) of any cabinet radiated spurious emission on any frequency up to ±70 MHz removed from the carrier should not exceed 10 nW. More than 70 MHz removed from the carrier, the spurious emissions should not exceed 10 nW plus an additional −6 dB/octave in frequency up to 1 000 MHz.

1.7   For receivers with DSC and C4FM capability. C4FM (constant envelope four-level FM) digital modulation in this implementation is compatible with CQPSK (compatible quadrature phase-shift key) modulation for both transmission and reception.

1.7.1   For DSC operation on 25 kHz channels, the receiver must be capable of error-free reception of any DSC data packet at 0.3 µV.

1.7.2   For DSC operation on interleaved (12.5 kHz offset) channels, the receiver must be capable of error-free reception of a DSC data packet at 0.3 µV at a reduced maximum deviation of ±2.5 kHz.

1.7.3   For C4FM operation at 9 600 bit/s, the receiver must be capable of error-free reception of a data packet of 512 characters at 0.5 µV. Forward error correction (FEC) may be applied to accomplish the error-free reception.

2   Transmitter performance

2.1   The frequency tolerance for coast station transmitters should not exceed one part in 10^6 and that for ship station transmissions should not exceed five parts in 10^6.

2.2   Spurious emissions on discrete frequencies, when measured in a non-reactive load equal to the nominal output impedance of the transmitter, should be in accordance with the provisions of RR Appendix 3.

2.3   The carrier power for coast station transmitters should normally not exceed 50 W (e.r.p.).

2.4   The carrier power for ship stations transmitters should not exceed 25 W and means should be provided to readily reduce this to 1 W or less for use at short ranges.

2.5   The frequency deviation should not exceed ±2.5 kHz when transmitting on NBFM 12.5 kHz channels. The occupied bandwidth on these channels should not exceed 11 kHz. Deviation limiting circuits should be employed such that the maximum frequency deviation attainable should be independent of the input audio frequency. If a modulation switch is employed, ±5 kHz deviation should be allowed for use on the wideband frequency modulation (WBFM) 25 kHz channels.

2.6   The upper limit of the audio-frequency band should not exceed 3 kHz.

2.7   The cabinet radiated power should not exceed 25 µW.

2.8   Voice transmissions should be by means of standard maritime VHF FM with a 6 dB/octave pre-emphasis. This is necessary to ensure reliable, safe, interoperable communications on the high seas and in the waterways.

2.9   For transmitters with DSC and C4FM capability

2.9.1   Transmitters with DSC capability should comply with the requirements of Recommendations ITU-R M.493, ITU-R M.541, and IMO A.803 (19) as a minimum. Stations should have provision for monitoring the VHF channel used for DSC purposes to determine the presence of a signal and, except for distress and safety calls, provide facilities for automatically preventing the transmission of a DSC call until the channel is free.

2.9.2   DSC (1 200 bit/s) operation should be used at all times when operating on channel 70. Channel 70 should not be used as a working channel for any purposes. This channel should be kept as an international distress and calling channel. Passing of data for all other purposes such as data messaging, security monitoring, vessel tracking, and automated dependent surveillance (ADS) should be accomplished on another working channel.

2.9.3   General purpose data transmission should be performed on both wideband 25 kHz channels and narrow-band interleaved (12.5 kHz offset) channels and should utilize the DSC protocol to the fullest extent practicable. Enhancements to the DSC protocol should be developed as needed and coordinated in order to maintain regulatory control and thus ensure interoperability between equipments from various manufacturers.

2.9.4   DSC (1 200 bit/s) operation on narrow-band interleaved (12.5 kHz offset) channels should be at a reduced maximum deviation of ±2.5 kHz.

2.9.5   High speed (9 600 bit/s) data transmissions should be performed using C4FM modulation with baseband filter shaping.

2.9.5.1   C4FM modulation on 12.5 kHz offset frequency channels

The C4FM modulator consists of a Nyquist raised cosine filter, cascaded with a shaping filter, cascaded with a frequency modulator.

2.9.5.2   C4FM Nyquist filter

The dibits of information (i.e., 4 800 symbols/s) are filtered with a raised cosine filter which satisfies the Nyquist criterion minimizing inter-symbol interference. The group delay of the filter is flat over the passband for $|f| < 2 880$ Hz. The magnitude response of the filter is:

approximately 1	for	$|f| < 1 920$ Hz
$0.5 + 0.5 \cos (2\pi f / 1 920)$	for $1 920$ Hz $< |f| < 2 880$ Hz	
0	for	$|f| \geq 2 880$ Hz

2.9.5.3   C4FM shaping filter

The shaping filter has a flat group delay over the band-pass for $|f| < 2 880$ Hz. The magnitude response of the filter for $|f| < 2 880$ Hz is $(\pi f / 4 800)/\sin(\pi f / 4 800)$.

2.9.5.4   C4FM frequency modulator

The deviation is +1.8 kHz for dibit 01, +0.6 kHz for dibit 00, –0.6 kHz for dibit 10, and –1.8 kHz for dibit 11.

ANNEX 4

Assignment of channel numbers to interleaved channels and simplex operation of duplex channels in the VHF maritime band

1   For channel number assignments to interleaved narrow-band channels at 12.5 kHz offsets:

First 25 kHz Channel	Interleaved 12.5 kHz Channel	Second 25 kHz Channel	SHIP	SHIP & COAST	COAST
			CHANNEL NUMBER		
		60	156.025		160.625
	260		156.0375		160.6375
01			156.050		160.650
	201		156.0625		160.6625
		61	156.075		160.675
	261		156.0875		160.6875
02			156.100		160.700
	202		156.1125		160.7125
		62	156.125		160.725
	262		156.1375		160.7375
03			156.150		160.750
	203		156.1625		160.7625
		63	156.175		160.775
	263		156.1875		160.7875
04			156.200		160.800
	204		156.2125		160.8125
		64	156.225		160.825
	264		156.2375		160.8375
05			156.250		160.850
	205		156.2625		160.8625
		65	156.275		160.875
	265		156.2875		160.8875
06				156.300	
	206		156.3125		160.9125
		66	156.325		160.925
	266		156.3375		160.9375
07			156.350		160.950
	207		156.3625		160.9625
		67		156.375	
	267			156.3875	
08				156.400	
	208			156.4125	
		68		156.425	
	268			156.4375	

First 25 kHz Channel	CHANNEL NUMBER Interleaved 12.5 kHz Channel	Second 25 kHz Channel	SHIP	SHIP & COAST	COAST
09				156.450	
	209			156.4625	
		69		156.475	
	269			156.4875	
10				156.500	
	210			156.5125	DSC Guardband
		70		156.525	**DSC Calling, distress & safety**
	270			156.5375	DSC Guardband
11				156.550	
	211			156.5625	
		71		156.575	
	271			156.5875	
12				156.600	
	212			156.6125	
		72		156.625	
	272			156.6375	
13				156.650	
	213			156.6625	
		73		156.675	
	273			156.6875	
14				156.700	
	214			156.7125	
		74		156.725	
	274			156.7375	
15				156.750	
	215			156.7625	
		75		156.775	Guardband
	275			156.7875	Guardband
16				**156.800**	**Calling, distress & safety**
	216			156.8125	Guardband
		76		156.825	Guardband
	276			156.8375	
17				156.850	
	217			156.8625	
		77		156.875	
	277			156.8875	
18			156.900		161.500
	218		156.9125		161.5125
		78	156.925		161.525
	278		156.9375		161.5375
19			156.950		161.550
	219		156.9625		161.5625

First 25 kHz Channel	CHANNEL NUMBER Interleaved 12.5 kHz Channel	Second 25 kHz Channel	SHIP	SHIP & COAST	COAST
		79	156.975		161.575
	279		156.9875		161.5875
20			157.000		161.600
	220		157.0125		161.6125
		80	157.025		161.625
	280		157.0375		161.6375
21			157.050		161.650
	221		157.0625		161.6625
		81	157.075		161.675
	281		157.0875		161.6875
22			157.100		161.700
	222		157.1125		161.7125
		82	157.125		161.725
	282		157.1375		161.7375
23			157.150		161.750
	223		157.1625		161.7625
		83	157.175		161.775
	283		157.1875		161.7875
24			157.200		161.800
	224		157.2125		161.8125
		84	157.225		161.825
	284		157.2375		161.8375
25			157.250		161.850
	225		157.2625		161.8625
		85	157.275		161.875
	285		157.2875		161.8875
26			157.300		161.900
	226		157.3125		161.9125
		86	157.325		161.925
	286		157.3375		161.9375
27			157.350		161.950
	227		157.3625		161.9625
		87	157.375		161.975
	287		158.3875		161.9875
28			157.400		162.000
	228		157.4125		162.0125
		88	157.425		162.025

2   Extension of channel number assignments for migration to 6.25 kHz channel spacing from the current 25 kHz channel spacing with interleaved 12.5 kHz offset frequencies channels: (This channel numbering sequence is provided as an example.)

CHANNEL No. (6.25 kHz spacing)				SHIP	SHIP & COAST	COAST
			60	156.025		160.625
		160		156.03125		160.63125
	260			156.0375		160.6375
360				156.04375		160.64375
01				156.050		160.650
101				156.05625		160.65625
	201			156.0625		160.6625
		301		156.06875		160.66875
			61	156.075		160.675

3   For channel number assignments to simplex operation of duplex channels: (This channel numbering sequence is provided as an example.)

CHANNEL No.	SHIP	SHIP & COAST	COAST
For normal duplex operation:			
60	156.025	–	160.625
For simplex operation of ship station frequency:			
1 060 (see Note 1)	–	156.025	–
For simplex operation of coast station frequency:			
2 060 (see Note 1)	–	160.625	–

NOTE 1 – This method of numbering a duplex channel used for simplex operation is in accordance with Recommendation ITU-R M.493, Annex 1, Table 13.

4   For channel number assignments to narrow-band operation (12.5 kHz) on 25 kHz channels: (This channel numbering sequence is provided as an example.)

CHANNEL No.	SHIP	SHIP & COAST	COAST
For normal channel operation:			
60	156.025	–	160.625
For 12.5 kHz operation on 25 kHz channel:			
460	156.025	–	160.625

RECOMMENDATION ITU-R SM.1138-2

Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions

(1995-2007-2008)

Scope

This Recommendation serves as a basis for the determination of necessary bandwidths of emissions under amplitude, frequency and pulse modulation by various types of signals. Sample calculations and designation of emissions are also provided.

The ITU Radiocommunication Assembly,

considering

a)   that the assignment of frequencies requires the determination of the necessary bandwidth of emissions;

b)   that necessary bandwidth is a key data element of all automated spectrum-management systems,

recommends

1   that the formulae given in Annex 1 shall be used to calculate the necessary bandwidth when required by the Radio Regulations (RR).

Annex 1

Determination of necessary bandwidths, including examples for their calculation and associated examples for the designation of emissions

1   The necessary bandwidth is not the only characteristic of an emission to be considered in evaluating the interference that may be caused by that emission.

2   In the formulation of the table, the following terms have been employed:

B_n: necessary bandwidth (Hz)

B: modulation rate (Bd)

N: maximum possible number of black plus white elements to be transmitted per second, in facsimile

M: maximum modulation frequency (Hz)

C: sub-carrier frequency (Hz)

D: peak deviation, i.e. half the difference between the maximum and minimum values of the instantaneous frequency. The instantaneous frequency (Hz) is the time rate of change in phase (rad) divided by 2π

t: pulse duration (s) at half-amplitude

t_r: pulse rise time (s) between 10% and 90% amplitude

K: an overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion. In the case of orthogonal frequency division multiplexed multi-carrier signal, K is the number of active sub-carriers as defined by equation (52) in Recommendation ITU-R SM.328

N_c: number of baseband channels in radio systems employing multichannel multiplexing

f_p: continuity pilot sub-carrier frequency (Hz) (continuous signal utilized to verify performance of frequency-division multiplex systems)

N_s: frequency separation between two sub-carriers (kHz).

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
I. NO MODULATING SIGNAL			
Continuous wave emission	–	–	NONE
II. AMPLITUDE MODULATION			
1. Signal with quantized or digital information			
Continuous wave telegraphy, Morse code	$B_n = BK$ $K = 5$ for fading circuits $K = 3$ for non-fading circuits	25 words per minute $B = 20$, $K = 5$ Bandwidth: 100 Hz	100HA1AAN
Telegraphy by on-off keying of a tone modulated carrier, Morse code	$B_n = BK + 2M$ $K = 5$ for fading circuits $K = 3$ for non-fading circuits	25 words per minute $B = 20$, $M = 1\,000$, $K = 5$ Bandwidth: 2 100 Hz = 2.1 kHz	2K10A2AAN
Selective calling signal using sequential single frequency code, single-sideband full carrier	$B_n = M$	Maximum code frequency is: 2 110 Hz $M = 2\,110$ Bandwidth: 2 110 Hz = 2.11 kHz	2K11H2BFN
Direct-printing telegraphy using a frequency shifted modulating sub-carrier, with error-correction, single-sideband, suppressed carrier (single channel)	$B_n = 2M + 2DK$ $M = \dfrac{B}{2}$	$B = 50$ $D = 35$ Hz (70 Hz shift) $K = 1.2$ Bandwidth: 134 Hz	134HJ2BCN
Telegraphy, multichannel with voice frequency, error-correction, some channels are time-division multiplexed, single-sideband, reduced carrier	B_n = highest central frequency + $M + DK$ $M = \dfrac{B}{2}$	15 channels; highest central frequency is: 2 805 Hz $B = 100$ $D = 42.5$ Hz (85 Hz shift) $K = 0.7$ Bandwidth: 2 885 Hz = 2.885 kHz	2K89R7BCW
2. Telephony (commercial quality)			
Telephony, double-sideband (single channel)	$B_n = 2M$	$M = 3\,000$ Bandwidth: 6 000 Hz = 6 kHz	6K00A3EJN
Telephony, single-sideband, full carrier (single channel)	$B_n = M$	$M = 3\,000$ Bandwidth: 3 000 Hz = 3 kHz	3K00H3EJN
Telephony, single-sideband, suppressed carrier (single channel)	$B_n = M$ – lowest modulation frequency	$M = 3\,000$ lowest modulation frequency = 300 Hz Bandwidth: 2 700 Hz = 2.7 kHz	2K70J3EJN

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
2. Telephony (commercial quality) (*cont.*)			
Telephony with separate frequency modulated signal to control the level of demodulated speech signal, single-sideband, reduced carrier (Lincompex) (single channel)	$B_n = M$	Maximum control frequency = 2 990 Hz $M = 2\,990$ Bandwidth: 2 990 Hz = 2.99 kHz	2K99R3ELN
Telephony with privacy, single-sideband, suppressed carrier (two or more channels)	$B_n = N_c\,M$ – lowest modulation frequency in the lowest channel	$N_c = 2$ $M = 3\,000$ lowest modulation frequency = 250 Hz Bandwidth: 5 750 Hz = 5.75 kHz	5K75J8EKF
Telephony, independent sideband (two or more channels)	B_n = sum of M for each sideband	2 channels $M = 3\,000$ Bandwidth: 6 000 Hz = 6 kHz	6K00B8EJN
3. Sound broadcasting			
Sound broadcasting, double-sideband	$B_n = 2M$ M may vary between 4 000 and 10 000 depending on the quality desired	Speech and music $M = 4\,000$ Bandwidth: 8 000 Hz = 8 kHz	8K00A3EGN
Sound broadcasting, single-sideband, reduced carrier (single channel)	$B_n = M$ M may vary between 4 000 and 10 000 depending on the quality desired	Speech and music $M = 4\,000$ Bandwidth: 4 000 Hz = 4 kHz	4K00R3EGN
Sound broadcasting, single-sideband, suppressed carrier	$B_n = M$ – lowest modulation frequency	Speech and music $M = 4\,500$ lowest modulation frequency = 50 Hz Bandwidth: 4 450 Hz = 4.45 kHz	4K45J3EGN
4. Television			
Television, vision and sound	Refer to relevant ITU-R documents for the bandwidths of the commonly used television systems	Number of lines: 625 Nominal video bandwidth = 5 MHz Sound carrier relative to video carrier: 5.5 MHz Total vision Bandwidth: 6.25 MHz FM sound bandwidth including guardbands: 750 kHz RF channel Bandwidth: 7 MHz	6M25C3F -- 750KF3EGN
5. Facsimile			
Analogue facsimile by sub-carrier frequency modulation of a single-sideband emission with reduced carrier, monochrome	$B_n = C + \dfrac{N}{2} + DK$ $K = 1.1$ (typically)	$N = 1\,100$ corresponding to an index of cooperation of 352 and a cycler rotation speed of 60 rpm. Index of cooperation is the product of the drum diameter and number of lines per unit length. $C = 1\,900$ $D = 400$ Hz Bandwidth: 2 890 Hz = 2.89 kHz	2K89R3CMN
Analogue facsimile; frequency modulation of an audio frequency sub-carrier which modulates the main carrier, single-sideband suppressed carrier	$B_n = 2M + 2DK$ $M = \dfrac{N}{2}$ $K = 1.1$ (typically)	$N = 1\,100$ $D = 400$ Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98J3C --

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
6. Composite emissions			
Double-sideband, television relay	$B_n = 2C + 2M + 2D$	Video limited to 5 MHz, audio on 6.5 MHz, frequency modulated sub-carrier, sub-carrier deviation = 50 kHz: $C = 6.5 \times 10^6$ $D = 50 \times 10^3$ Hz $M = 15\,000$ Bandwidth: 13.13×10^6 Hz = 13.13 MHz	13M1A8W --
Double-sideband radio-relay system, frequency division multiplex	$B_n = 2M$	10 voice channels occupying baseband between 1 kHz and 164 kHz $M = 164\,000$ Bandwidth: 328 000 Hz = 328 kHz	328KA8E --
Double-sideband emission of VOR with voice (VOR: VHF omnidirectional radio range)	$B_n = 2C_{max} + 2M + 2DK$ $K = 1$ (typically)	The main carrier is modulated by: – a 30 Hz sub-carrier – a carrier resulting from a 9 960 Hz tone – a telephone channel – a 1 020 Hz keyed tone for continual Morse identification $C_{max} = 9\,960$ $M = 30$ $D = 480$ Hz Bandwidth: 20 940 Hz = 20.94 kHz	20K9A9WWF
Independent sidebands; several telegraph channels with error-correction together with several telephone channels with privacy; frequency division multiplex	B_n = sum of M for each sideband	Normally composite systems are operated in accordance with standardized channel arrangements (e.g. Rec. ITU-R F.348). 3 telephone channels and 15 telegraphy channels require the bandwidth: 12 000 Hz = 12 kHz	12K0B9WWF
7. Standard frequency and time signals			
7.1 High frequency (voice)			
Voice announcements, double-sideband	$B_n = 2M$	Speech $M = 4\,000$ Bandwidth: 8 000 Hz = 8 kHz	8K00A3XGN
7.2. High frequency (time code)			
Time code as telegraphy	$B_n = BK + 2M$	$B = 1/\text{s}$ $M = 1$ $K = 5$ Bandwidth: 7 Hz	7H00A2XAN
7.3. Low frequency (time code)			
Time code as telegraphy	$B_n = BK + 2M$	$B = 1/\text{s}$ $M = 1$ $K = 3$ Bandwidth: 5 Hz	5H00A2XAN

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
III-A. FREQUENCY MODULATION			
1. Signal with quantized or digital information			
Telegraphy without error-correction (single channel)	$B_n = 2M + 2DK$ $M = \dfrac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) Bandwidth: 304 Hz	304HF1BBN
Telegraphy, narrow-band direct-printing with error-correction (single channel)	$B_n = 2M + 2DK$ $M = \dfrac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) Bandwidth: 304 Hz	304HF1BCN
Selective calling signal	$B_n = 2M + 2DK$ $M = \dfrac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) Bandwidth: 304 Hz	304HF1BCN
Four-frequency duplex telegraphy	$B_n = 2M + 2DK$ B: modulation rate (Bd) of the faster channel. If the channels are synchronized: $M = \dfrac{B}{2}$ (otherwise, $M = 2B$) $K = 1.1$ (typically)	Spacing between adjacent frequencies = 400 Hz Synchronized channels $B = 100$ $M = 50$ $D = 600$ Hz Bandwidth: 1 420 Hz = 1.42 kHz	1K42F7BDX
2. Telephony (commercial quality)			
Commercial telephony	$B_n = 2M + 2DK$ $K = 1$ (typically, but under certain conditions a higher value of K may be necessary)	For an average case of commercial telephony, $D = 5\ 000$ Hz $M = 3\ 000$ Bandwidth: 16 000 Hz = 16 kHz	16K0F3EJN
3. Sound broadcasting			
Sound broadcasting	$B_n = 2M + 2DK$ $K = 1$ (typically)	Monaural $D = 75\ 000$ Hz $M = 15\ 000$ Bandwidth: 180 000 Hz = 180 kHz	180KF3EGN
4. Facsimile			
Facsimile by direct frequency modulation of the carrier; black and white	$B_n = 2M + 2DK$ $M = \dfrac{N}{2}$ $K = 1.1$ (typically)	$N = 1\ 100$ elements/s $D = 400$ Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98F1C --
Analogue facsimile	$B_n = 2M + 2DK$ $M = \dfrac{N}{2}$ $K = 1.1$ (typically)	$N = 1\ 100$ elements/s $D = 400$ Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98F3C --

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
5. Composite emissions (see Table III-B)			
Radio-relay system, frequency division multiplex	$B_n = 2f_p + 2DK$ $K = 1$ (typically)	60 telephone channels occupying baseband between 60 kHz and 300 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 331 kHz produces 100 kHz rms deviation of main carrier. $D = 200 \times 10^3 \times 3.76 \times 2.02$ $\quad = 1.52 \times 10^6$ Hz $f_p = 0.331 \times 10^6$ Hz Bandwidth: 3.702×10^6 Hz $= 3.702$ MHz	3M70F8EJF
Radio-relay system, frequency division multiplex	$B_n = 2M + 2DK$ $K = 1$ (typically)	960 telephone channels occupying baseband between 60 kHz and 4 028 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 4 715 kHz produces 140 kHz rms deviation of main carrier. $D = 200 \times 10^3 \times 3.76 \times 5.5$ $= 4.13 \times 10^6$ Hz $M = 4.028 \times 10^6$ $f_p = 4.715 \times 10^6$ $(2M + 2DK) > 2f_p$ Bandwidth: 16.32×10^6 Hz = 16.32 MHz	16M3F8EJF
Radio-relay system, frequency division multiplex	$B_n = 2f_p$	600 telephone channels occupying baseband between 60 kHz and 2 540 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 8 500 kHz produces 140 kHz rms deviation of main carrier. $D = 200 \times 10^3 \times 3.76 \times 4.36$ $= 3.28 \times 10^6$ Hz $M = 2.54 \times 10^6$ $K = 1$ $f_p = 8.5 \times 10^6$ $(2M + 2DK) < 2f_p$ Bandwidth: 17×10^6 Hz = 17 MHz	17M0F8EJF
Stereophonic sound broadcasting with multiplexed subsidiary telephony sub-carrier	$B_n = 2M + 2DK$ $K = 1$ (typically)	Pilot tone system; $M = 75\ 000$ $D = 75\ 000$ Hz Bandwidth: $300\ 000$ Hz = 300 kHz	300KF8EHF

III-B. MULTIPLYING FACTORS FOR USE IN COMPUTING D, PEAK FREQUENCY DEVIATION, IN FM FREQUENCY DIVISION MULTIPLEX (FM-FDM) MULTI-CHANNEL EMISSSIONS		

For FM-FDM systems the necessary bandwidth is:

$$B_n = 2M + 2DK$$

The value of D, or peak frequency deviation, in these formulae for B_n is calculated by multiplying the rms value of per-channel deviation by the appropriate "multiplying factor" shown below.

In the case where a continuity pilot of frequency f_p exists above the maximum modulation frequency M, the general formula becomes:

$$B_n = 2f_p + 2DK$$

In the case where the modulation index of the main carrier produced by the pilot is less than 0.25, and the rms frequency deviation of the main carrier produced by the pilot is less than or equal to 70% of the rms value of per-channel deviation, the general formula becomes either:

$$B_n = 2f_p \qquad \text{or} \qquad B_n = 2M + 2DK$$

whichever if greater.

Number of telephone channels N_c	Multiplying factor[1]	
	(Peak factor)$\times$antilog $\left[\dfrac{\text{value in dB above modulation reference level}}{20} \right]$	
$3 < N_c < 12$	$4.47 \times$antilog $\left[\dfrac{\text{a value in dB specified by the equipment manufacturer or station licensee, subject to administration approval}}{20} \right]$	
$12 \le N_c < 60$	$3.76 \times$antilog $\left[\dfrac{2.6 + 2 \log N_c}{20} \right]$	

Number of telephone channels N_c	Multiplying factor[2]	
	(Peak factor)$\times$antilog $\left[\dfrac{\text{value in dB above modulation reference level}}{20} \right]$	
$60 \le N_c < 240$	$3.76 \times$antilog $\left[\dfrac{-1 + 4 \log N_c}{20} \right]$	
$N_c \ge 240$	$3.76 \times$antilog $\left[\dfrac{-15 + 10 \log N_c}{20} \right]$	

[1] In the above chart, the multipliers 3.76 and 4.47 correspond to peak factors of 11.5 and 13.0 dB, respectively.

[2] In the above chart, the multipliers 3.76 correspond to peak factors of 11.5 dB.

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
IV. PULSE MODULATION			
1. Radar			
Unmodulated pulse emission	$B_n = \dfrac{2K}{t}$ K depends upon the ratio of pulse duration to pulse rise time. Its value usually falls between 1 and 10 and in many cases it does not need to exceed 6	Primary radar range resolution = 150 m $K = 1.5$ (triangular pulse where $t \simeq t_r$, only components down to 27 dB from the strongest are considered) Then: $t = \left[\dfrac{2 \times \text{(range resolution)}}{\text{velocity of light}} \right]$ $= \dfrac{2 \times 150}{3 \times 10^8}$ $= 1 \times 10^{-6}$ s Bandwidth: 3×10^6 Hz = 3 MHz	3M00P0NAN
2. Composite emissions			
Radio-relay system	$B_n = \dfrac{2K}{t}$ $K = 1.6$	Pulse position modulated by 36 voice channel baseband; pulse width at half amplitude = 0.4 μs Bandwidth: 8×10^6 Hz = 8 MHz (Bandwidth independent of the number of voice channels)	8M00M7EJT
3. Standard frequency and time signals			
3.1 High frequency (tone bursts)			
Ticks used for epoch measurement	$B_n = 2/t_r$	$t_r = 1$ ms Bandwidth: 2 000 Hz = 2 kHz	2K00K2XAN
3.2 Low frequency (time code)			
Time code leading edge used for epoch measurement	$B_n = 2/t_r$	$t_r = 1$ ms Bandwidth = 2 000 Hz = 2 kHz	2K00K2XAN
V. MISCELLANEOUS			
Orthogonal frequency division multiplexing (OFDM) or coded OFDM (COFDM)	$B_n = N_s \cdot K$	53 active sub-carriers are used, each spaced 312.5 kHz apart ($K = 53$ and $N_s = 312.5$ kHz). Data sub-carriers can be BPSK, QPSK, QAM modulated $B_n = 312.5$ kHz $\times$ 53 = 16.6 MHz	16M6W7D

RECOMMENDATION ITU-R SA.1154*,**

**Provisions to protect the space research (SR), space operations (SO)
and Earth exploration-satellite services (EES) and to facilitate
sharing with the mobile service in the 2 025-2 110 MHz
and 2 200-2 290 MHz bands**

(1995)

The ITU Radiocommunication Assembly,

considering

a)   that the bands 2 025-2 110 MHz and 2 200-2 290 MHz are allocated on a primary basis to three of the space science services (SR, SO, EES), the fixed service (FS) and the mobile service (MS) subject to the provisions of Nos. 5.391 and 5.392 of the Radio Regulations (RR);

b)   that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92), in its Resolution No. 211, invites the ex-CCIR to continue to study appropriate provisions to protect the space science services operating in the bands 2 025-2 110 MHz and 2 200-2 290 MHz from harmful interference from emissions by stations of the mobile service and to report the results of studies to the next competent conference;

c)   that there is an increasing use of SR, SO and EES services in these frequency bands by space stations in low-Earth orbit (LEO);

d)   that the introduction of future high density or conventional land mobile systems in the 2 025-2 110 MHz and 2 200-2 290 MHz bands would cause unacceptable interference to the SR, SO and EES services; for further information see Annex 1;

e)   that studies indicate that specific low density mobile systems, such as those described in Annex 2, could share the 2 025-2 110 MHz and 2 200-2 290 MHz bands with the SR, SO and EES services;

f)   that in some countries the space science services have successfully shared for many years with low density mobile electronic news gathering (ENG) systems (see Annex 3) and aeronautical mobile telemetry systems (see Annex 4) without restrictions, however, restrictions may be needed in the future considering the expected growth rate of these systems;

g)   that space science service operations in the band 2 200-2 290 MHz are more vulnerable to interference than operations in the band 2 025-2 110 MHz because of high gain antennas of geostationary data relay satellite (DRS) spacecraft pointing towards the Earth when tracking a low-Earth orbiting spacecraft;

h)   that the protection criteria required for the SR service are the most stringent of the three space science services and provide adequate protection for the SR, SO and EES services;

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*   This Recommendation should be brought to the attention of Radiocommunication Study Groups 4, 8 and 9.

** Radiocommunication Study Group 7 made editorial amendments to this Recommendation in 2003 in accordance with Resolution ITU-R 44.

j)   that Recommendation ITU-R SA.609 (§ 1, 1.1, 1.2 and 2) specifies the protection criteria for the SR service;

k)   that the protection criteria of Recommendation ITU-R SA.609 have been used repeatedly in sharing studies and are widely recognized;

l)   that SR, SO and EES services use the 2 025-2 110 MHz and 2 200-2 290 MHz bands for Earth-to-space, space-to-Earth and space-to-space radiocommunications. The space-to-space links typically include the use of a DRS as described in the hypothetical reference system in Recommendations ITU-R SA.1020 and ITU-R SA.1018. The sharing criteria should consider the protection requirements of DRS radiocommunication links operating in the 2 025-2 110 MHz and 2 200-2 290 MHz bands;

m)   that for the protection of SR, SO and EES services, Earth-to-space and space-to-Earth links, a N/I of 6 dB, resulting in a 1 dB degradation is considered sufficient in most cases;

n)   that, taking into account the typically low margins on space-to-space links of 2 dB and less, a N/I of 10 dB, resulting in a 0.4 dB degradation is considered necessary for DRS space-to-space links;

o)   that the bands under consideration are shared with the FS and the MS. Each service is assumed to contribute half of the total interference to the spacecraft. Due to expected coordination only one of the services is assumed to interfere with an earth station;

p)   that DRS spacecraft are typically located on the geostationary orbit (GSO);

q)   that the 2 025-2 110 MHz band is used for SR, SO and EES Earth-to-space links to both low-Earth orbiting and GSO spacecraft. This band is also used for SR, SO and ESS space-to-space links, typically for radiocommunications from DRS spacecraft to low-Earth orbiting spacecraft;

r)   that the 2 200-2 290 MHz band is used for SR, SO and EES space-to-Earth links from both low-Earth orbiting and GSO spacecraft. This band is also used for SR, SO and EES space-to-space links, typically for radiocommunications from low-Earth orbiting spacecraft to DRS spacecraft;

s)   that terms concerning the density mobile systems refer to the number of systems and the population distribution of systems,

recognizing

1   that specifying a maximum number of mobile stations worldwide operating in the 2 025-2 110 MHz and 2 200-2 290 MHz bands such that the aggregate interference level does not exceed the sharing criteria may constitute a valid technical solution. However, the implementation of such a solution may not be practical,

further recognizing

1   that it is a unique combination of technical and operational characteristics of specific mobile systems that facilitate sharing, and sharing between such mobile systems and the SR, SO and EES services can be described in both qualitative and quantitative terms,

recommends

1   that the following provisions are suitable to protect the SR, SO and EES services from aggregate interference from emissions of mobile systems in the 2 025-2 110 MHz band:

1.1   that the aggregate interference at the input terminals of the spacecraft receiver, except in the case of a space-to-space link, should not exceed −180 dB(W/kHz) for more than 0.1% of the time;

1.2   that in the case of space-to-space links the aggregate interference at the input terminals of the spacecraft receiver should not exceed −184 dB(W/kHz) for more than 0.1% of the time;

2   that the following provisions are suitable to protect the SR, SO and EES services from aggregate interference from emissions of mobile systems in the 2 200-2 290 MHz band:

2.1   that the aggregate interference at the input terminals of the receiver in the earth station should not exceed −216 dB(W/Hz) for more than 0.1% of the time;

2.2   that the aggregate interference at the input terminals of the DRS spacecraft receiver should not exceed −184 dB(W/kHz) for more than 0.1% of the time;

3   that high density or conventional type mobile systems should not be introduced in the 2 025-2 110 MHz and 2 200-2 290 MHz bands, because they will cause unacceptable interference in the SR, SO and EES services as confirmed in Annex 1;

4   that new mobile systems should be introduced in such a way that their long term, worldwide deployment would not cause aggregate interference levels in excess of the values given in § 1 and 2;

5   that technical and operational parameters such as low power spectral densities, low worldwide population densities and intermittent transmissions (see Annex 2) be preferred for the introduction of new mobile systems;

6   that during the consideration of new low density mobile systems for introduction in the 2 025-2 110 MHz band, technical and operational characteristics, similar to those described in Annex 3, should be used for guidance;

7   that during the consideration of new low density mobile systems for introduction in the 2 200-2 290 MHz band, technical and operational characteristics, similar to those described in Annex 4, should be used for guidance.

Annex 1

Compatibility study of space research/space operations and high density land mobile systems

1   Introduction

Sharing between high density and conventional land mobile systems on the one hand and space services on the other hand is not feasible. This Annex is based on contributions which lead to this conclusion and provides the underlying analysis. The mobile system considered in this study is the future public land mobile telecommunication system (FPLMTS). The model used is also applicable to conventional type mobile systems.

The bands 2 025-2 110 GHz and 2 200-2 290 MHz are intensively used for space operations, Earth exploration by satellite, and space research on a worldwide basis with numerous agreements for international cross-support among space agencies. Due to the long distances between transmitters and receivers, signal levels at the receivers are very low. Consequently these services are very sensitive to interference requiring high protection levels as specified in the RR and ITU-R Recommendations.

Figure 1 shows the various links considered and the resulting interference configurations. Only voice services are considered for the personal and mobile stations. Additional interference from base stations has not been studied yet.

FIGURE 1

Interference configurations between FPLMTS units and space services
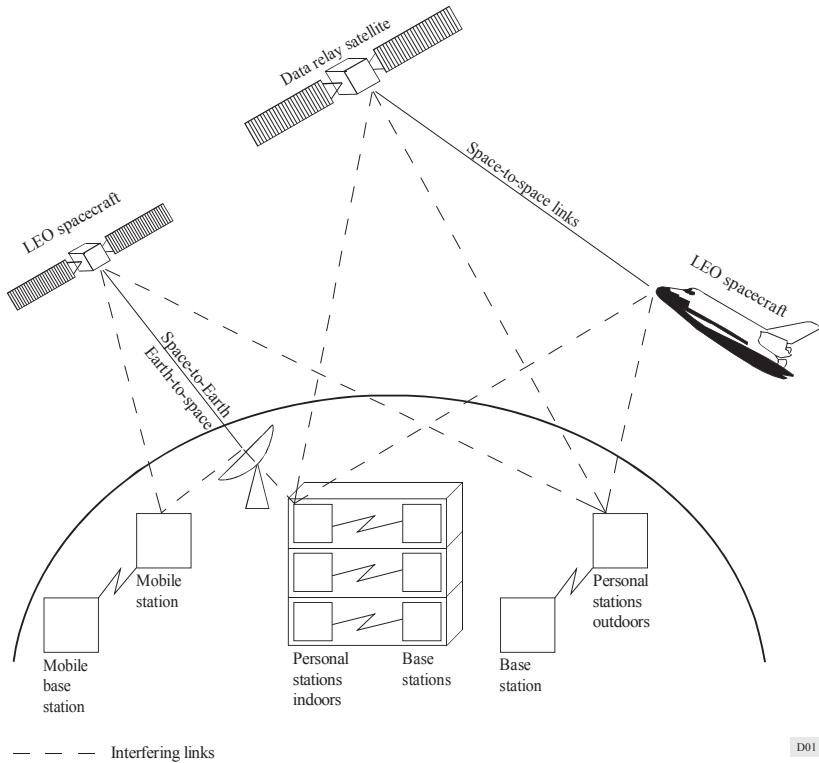
At present it is already a challenge for frequency managers to satisfy new assignment requests for the currently allocated space services in such a way as to minimize interference impacts on existing assignments. Consequently, intra-service sharing with additional users becomes increasingly difficult.

In the case of mobile services antenna patterns are quasi omnidirectional and the envisaged tens of millions of mobile transmitters have a very high cumulative interference level. As FPLMTS units are "mobile" by definition, coordination is not possible for obvious reasons. It can be demonstrated that for practically every configuration considered, sharing with these mobile systems is not feasible.

2 Radio regulatory and band occupation aspects

The 2 025-2 110 MHz and 2 200-2 290 MHz bands are allocated on a co-primary basis to the SR, SO and EES and the mobile service in all ITU regions.

Maximum tolerable interference levels for earth stations are defined in Appendix 7 to the RR, Table 8b and in Recommendations ITU-R SA.363 and ITU-R SA.609. Antenna diagrams for earth stations are based on the radiation patterns specified in Appendix 8 to the RR, Annex III. The minimum elevation angles for earth station antennas are in agreement with RR No. 21.15 and RR No. 21.14. Interference levels for spacecraft receivers are specified in Recommendations ITU-R SA.609 and ITU-R SA.363.

In the band 2 025-2 110 MHz there are currently more than 300 assignments. In the band 2 200-2 290 MHz the number of assignments is above 350. For the space-to-space links there are currently six allocations for the data relay system with a number of additional ones in progress for the international space station programme as well as for the European and the Japanese data relay satellite programmes.

It is apparent that the bands under consideration are heavily used by space services and that a large number of satellites and earth stations would be affected by land mobile services operating in these frequency bands.

3 Land mobile services (FPLMTS) system assumptions

A wide range of services is foreseen for future mobile communication systems. One of the services envisaged for operation in the bands near 2 GHz is the future public land mobile telecommunication system (FPLMTS). The designated bandwidth for these services is 230 MHz.

The FPLMTS is in the planning stage with preliminary figures on subscriber rates, traffic densities, and power levels. Radiocommunication Study Group 8 provided relatively detailed assumptions on power levels, bandwidth requirements, traffic density, etc. A summary of system assumptions provided is listed in Table 1.

TABLE 1

Summary of system assumptions

	Mobile station outdoor	Personal station outdoor	Personal station Indoor
Base station antenna height (m)	50	< 10	< 3
Traffic density urban area (E/km^2)	500 (0.25)	1 500 (1.2)	20 000 (1.2)
Cell area (km^2)	0.94	0.016	0.0006
Duplex bandwidth per channel (kHz)	25	50	50
Traffic per cell (E)	470	24	12
Number of channels per cell	493	34	23
Bandwidth for voice services (MHz)	111	27	24
Station power range (W)	1-5	0.02-0.05	0.003-0.01
Speech coding rate (kbit/s)	8	(16)	(16)
Peak-to-mean ratio for traffic	(3)	3	(3)
Peak traffic density per station (E)	0.1 (0.04)	0.04 (0.1)	0.2 (0.1)
Subscriber rate (penetration) (%)	50 (10)	80 (20)	(20)

In some cases it was found that for an average interference assessment the FPLMTS assumptions were too optimistic, in particular regarding traffic density and subscriber rate. Values quoted between brackets have been used instead. With the original FPLMTS data the interference excess values would be higher. Where no data were available the numbers between brackets have been used for the calculations.

Only the voice services have been taken into account but it is expected that non-voice services will result in very similar values.

The traffic density assumptions for the analyses are based upon figures available for Europe. The population in all common market countries is currently around 323 million living in an area of 2.3 million km^2. This leads to an average of 140 people per km^2 used as a basis for interference calculation to earth stations.

The traffic density assumptions for the interference scenario for spacecraft receivers can be derived in a similar way. A geostationary spacecraft "sees" an area as indicated in Fig. 3 with approximately 4 billion people living in it by the year 2000. The minimum orbit height of a spacecraft is 250 km. Figure 4 shows the area seen by a spacecraft flying at orbit heights of 250 km and 750 km, respectively. The interference reception area for a 250 km orbit is already 9.6 million m^2. The population living in this area is estimated to more than 600 million people. Figure 5 shows interference reception areas for low inclination orbits around 29° which are typical for space shuttle type orbits.

Environmental attenuation for transmission paths through windows, walls, ceilings, buildings and trees have been taken into account for all FPLMTS services. Typical attenuation figures are assumed to be; for windows (6.6 dB), walls and ceilings (27 dB). It was assumed that the signal of most but not all indoor personal units would be attenuated. There will remain a small percentage of

terminals which will radiate through open windows, on balconies, terraces or other "open" locations. For this study it was assumed that the signal from around 5% of the units is hardly attenuated and from 25% of units attenuated by glass. The interference from the remaining 70% of units was considered insignificant. An average attenuation of 10 dB has consequently been taken into account for indoor personal units. The signals from outdoor personal units and mobile units will only be attenuated if the signal is going through buildings and trees. This is often the case for low elevation angles but less significant for higher angles. Considering that the main interference comes from units close to the subsatellite point, which means high elevation angles, an average attenuation of not more than 3 dB is expected.

The interference caused by base stations has not been studied in this paper as sufficient technical information was not available. It is evident that the same order of magnitude must be expected in addition.

4 Protection requirements for space services

4.1 Protection requirements for earth stations

The maximum interference levels at the earth station receivers depend on the service in operation and are in agreement with Appendix 7 to the RR, Table 8b and Recommendation ITU-R SA.363. These values and the corresponding minimum elevation angles Θ_r are as follows:

1. Space operation: -184.0 dB(W/kHz), $\Theta_r = 3°$

2. Space Research: -216.0 dB(W/Hz), $\Theta_r = 5°$

For typical support of SO and Space Research missions, antennas with a diameter between 5.5 and 15 m are in operation for general support up to and beyond the geostationary orbit. Figure 2 shows antenna gain characteristics for the stations considered. The radiation patterns are based on Appendix 8 to the RR, Annex III.

4.2 Protection requirements for spacecraft receivers

Typical system noise temperatures of spacecraft receivers range around 800 K resulting in a noise spectral density of around -200 dB(W/Hz). Some critical space research missions require noise temperatures down to 600 K.

Recommendation ITU-R SA.609 specifies that interference shall not exceed a value of -177 dB(W/kHz) at the input terminals of the receiver for more than 0.1% of time. With fixed, mobile and space services in this band, each service is assumed to contribute one third of the total interference. This results in -182 dB(W/kHz) equivalent to -212 dB(W/Hz) acceptable interference contribution from mobile services. This number fits well with the protection criteria in *recommends* 1.1, 1.2 and 2.2.

The average gain of a quasi omnidirectional antenna is around 0 dBi with gain minima exceeding occasionally -6 dBi. Such an antenna is required to establish a link to the spacecraft in emergency cases or when other antennas cannot be used for technical or operational reasons, for instance during launch and early orbit phases. This applies also to communication satellites. With a 0 dBi antenna the acceptable interference from mobile units at the antenna input is consequently -212 dB(W/Hz).

FIGURE 2

Typical antenna characteristics for satellite earth stations

Frequency = 2.25 GHz
G_{min} = − 6 and − 10 dBi
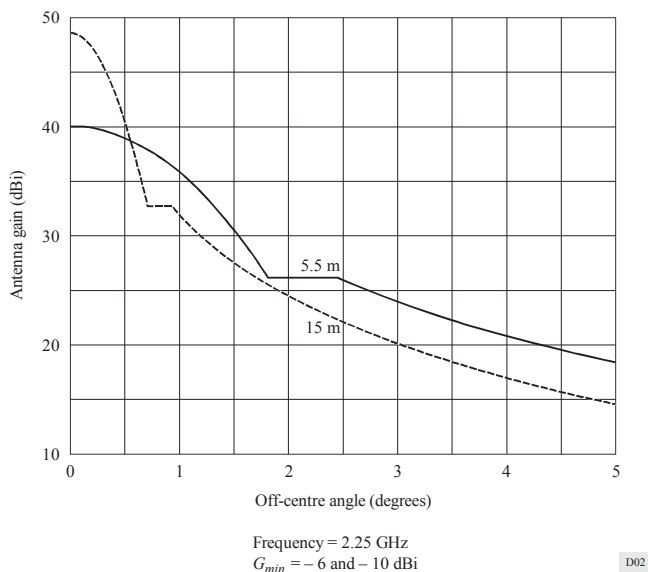
D02

The situation is more severe for a space-to-space link where, for example, a data relay satellite points a high gain antenna to a low-Earth orbiting satellite. Applying the same assumptions as above but taking a typical antenna gain of 35 dBi the acceptable interference level is consequently −247 dB(W/Hz) at the input of the antenna.

Recommendation ITU-R SA.363 specifies a C/I protection ratio of 20 dB for space operations. In recent years many space agencies have introduced channel coding techniques in order to conserve transmitter power and consequently also reduce interference to other systems. Two cases, i.e. uncoded and coded transmissions, have to be distinguished:

– Uncoded transmissions require an E_s/N_0 of 9.6 dB for a bit-error rate of 10^{-5}. Adding a typical margin of 3 dB results in a required C/N of 12.6 dB. The total interference-to-noise ratio I/N is consequently −7.4 dB. Allowing one third of the total interference for mobile services leads to an I_m/N of −12.4 dB. For a typical noise power density of −200 dB(W/Hz) the acceptable interference is −212.4 dB(W/Hz).

– Coded transmissions require an E_s/N_0 of 1.5 dB for a bit-error rate of 10^{-5} with standard convolutional channel coding. Adding a typical margin of 3 dB results in a required C/N of 4.5 dB. The I/N is consequently −15.5 dB. Allowing one third of the total interference for mobile services leads to an I_m/N of −20.5 dB. For a noise power density of −200 dB(W/Hz) the acceptable interference is −217.5 dB(W/Hz), that is 5 dB lower than the protection value of Recommendation ITU-R SA.609.

Although coded transmissions require higher protection levels, for this study a protection criterion of −212 dB(W/Hz) has been adopted as it is consistent with values specified in Recommendations ITU-R SA.609 and ITU-R SA.363.

5 Interference analysis

5.1 Earth-to-space link (2 025-2 110 MHz)

5.1.1 Interference caused to the spacecraft

Earth-to-space links considered in this analysis are based on orbit heights between 250 and 36 000 km as more than 90% of all spacecraft are operated at or below the geostationary orbit.

Figure 3 shows the area from which a geostationary spacecraft will receive signals via a quasi omnidirectional antenna. The arbitrarily selected position of the spacecraft is 10° W. It is estimated that in the worst case the spacecraft can see an area where more than 70% of all mobile terminals on the Earth are located.

FIGURE 3

Interference reception area for geostationary satellites
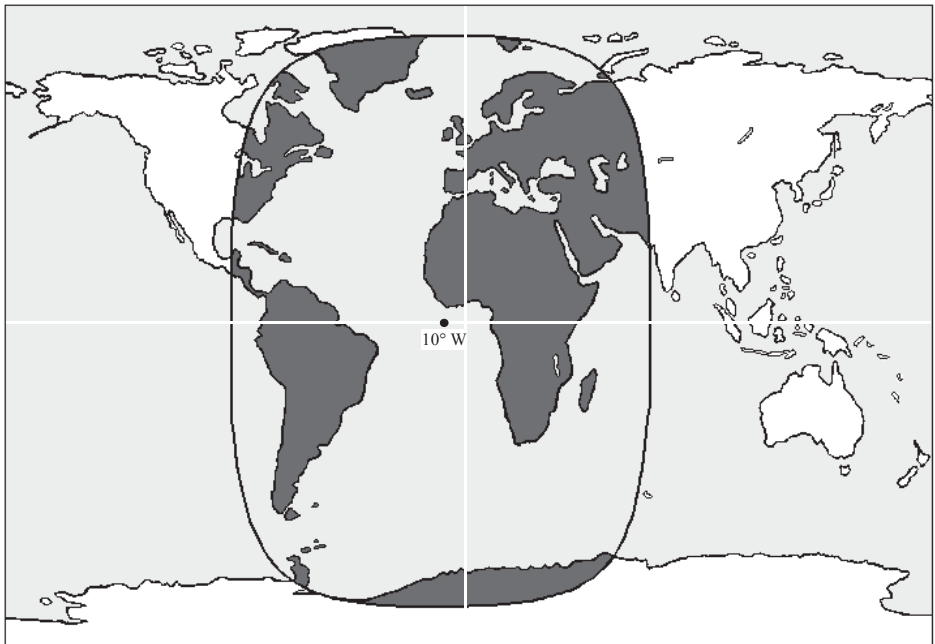
Figure 4 shows the area from which a low-Earth orbiting satellite at orbit heights between 250 and 750 km will receive signals. The position of the spacecraft has in this case been assumed to be above the middle of Europe. The resulting "window" will move along the ground track given in dotted lines. It is apparent that a very large area with potentially millions of transmitting mobiles can be seen by the spacecraft.

Figure 5 shows the total area from which space shuttle type spacecraft with a typical inclination of 29° will receive interference.

FIGURE 4

Interference reception area for low-Earth orbiters ($i = 98°$)
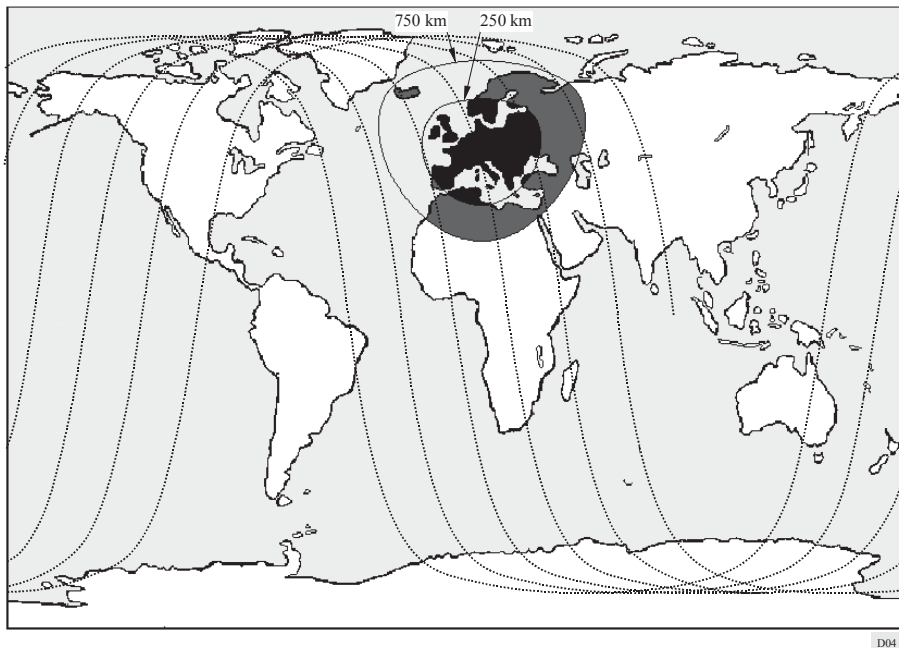
The area of interference A_i is determined by:

$$A_i = \frac{2\pi R^2 h}{R + h}$$

where:

  R :   Earth radius (6 378 km)

  h :   orbit height (250 to 36 000 km).

At an altitude of 250 km the spacecraft will receive interference from an area of 9.6 million km². This number increases to 27 million km² for an orbit height of 750 km. The maximum area seen by a geostationary satellite is 217 million km².

The interference spectral density level P_i received by a spacecraft antenna from one single mobile transmitter can be calculated as follows:

$$P_i = \frac{E_i c^2}{B_i (4\pi x f)^2}$$

FIGURE 5

Interference reception area for low-Earth orbiters ($i = 29°$)
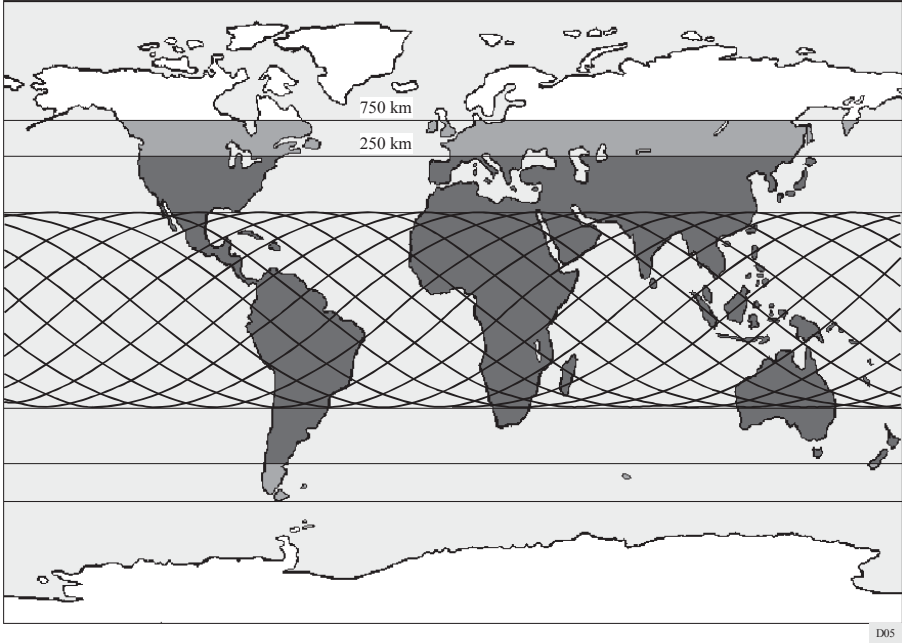
The cumulative interference $P_{\Sigma i}$ from all mobiles in the interference area is given by:

$$P_{\Sigma i} = \int_{x=h}^{d_m} \frac{n_a P_i B_i h^2 \, dA_{(x)}}{B_m A_i x^2} \, dx = \frac{n_a E_i c^2}{(4\pi f)^2 B_m A_i} \int_{x=h}^{d_m} \frac{dA_{(x)}}{x^2} \, dx$$

$$A_{(x)} = \frac{\pi R (x^2 - h^2)}{R + h}$$

$$\frac{dA_{(x)}}{dx} = \frac{2\pi R}{R + h} x$$

$$d_m = \sqrt{(R + h)^2 - R^2}$$

$$P_{\Sigma i} = \frac{n_a E_i c^2}{(4\pi f)^2 B_m R h} \, [\ln(d_m) - \ln(h)]$$

where:

P_i: power density of interferer

E_i: e.i.r.p. of interferer

x: distance to interferer

f :   transmission frequency

n_a :   number of active mobiles

c :   speed of light

B_i :   bandwidth of one mobile

B_m :   bandwidth of mobile service

d_m :   maximum distance to interferer.

For the sake of simplicity an equal distribution of active terminals over the available bandwidth and over the interference area has been assumed. Table 2 lists the detailed assumptions made and the resulting interference levels. It must be concluded that sharing for these links is impossible as the interference levels are several orders of magnitude above acceptable levels.

5.1.2   Interference caused to mobile units

Mobile units will receive harmful interference from a transmitting earth station if operated within a certain distance of that station. Maximum e.i.r.p. levels for the support of near-Earth satellites range typically from 66 to 78 dBW.

Taking into account the antenna gains in the horizontal direction as shown in Fig. 2 and the fact that an antenna radiates in principle into all directions with a lowest gain specification of −10 dBi for the back of the antenna (−6 dBi for a 5.5 m antenna) the following e.i.r.p. levels around the antenna must be expected in the horizontal direction. E.i.r.p. density levels depend very much on the transmitted data rate. For the SO service the maximum data rate is typically a few kbit/s whereas for the SR service a range from at least 1 kbit/s to 100 kbit/s must be taken into account.

Antenna diameter (m)	e.i.r.p. range (dBW)	e.i.r.p. density range (dB(W/4 kHz))
5.5 (3°)	20-50	14-47
15 (3°)	19-50	13-47

Protection levels of the FPLMTS units are not known, but the system will be self-interference limited and not noise limited. Assuming that interference levels of around −150 dB(W/4 kHz) are acceptable, and assuming some further loss due to signal diffraction, a protection zone of up to 100 km may be required to allow satisfactory operation of the mobile units.

5.2   Space-to-Earth link (2 200-2 290 MHz)

For these links a distinction between the various space services must be made. The most critical one is space research but results for space operation and Earth exploration are in fact very similar.

Assumptions on the distribution of mobile transmitters around a satellite earth station are difficult to make as they depend to a large extent on the location of the station. An average distribution based on the number of inhabitants in the European common market countries has been assumed. The average population density is 140 people per km^2 resulting from 323 million people living in 2.3 million km^2. The resulting average traffic density is 2.8 E/km^2 for personal stations and 0.56 E/km^2 for mobile stations.

TABLE 2

Earth-to-space links (2 025-2 110 MHz)

	Indoor personal station		Outdoor personal station		Mobile station	
Spacecraft orbit height (km)	250	36 000	250	36 000	250	36 000
e.i.r.p. of single FPLMTS unit (W)	0.003	0.003	0.020	0.020	1.00	1.00
Channel bandwidth for voice communications (kHz)	50.0	50.0	50.0	50.0	25.0	25.0
e.i.r.p. density of single FPLMTS unit (dB(W/Hz))	−72.2	−72.2	−64.0	−64.0	−44.0	−44.0
Space (spreading) loss (dB)	146.7	189.8	146.7	189.8	146.7	189.8
Interference of a single unit (dB(W/Hz))	−218.9	−262.1	−210.7	−253.8	−190.7	−233.8
Acceptable interference density (dB(W/Hz))	−212.0	−212.0	−212.0	−212.0	−212.0	−212.0
Interference excess of one unit (dB)	−6.9	−50.1	1.3	−41.8	21.3	−21.8
Area of interference seen by spacecraft (millions/km²)	9.64	217.13	9.64	217.13	9.64	217.13
Total number of population in area (millions)	600	4 000	600	4 000	600	4 000
Percentage of subscribers to service (%)	20.0	20.0	20.0	20.0	10.0	10.0
Average units in total per km²	12.4	3.7	12.4	3.7	6.2	1.8
Percentage of active units in area (%)	10.0	10.0	10.0	10.0	4.0	4.0
Simultaneously active units in area (millions)	12.0	80.0	12.0	80.0	2.4	16.0
Average active units per km² (E/km²)	1.24	0.37	1.24	0.37	0.25	0.07
Envisaged service bandwidth (voice channels) (MHz)	24	24	27	27	111	111
Number of active units per channel	25 000	166 667	22 222	148 148	541	3 604
Environmental attenuation (buildings, trees) (dB)	10.0	10.0	3.0	3.0	3.0	3.0
Cumulative interference from all active units (dB(W/Hz))	−196	−221	−181	−206	−177	−202
Average excess of acceptable interference (dB)	16.0	−8.5	30.7	6.2	34.6	10.1
Increased interference during peak activities (dB)	5.0	5.0	5.0	5.0	5.0	5.0
Increased interference with higher power levels (dB)	5.2	5.2	4.0	4.0	7.0	7.0
Increased interference over high density areas (dB)	5.3	0.0	5.3	0.0	5.3	0.0
Worst case excess of acceptable interference (dB)	31.5	1.7	45.0	15.2	51.8	22.1

The interference is integrated over a distance ranging from 1-10 km around the station for which a line-of-sight connection can be assumed. For most station locations it cannot be excluded that mobiles come even closer than 1 km. Additional interference is of course received from further distant mobile terminals but for the sake of simplicity this is not taken into account here. The antenna gain varies with the azimuth angle and has been integrated over 360° in order to come to an average antenna gain value.

The cumulative interference is determined by:

$$P_{\Sigma i} = \int_{x=d_1}^{d_2} \frac{md_a\, P_i\, B_i\, dA_{(x)}}{B_m}\ dx = \frac{md_a\, E_i\, c^2}{(4\pi f)^2\, B_m} \int_{x=d_1}^{d_2} \frac{dA_{(x)}}{x^2}\ dx$$

$$A_{(x)} = \pi\, x^2$$

$$\frac{dA_{(x)}}{dx} = 2\pi\, x$$

$$P_{\Sigma i} = \frac{md_a\, E_i\, c^2}{8\pi\, f^2\, B_m}\ [\ln(d_2)\ -\ \ln(d_1)]$$

where:

md_a: average mobile density

d_1: minimum radius around station

d_2: maximum radius around station.

Tables 3a and 3b list the detailed results for the space services considered. The worst-case results from a mobile unit transmitting into the direction of the main beam. A single station transmitting at a distance of 10 km was assumed representative although a much shorter distance is possible. The main conclusion to be drawn is that, even when an average gain specification of a few dBi around the antenna is assumed and a simplified interference calculation unfavourable to the space services is performed, interference levels are produced which are several orders of magnitude above the acceptable levels; hence sharing is impossible.

5.3 Space-to-space link (2 025-2 110 MHz)

The most critical case in this category is the link between a geostationary satellite, for example a data relay satellite, and a low-Earth orbiting satellite. The orbit height of the latter one ranges typically between 250 and 1 000 km.

Such a link is for example representative for a manned space shuttle which will orbit around 400 km. It is imperative that this spacecraft has an omnidirectional antenna in order to enable safe commanding and communications during every flight phase and in particular in emergency situations.

Due to power flux-density limitations on the Earth, a limit is also set on the e.i.r.p. which the data relay satellite may radiate towards the Earth, i.e. towards the low orbiting satellite. This results in very tight link margins. Interference, even at low levels, is extremely critical.

The calculated interference levels are so high that any data or communication links to low orbiting spacecraft are totally blanked out. An e.i.r.p. increase on the transmitting geostationary satellite is not feasible due to power flux-density restrictions. Consequently, sharing with land mobiles is impossible.

Table 4 lists the detailed results.

TABLE 3

Space-to-Earth links (2 200-2 290 MHz)

Table 3a: Space operation service

	Indoor personal station		Outdoor personal station		Mobile station	
Average horizontal gain of earth station (5.5 m) (dBi)		24.0		24.0		24.0
Maximum horizontal gain of earth station (3°) (dBi)	7.5		7.5		7.5	
Active units per km² (E/km²)	2.800		2.800		0.560	
Active unit density per channel per km²	0.0058		0.0052		0.0001	
e.i.r.p. of single FPLMTS unit (W)	0.003	0.003	0.020	0.020	1.000	1.000
e.i.r.p. density of single FPLMTS unit (dB(W/Hz))	−72.2	−72.2	−64.0	−64.0	−44.0	−44.0
Acceptable interference density at receiver input (dB(W/kHz))	−184.0	−184.0	−184.0	−184.0	−184.0	−184.0
Acceptable interference density at antenna input (dB(W/kHz))	−191.5	−208.0	−191.5	−208.0	−191.5	−208.0
Interference of units between 1 and 10 km (dB(W/kHz))	−152.4	−161.5	−144.7	−153.3		
Interference of 1 unit at 10 km distance (LOS)(dB(W/kHz))					−140.9	−133.3
Excess of acceptable interference (dB)	39.1	46.5	46.8	54.7	50.6	74.7

Table 3b: Space research

	Indoor personal station		Outdoor personal station		Mobile station	
Average horizontal gain of earth station (15 m) (dBi)		14.5		14.5		14.5
Maximum horizontal gain of earth station (5°) (dBi)	2.4		2.4		2.4	
Active units per km² (E/km²)	2.800		2.800		0.560	
Active unit density per channel per km²	0.0058		0.0052		0.0001	
e.i.r.p. of single FPLMTS unit (W)	0.003	0.003	0.020	0.020	1.000	1.000
e.i.r.p. density of single FPLMTS unit (dB(W/Hz))	−72.2	−72.2	−64.0	−64.0	−44.0	−44.0
Acceptable interference density at receiver input (dB(W/Hz))	−220.0	−220.0	−220.0	−220.0	−220.0	−220.0
Acceptable interference density at antenna input (dB(W/Hz))	−222.4	−234.5	−222.4	−234.5	−222.4	−234.5
Interference of units between 1 and 10 km (dB(W/Hz))	−182.4	−191.5	−174.7	−183.3		
Maximum interference of 1 unit at 10 km distance (dB(W/Hz))					−170.9	−163.3
Excess of acceptable interference (dB)	40.0	43.0	47.7	51.2	51.5	71.2

TABLE 4

Space-to-space links (2 025-2 110 MHz)

	Indoor personal station		Outdoor personal station		Mobile station	
Spacecraft orbit height (km)	250	750	250	750	250	750
e.i.r.p. of single FPLMTS unit (W)	0.003	0.003	0.020	0.020	1.00	1.00
Channel bandwidth for voice communications (kHz)	50.0	50.0	50.0	50.0	25.0	25.0
e.i.r.p. density of single FPLMTS unit (dB(W/Hz))	−72.2	−72.2	−64.0	−64.0	−44.0	−44.0
Space (spreading) loss (dB)	146.7	156.2	146.7	156.2	146.7	156.2
Interference of a single unit (dB(W/Hz))	−218.9	−228.4	−210.7	−220.2	−190.7	−200.2
Acceptable interference density (dB(W/Hz))	−212.0	−212.0	−212.0	−212.0	−212.0	−212.0
Interference excess of one unit (dB)	−6.9	−16.4	1.3	−8.2	21.3	11.8
Area of interference seen by spacecraft (million/km^2)	9.64	26.89	9.64	26.89	9.64	26.89
Total number of population in area (millions)	600	800	600	800	600	800
Percentage of subscribers to service (%)	20.0	20.0	20.0	20.0	10.0	10.0
Average units in total per km^2	12.4	5.9	12.4	5.9	6.2	3.0
Percentage of active units in area (%)	10.0	10.0	10.0	10.0	4.0	4.0
Simultaneously active units in area (millions)	12.0	16.0	12.0	16.0	2.4	3.2
Average active units per km^2 (E/km^2)	1.24	0.59	1.24	0.59	0.25	0.12
Envisaged service bandwidth (voice channels) (MHz)	24	24	27	27	111	111
Number of active units per channel	25 000	33 333	22 222	29 630	541	721
Environmental attenuation (buildings, trees) (dB)	10.0	10.0	3.0	3.0	3.0	3.0
Cumulative interference from all active units (dB(W/Hz))	−196.0	−200.9	−181.3	−186.2	−177.4	−182.3
Average excess of acceptable interference (dB)	16.0	11.1	30.7	25.8	34.6	29.7
Increased interference during peak activities (dB)	5.0	5.0	5.0	5.0	5.0	5.0
Increased interference with higher power levels (dB)	5.2	5.2	4.0	4.0	7.0	7.0
Increased interference over high density areas (dB)	5.3	3.0	5.3	3.0	5.3	3.0
Worst case excess of acceptable interference (dB)	31.5	24.3	45.0	37.8	51.8	44.6

5.4   Space-to-space link (2 200-2 290 MHz)

This frequency band is used for data links from low orbiting satellites to geostationary data relay satellites and for short range communications between low orbiting satellites and eventually also between astronauts. Orbit heights between 250 and 36 000 km have consequently to be taken into account.

In principle, the same assumptions as listed above are applicable with the exception that the geostationary satellite uses high gain antennas for the links to the low orbiters. This results in very low acceptable interference levels at the input of the antenna. The beamwidth of the antenna is typically a few degrees so that interference from an area somewhat smaller than for the 250 km orbit can be received. Figure 6 gives a typical example for the area from which interference will be received by a data relay satellite when tracking a low-Earth orbiter.

FIGURE 6

Coverage of a data relay satellite antenna and a 250 km LEO
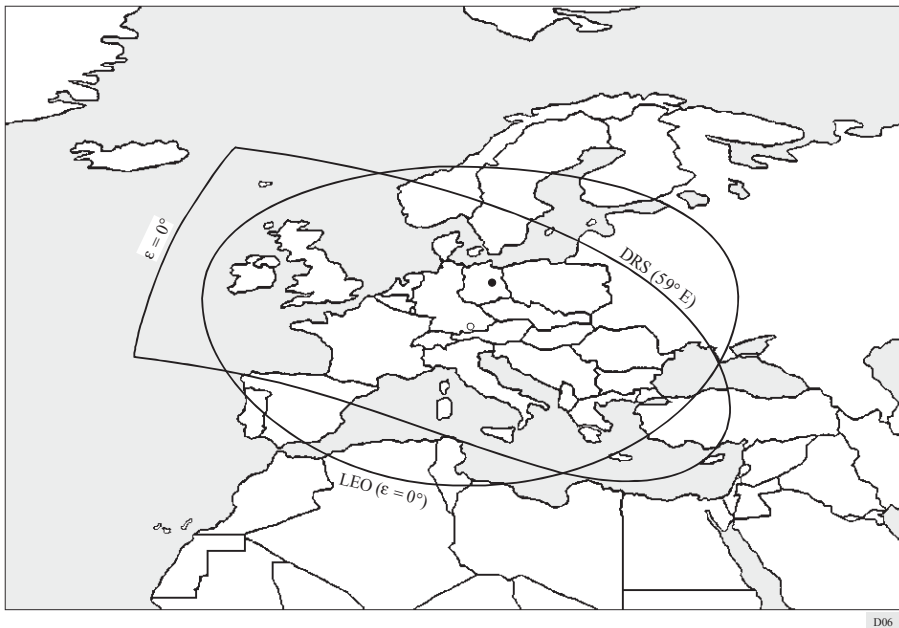
Table 5 lists the detailed results. Also in this case sharing is unfortunately impossible.

5.5   Worst-case scenarios for all links

The assumptions used for the interference studies above are based on an average distribution of mobiles over the interference area, an average activity, minimum power levels for the FPLMTS units and an equal occupation of all available channels. The resulting interference excess values are consequently average numbers on the low end.

TABLE 5

Space-to-space links (2 200-2 290 MHz)

	Indoor personal station		Outdoor personal station		Mobile station	
Spacecraft orbit height (km)	250	36 000	250	36 000	250	36 000
e.i.r.p. of single FPLMTS unit (W)	0.003	0.003	0.020	0.020	1.000	1.000
Channel bandwidth for voice communications (kHz)	50.0	50.0	50.0	50.0	25.0	25.0
e.i.r.p. density of single FPLMTS unit (dB(W/Hz))	−72.2	−72.2	−64.0	−64.0	−44.0	−44.0
Space (spreading) loss (dB)	146.7	189.8	146.7	189.8	146.7	189.8
Interference of a single unit (dB(W/Hz))	−218.9	−262.1	−210.7	−253.8	−190.7	−233.8
Acceptable interference density (dB(W/Hz))	−212.0	−247.0	−212.0	−247.0	−212.0	−247.0
Interference excess of one unit (dB)	−6.9	−15.1	1.3	−6.8	21.3	13.2
Area of interference seen by spacecraft (millions/km²)	9.64	8.00	9.64	8.00	9.64	8.00
Total number of population in area (millions)	600	500	600	500	600	500
Percentage of subscribers to service (%)	20.0	20.0	20.0	20.0	10.0	10.0
Average units in total per km²	62.2	62.5	62.2	62.5	62.2	62.5
Percentage of active units in area (%)	10.0	10.0	10.0	10.0	4.0	4.0
Simultaneously active units in area (millions)	12.0	10.0	12.0	10.0	2.4	2.0
Average active units per km² (erlangs/km²)	1.24	1.25	1.24	1.25	0.25	0.25
Envisaged service bandwidth (voice channels) (MHz)	24	24	27	27	111	111
Number of active units per channel	25 000	20 833	22 222	18 519	541	450
Environmental attenuation (buildings, trees) (dB)	10.0	10.0	3.0	3.0	3.0	3.0
Cumulative interference from all active units (dB(W/Hz))	−196.0	−218.9	−181.3	−211.1	−177.4	−207.3
Average excess of acceptable interference (dB)	16.0	27.2	30.7	34.9	34.6	38.8
Increased interference during peak activities (dB)	5.0	5.0	5.0	5.0	5.0	5.0
Increased interference with higher power levels (dB)	5.2	5.2	4.0	4.0	7.0	7.0
Increased interference over high density areas (dB)	5.3	0.0	5.3	0.0	5.3	0.0
Worst case excess of acceptable interference (dB)	31.5	37.4	45.0	43.9	51.8	50.8

If the spacecraft flies over large cities or highly populated areas in Europe the cumulative interference will increase significantly due to the shorter distance from a high number of mobiles to the spacecraft. To take into account large urban and suburban areas it was assumed that 20% of all mobile units seen by the spacecraft are close to the subsatellite point. This is easily possible over large cities like Paris and London with traffic densities up to 20 000 E/km^2 per building floor. This results in increased interference between 3 dB for a 750 km orbit and 5 dB for a 250 dB orbit. For the geostationary orbits no increase was assumed as it is unlikely that a very high mobile concentration can be found near the equator.

An interference increase will also occur at times with peak activities. A traffic density increase up to a factor of 3 can be assumed. This leads to a potential increase of interference between 4 and 7 dB. Another reason for higher interference can be unequal occupation of channels but as this is difficult to estimate it has not been taken into account in this study.

For the Earth-to-space and the two space-to-space links it can be concluded that the worst-case interference can be between 9 and 16 dB higher than the average value.

The situation for the space-to-Earth link is slightly different. The worst case would be a mobile transmitting in the vicinity of the station near the direction of the main beam. Assuming a distance of 10 km between the mobile and the earth station the corresponding interference level would be 43-75 dB above specified protection levels.

6   Conclusions

A short summary of interference excess is listed in Table 6 for all links analysed. The lower value is based on average interference excess. The higher value takes into account worst cases with respect to increased mobile densities in highly populated areas, upper limits of specified operating power, and times with high communication activity. Unequal channel occupation, yet another source of increased interference, has not been considered.

TABLE 6

Interference summary for all links and all mobile units considered

Interference excess (dB)	Indoor personal station	Outdoor personal station	Mobile station
Earth-to-space (2 025-2 110 MHz)	16-32	31-45	35-52
Space-to-Earth (2 200-2 290 MHz)	39-47	47-55	51-75
Space-to-space (2 025-2 110 MHz)	16-32	31-45	35-52
Space-to-space (2 200-2 290 MHz)	27-37	35-45	39-52

An interference analysis between FPLMTS type land mobile systems and the space operations, space research and Earth-exploration service has been presented. On all types of links considered in this Recommendation sharing with this and similar high density mobile systems is not feasible. The resulting interference levels are orders of magnitude higher than acceptable levels specified in the RR and in ITU-R Recommendations.

Annex 2

Summary of studies of the characteristics of mobile systems that facilitate radio-frequency compatibility with the space science services

1   Introduction

This Annex summarizes the results of studies concerning the technical and operational characteristics of mobile systems that might be compatible with the SR, SO and EES systems operating in the 2 025-2 110 MHz and 2 200-2 290 MHz bands.

The characteristics of mobile systems that facilitate sharing are:

–   emissions of low power spectral density,

–   transmissions of an intermittent nature,

–   use of directional transmitting antennas,

–   number of mobile stations is self-limiting as a result of the nature of the application.

Studies concerning different sets of assumptions and ranges of values for these general characteristics are presented in the following sections. Further studies regarding the compatibility between mobile systems and space science systems in the 2 025-2 110 MHz and 2 200-2 290 MHz bands would be required to better define the interference environment.

2   Summary of studies of e.i.r.p. and antenna gain

The introduction of technical requirements for the mobile service in the bands 2 025-2 110 MHz and 2 200-2 290 MHz led to the proposal of an e.i.r.p. limit of 28 dBW together with a minimum antenna gain of 24 dBi in order to facilitate sharing with the space science services. Studies were conducted as to the interference effect of such systems on the space research service.

The model used in the study assumed a global and uniform distribution of directional mobile terminals with antenna gains ranging between 22 and 26.5 dBi and e.i.r.p. ranging between 28 and 37 dBW. Orbital heights for spacecraft between 250 km and 36 000 m were taken into account.

The study results show that space science operations in the 2 200-2 290 MHz band are significantly more susceptible to interference than in the 2 025-2 110 MHz band. An antenna gain sensitivity analysis was performed. For the case of constant e.i.r.p. levels, the probability of interference decreases with increasing antenna gain as shown in Fig. 7. The Figure also shows a non-linear increase in interference probability with linearly increasing e.i.r.p.

The study finally concluded that the proposed e.i.r.p. limit of 28 dBW, together with an antenna gain in excess of 24 dBi, are adequate provisions to enable sharing with around 1 000 mobile systems of such kind worldwide.

3 A summary of a study of interference from certain mobile systems

A study was conducted that considered four possible scenarios concerning interference to space science services systems as shown in Table 7.

The characteristics of the systems used in the study are discussed in the following.

3.1 System characteristics

3.1.1 Receive characteristics

3.1.1.1 Data relay satellite

Receive antenna (assumed to track the LEO spacecraft when visible):

– boresight gain = 34 dBi;

– off-beam characteristics in accordance with the reference radiation pattern for single feed circular beams (near in side-lobe level of –20 dB) as defined in Recommendation ITU-R S.672.

FIGURE 7

Interference probability for various ENG system characteristics

1 000 ENG systems
10 % activity

D07
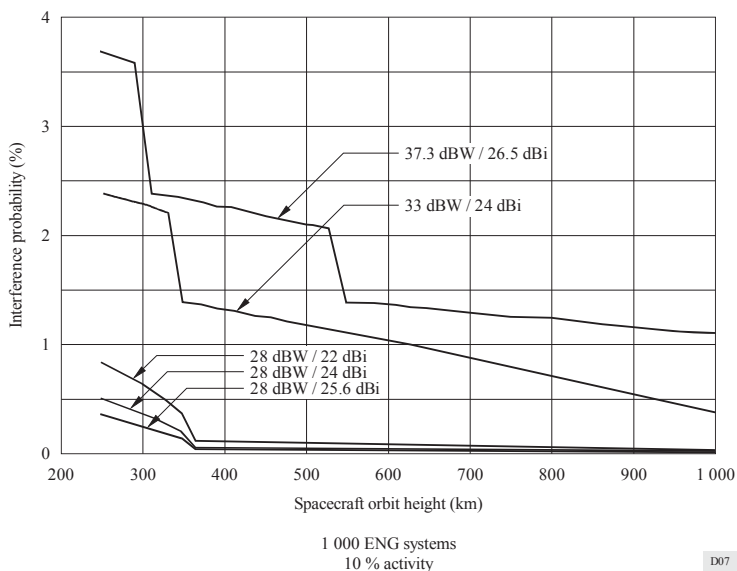
TABLE 7

	2 025-2 110 MHz	2 200-2 290 MHz
Space services Data relay	Space-to-space (Forward) (1)	Space-to-space (Return) (3)
Space services Direct-to-ground	Earth-to-space (2)	Space-to-Earth (4)
Mobile	Directional (ENG)	Omnidirectional

3.1.1.2   LEO spacecraft (DRS pointing)

Receive antenna (assumed to track the geostationary relay satellite when visible):

–   boresight gain = 25 dBi;

–   off-beam characteristics in accordance with the reference radiation pattern for single feed circular beams (near in side-lobe level of –20 dB) as defined in Recommendation ITU-R S.672;

–   orbit altitude = 300 km;

–   inclination = 29°.

3.1.1.3   LEO spacecraft (Earth pointing)

Receive antenna omnidirectional (gain = 0 dBi):

–   orbit altitude = 300 km;

–   inclination = 29°.

3.1.1.4   Earth station

Receive antenna (assumed to track the LEO spacecraft when visible):

–   boresight gain = 45 dBi;

–   off-beam characteristics in accordance with those defined in RR Appendices 28 and 29.

3.1.2   Transmit characteristics

3.1.2.1   Mobile terminal (directional) – ENG

–   antenna boresight gain = 25 dBi;

–   power spectral density into the antenna = –38 dB(W/kHz);

–   off-beam characteristics in accordance with those defined in RR Appendices 28 and 29.

3.1.2.2   Mobile terminal (omnidirectional)

–   antenna gain = 0 dBi;

–   power spectral density into the antenna = –42 dB(W/kHz).

3.2   Summary and conclusions

Four geometric configurations (A-D) were evaluated for the scenarios shown in Table 7 using the technical characteristics shown above. The results of a probabilistic analysis are summarized in Table 8.

TABLE 8

Reference	Entry	Maximum level of interference relative to criterion (dB)	Probability criterion exceeded (%)
1 A 1 B 1 C 1 D	ENG into LEO (DRS pointing)	+ 31.0 + 7.5 + 6.5 + 6.5	0.65 0.20 0.15 0.15
2 A 2 B 2 C 2 D	ENG into LEO (Earth pointing)	+ 2.5 + 2.5 + 2.5 + 2.5	0.20 0.04 0.045 0.035
3 A 3 B 3 C 3 D	Omni into DRS	− 16.5 − 16.5 − 15.0 − 15.0	2.50[1] 1.50[1] 0.15[1] 0.50[1]
4 A 4 B	Omni into ES	+ 48.5 + 48.0	1.00 0.55

[1]   Probability of maximum level of interference.

3.2.1   Interference from directional mobiles to a LEO spacecraft (DRS pointing) in the band 2 025-2 110 MHz

The values in Table 8 suggest that a single ENG terminal in various geometric configurations can exceed the applicable protection criteria. However, considering the majority of configurations, if the ENG transmit power were decreased by 1 dB then the probability that the protection criterion would be exceeded would be decreased to 0.1%. This would not, of course, be true for the more critical geometric configurations and, therefore, some constraints may need to be placed on the siting of terrestrial ENG terminals.

3.2.2   Interference from directional mobiles to a LEO spacecraft (Earth pointing) in the band 2 025-2 110 MHz

The results suggest that two or three spatially separated co-channel terminals would be acceptable. This translates into an acceptable community of between 100 and 150 ENG terminals not considering the worst case geometry.

3.2.3   Interference from omnidirectional mobiles to a geostationary data relay satellite (tracking a LEO spacecraft) in the band 2 200-2 290 MHz

The values presented in Table 8 show that the interfering power levels from a single omnidirectional terminal are well within the permissible criteria. However, the probabilities of these

levels occurring are high and hence multiple terminals could give rise to aggregate levels of interference which whilst just exceeding the permissible power levels would exceed the permissible levels many times in terms of probability of occupance.

3.2.4 Interference from omnidirectional mobiles to an earth station (tracking a LEO spacecraft) in the band 2 200-2 290 MHz

Assuming no line-of-sight paths such that the basic transmission loss follows an inverse third power law, a single omnidirectional terminal may operate within 0.5 km of an earth station (with an elevation greater than 5°).

Annex 3

Description of certain electronic news gathering (ENG) systems operating in the 2 025-2 110 MHz band

1 Introduction

This Annex presents information about the unique technical and operational characteristics used by specific ENG systems operated by one administration that may facilitate sharing with the SR, SO, and EES services.

2 Characteristics/description of ENG systems

ENG systems include both mobile point-of-view and transportable ENG systems that provide video from a variety of locations and activities. ENG systems are used for on-location coverage of news events or interviews and live-action video during sports or entertainment events. Because of the value of on-location video, most local television stations in urban areas of the United States of America operate ENG systems. The transportable ENG systems, used for on-location coverage, are generally mounted in vans and operate in a stationary mode transmitting video to a fixed receive site. These systems provide mobility for news coverage throughout a geographic region.

3 ENG systems and environments

This section describes two common operational modes.

3.1 Transportable

The transportable ENG systems described in the previous section are used for live or taped on-location video for news, sports, and entertainment broadcasts. The transportable ENG systems are generally mounted in vans and use transmitters operating around 10.8 dBW of power. These systems utilize directional antennas with gains between 20-22 dBi mounted on top of a pneumatic

mast of up to 15 m in height. ENG systems may employ linear or circular polarization to provide additional interference protection from each other. Many ENG systems (probably 30-50%) transmit with up to 5 dB of transmission line loss.

3.2 Point-of-view

Small light-weight microwave transmitters are used for mobile and close-up video situations since live pictures are desired and because video recorders are impractical due to size and ruggedness requirements. These transmitters usually operate with up to 5 dBW of power. These systems utilize essentially omnidirectional antennas with 0-3 dBi of gain and may also use linear or circular polarization.

A small point-of-view system usually operates instead of, rather than in addition to, a transportable ENG operation on the same channel. Point-of-view systems cannot usually operate simultaneously with transportable systems because the transportable systems cause excessive interference to the point-of-view receiver.

Table 9 presents characteristics of typical ENG systems that operate in the 2 025-2 110 MHz band.

TABLE 9

Typical 2 GHz ENG systems in use in the United States of America

Type of use	Transmitter location	Transmit power	Antenna gain (dBi)	Receiver location
ENG transportable (van)	Van mast	12 W	22	Tower
Temporary fixed link	Roof	12 W	25	Roof
Convention	Floor of convention hall	100 mW	0-5	Hall rafters
Point-of-view (e.g., skier)	On body/helmet	100 mW	0	Hillside or helicopter
Sports venues				
Playing field	Field	1 W	12	Pressbox
Golf course (system 1)	On golf course	3 W	16	Tethered blimp
Golf course (system 2)	On golf course	12 W	12	Crane
Racecam	In car	3 W	7	Helicopter
Helicopter	Relay helicopter	12 W	7	Ground receive
Marathon				
Motorcycle	Motorcycle	3 W	7	Helicopter
Relay vehicle	Pick-up truck	12 W	12	Helicopter
Helicopter	Relay helicopter	12 W	7	Roof

4   Operational characteristics

All ENG systems, cannot operate simultaneously. Since ENG systems are sensitive to interference, only one transmission per channel per receive site at a time is usually possible. Most television markets in the United States of America contain multiple receive sites that allow for simultaneous transmissions on a channel. In most large markets, however, only six simultaneous transmissions are possible on the busiest channel, and in most markets the number does not exceed two. More than two simultaneous transmissions on a single channel rarely occur. In fact, multiple ENG receive sites and systems exist only in the largest television markets, so most regions have little or no simultaneous ENG activity per channel.

Although used throughout the day, transportable ENG systems operate primarily during weekday local news broadcasts, which usually occur around 1200-1230, 1700-1900, and 2300-2330 local time. In most markets before the afternoon news hours around 1500-1700, ENG use is also significant. The popularity of local morning shows from 0600-0900 is increasing in various markets, and these shows also use ENG systems. Transportable ENG transmitters are operated approximately twice per day. Broadcast engineers estimate that each ENG operation transmits an average of 15 min per operation but can vary from about 5 min to perhaps as long as 5 h.

5   Spectrum use and characteristics

The 1 990-2 110 MHz band is used as the primary ENG band because of favourable propagation characteristics. These include the lower levels of foliage attenuation that apply at higher frequencies and the ability to "building bounce" a signal to achieve a temporary link to a fixed receive site despite unavoidable path blockage.

In the United States of America, the ENG frequency band is divided into 7 channels each with 17 MHz except the first channel which is 18 MHz as shown in Fig. 8. ENG systems are usually operated at the centre of each channel, but the lower offset and upper offset channels are also used. Consequently, 21 carrier frequencies are possible, but all carrier frequencies cannot be used simultaneously. ENG systems may operate at the centre channel, the lower offset channel, the higher offset channel, or the lower and higher offset channels simultaneously, depending on the need and adjacent channel use at any time. Since ENG systems are sensitive to interference, only one transmission per channel per receive site at a time is usually possible.

ENG systems use frequency modulation (FM) for transmitting video. The carrier is virtually never transmitted unmodulated by video raster.

FIGURE 8

ENG channel plan in use in the United States of America

Centre carrier frequencies (MHz)

| 1 999.00 | 2 016.50 | 2 033.50 | 2 050.50 | 2 067.50 | 2 084.50 | 2 101.50 |
| Channel 1 | Channel 2 | Channel 3 | Channel 4 | Channel 5 | Channel 6 | Channel 7 |

Offset low carrier frequency (MHz)

Offset high carrier frequency (MHz)
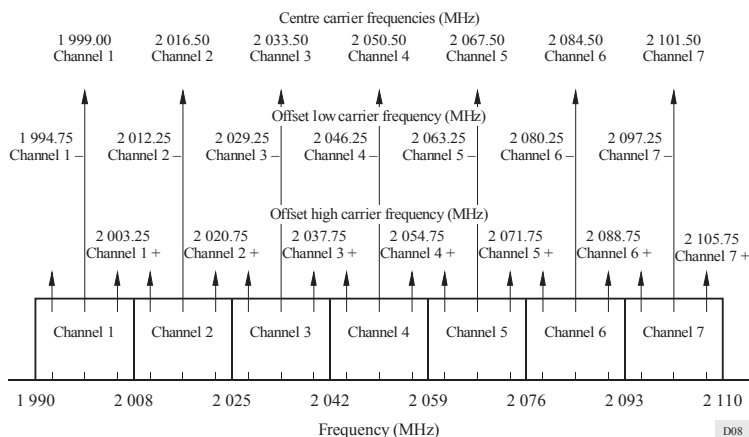
Annex 4

Description of certain aeronautical mobile telemetry systems operating in the 2 200-2 290 MHz band

1   Introduction

The aeronautical mobile telemetry systems operated by one administration consist of a small number of controlled, short duration transmitters operating in a few specific areas.

The number of simultaneously operating transmitting systems within any 1 000 km radius will rarely exceed 15. The maximum e.i.r.p. in the direction of a satellite in any 3 MHz bandwidth within any 1 000 km radius will rarely exceed 10 W.

2   Technical characteristics of aeronautical mobile telemetry systems

Aeronautical telemetry has been using the 2 200-2 290 MHz band for testing of missiles, space launch vehicles, air vehicles, and subsystems thereof since the late 1960s. The duration of the majority of these tests is less than 10 min, however some tests last for several hours. Telemetry operations can occur at any hour of the day with the peak usage during daylight hours. The majority of the flight tests occur at one (or more) of the test ranges operated by the United States of America government.

The characteristics of the telemetry transmitting systems are optimized for the vehicle being tested. Therefore, these characteristics vary considerably from vehicle to vehicle. There is no "typical" transmitting system. The effective radiated power of the telemetry systems is usually between 1 and 5 W. The required power level is determined by the amount of information to be transmitted, the maximum range between transmitting and receiving systems, the required data quality, and the sensitivity of the receiving system. The telemetry transmitting antennas are usually linearly polarized and are typically designed to have nearly isotropic coverage because the orientation of the vehicle under test with respect to the telemetry receiving antenna can change very rapidly. As the receiving antenna tracks a vehicle in flight, large variations occur in the signal levels at the receiver. These "fades" are caused by nulls in the vehicle antenna pattern and propagation anomalies such as multipath and ducting. The decrease in signal level during fades can exceed 30 dB. Therefore, a received signal considerably above threshold is required during optimum flight conditions to avoid data loss during signal fades.

The telemetry data formats and rates vary considerably from vehicle to vehicle. Most telemetry transmitting systems use frequency or phase modulation. The input to the transmitter may be digital, analogue, or a combination of digital and analogue. The 99% power bandwidths of the telemetry transmitting systems vary from less than 1 MHz to more than 10 MHz.

The required pre-detection signal-to-noise ratio (SNR) for acceptable data quality varies from 9 to 15 dB. The maximum distance between the vehicle under test and the telemetry receiving station is usually between 20 and 400 km (the maximum range for some tests is greater than 3 000 km). Typical receiver bandwidths vary from 0.5 to 10 MHz (these values are increasing). Receiving system noise temperatures vary between 200 K and 500 K. Main lobe gains of the receiving antennas vary from 6 dBi for some short-range mobile systems to greater than 50 dBi for large antennas. The larger antennas automatically track the test vehicle while the smaller antennas (gain less than 20 dBi) typically are pointed in the direction of the transmitter. The receiving antenna side lobes depend on the size and design of the receiving antenna. The majority of telemetry receiving antennas have diameters between 2.44 m (8 feet) and 10 m (32.8 feet).

3   Spectrum considerations

Aeronautical mobile telemetry system providers in the United States of America have divided this band into 90 channels each with a 1 MHz bandwidth. Multiple channels are assigned together when a wider bandwidth is needed.

Aeronautical telemetry operations are currently protected by coordination between the various users. The territory of the United States of America is divided into coordination areas. Area frequency coordinators assign and schedule frequency use within these areas.

The potential exists for significant interference between satellite earth stations co-located with aeronautical telemetry transmitting sites in the 2 200-2 290 MHz band. This problem is mitigated by controlling the time, frequency and location of the transmissions by each service in this band. Frequency interference control centres accommodate real-time changes and locate and identify any unauthorized transmissions.

A sample radiated power spectral density is shown in Fig. 9. This Figure shows the nominal power spectral density for one telemetry system. The data in this Figure is not typical, best case or worst case but is included only as an example of the spectral characteristics of the most common type of system currently used for aeronautical mobile telemetry systems. Some aeronautical mobile telemetry systems may have discrete spectral components during portions of a test flight, therefore the maximum spectral densities (dB(W/kHz)) may be significantly larger than the values shown in Fig. 9.

FIGURE 9

Sample spectrum
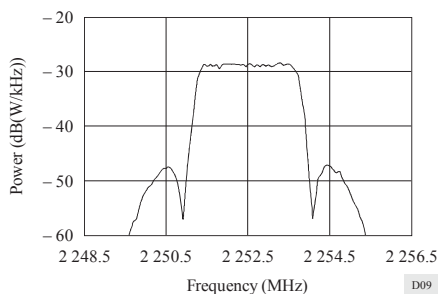
The maximum aggregate radiated power in any direction from all aeronautical mobile telemetry systems within a radius of 1 000 km will be less than 100 W in the band from 2 200-2 290 MHz. The maximum aggregate radiated power in any 3 MHz bandwidth will rarely exceed 10 W in any direction in any 1 000 km radius.

RECOMMENDATION ITU-R M.1171*

**RADIOTELEPHONY PROCEDURES IN THE
MARITIME MOBILE SERVICE**

(1995)

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to describe standard procedures for radiotelephony in the maritime mobile service,

recommends

1   that radiotelephony in the maritime mobile service should be performed in accordance with Annex 1.

ANNEX 1

Section I. Introduction

§ 1.   Radiotelephone stations should, as far as possible, be equipped with devices for instantaneous switching from transmission to reception and vice versa. This equipment is necessary for all stations participating in communication between ships and subscribers of the land telephone system.

§ 2.   (1) Stations equipped for radiotelephony may transmit and receive radiotelegrams by means of radiotelephony. Coast stations providing such service and open for public correspondence shall be indicated in the List of Coast Stations.

        (2) To facilitate radiocommunications the service abbreviations given in Recommendation ITU-R M.1172 may be used.

Section II. Calls by Radiotelephony

§ 3.   The provisions of this Section relating to the intervals between calls are not applicable to a station operating under conditions involving distress, urgency or safety.

§ 4.   (1) As a general rule, it rests with the ship station to establish communication with the coast station. For this purpose the ship station may call the coast station only when it comes within the service area of the latter, that is to say, that area within which, by using an appropriate frequency, the ship station can be heard by the coast station.

        (2) However, a coast station having traffic for a ship station may call this station if it has reason to believe that the ship station is keeping watch and is within the service area of the coast station.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO), and the Telecommunication Standardization Sector (ITU-T).

Note by the Secretariat: The references made to the Radio Regulations (RR) in this Recommendation refer to the RR as revised by the World Radiocommunication Conference 1995. These elements of the RR will come into force on 1 June 1998. Where applicable, the equivalent references in the current RR are also provided in square brackets.

§ 5.   (1)   In addition, each coast station shall, so far as practicable, transmit its calls in the form of "traffic lists" consisting of the call signs or other identification in alphabetical order of all ship stations for which it has traffic on hand. These calls shall be made at specified times fixed by agreement between the administrations concerned and at intervals of not less than two hours and not more than four hours during the working hours of the coast station.

(2)   Coast stations shall transmit their traffic lists on their normal working frequencies in the appropriate bands. The transmission shall be preceded by a general call to all stations.

(3)   The general call to all stations announcing the traffic lists may be sent on a calling frequency in the following form:

– "Hello all ships" or CQ (spoken as CHARLIE QUEBEC) not more than three times;

– the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

– " . . . Radio" not more than three times;

– "Listen for my traffic list on . . . kHz".

In no case may this preamble be repeated.

(4)   However, in the bands between 156 MHz and 174 MHz when the conditions for establishing contact are good, the call described in § 5.(3) above may be replaced by:

– "Hello all ships" or CQ (spoken as CHARLIE QUEBEC), once;

– the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

– " . . . Radio", twice;

– "Listen for my traffic list on channel . . . ".

In no case may this preamble be repeated.

(5)   The provisions of § 5.(3) are obligatory when 2 182 kHz or 156.8 MHz is used.

(6)   The hours at which coast stations transmit their traffic lists and the frequencies and classes of emission which they use for this purpose shall be stated in the List of Coast Stations.

(7)   Ship stations should as far as possible listen to the traffic lists transmitted by coast stations. On hearing their call sign or other identification in such a list they must reply as soon as they can do so.

(8)   When the traffic cannot be sent immediately, the coast station shall inform each ship station concerned of the probable time at which working can begin, and also, if necessary, the frequency and class of emission which will be used.

§ 6.   When a coast station receives calls from several ship stations at practically the same time, it decides the order in which these stations may transmit their traffic. Its decision shall be based on the priority (see RR No. S53.1 [No. 4441]) of the radiotelegrams or radiotelephone calls that the ship stations have on hand and on the need for allowing each calling station to clear the greatest possible number of communications.

§ 7.   (1)   When a station called does not reply to a call sent three times at intervals of two minutes, the calling shall cease.

(2)   However, when a station called does not reply, the call may be repeated at three-minute intervals.

(3)   In areas where reliable VHF communication with a called coast station is practicable, the calling ship station may repeat the call as soon as it is ascertained that traffic has been terminated at the coast station.

(4)   In the case of a communication between a station of the maritime mobile service and an aircraft station, calling may be renewed after an interval of five minutes.

(5)   Before renewing the call, the calling station shall ascertain that the station called is not in communication with another station.

(6)   If there is no reason to believe that harmful interference will be caused to other communications in progress, the provisions of § 7.(4) above are not applicable. In such cases the call, sent three times at intervals of two minutes, may be repeated after an interval of not less than three minutes.

(7)   However, before renewing the call, the calling station shall ascertain that further calling is unlikely to cause interference to other communications in progress and that the station called is not in communication with another station.

(8)   Ship stations shall not radiate a carrier wave between calls.

§ 8.   When the name and address of the administration or private operating agency controlling a ship station are not given in the appropriate list of stations or are no longer in agreement with the particulars given therein, it is the duty of the ship station to furnish as a matter of regular procedure, to the coast station to which it transmits traffic, all the necessary information in this respect.

§ 9.   (1)   The coast station may, by means of the abbreviation TR (spoken as TANGO ROMEO), ask the ship station to furnish it with the following information:

  a)   position and, whenever possible, course and speed;

  b)   next port of call.

(2)   The information referred to in § 9.(1) above, preceded by the abbreviation TR, should be furnished by ship stations, whenever this seems appropriate, without prior request from the coast station. The provision of this information is authorized only by the master or the person responsible for the ship.

Section III. Method of Calling, Reply to Calls and Signals Preparatory to Traffic when Using Calling Methods Other than Digital Selective Calling

A. Method of Calling

§ 10.   (1)   The call consists of:

  –   the call sign or other identification of the station called, not more than three times;

  –   the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

  –   the call sign or other identification of the calling station, not more than three times.

(2)   However, in the bands between 156 MHz and 174 MHz when the conditions for establishing contact are good, the call described in § 10.(1) above may be replaced by:

  –   the call sign of the station called, once;

  –   the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

  –   the call sign or other identification of the calling station, twice.

(3)   When calling a VHF coast station operating on more than one channel, a ship station calling on a working channel should include the number of that channel in the call.

(4)   When contact is established, the call sign or other identification may thereafter be transmitted once only.

(5)   When the coast station is fitted with equipment for selective calling in accordance with Recommendation ITU-R M.541, and the ship station is fitted with equipment for receiving such selective calls, the coast station shall call the ship by transmitting the appropriate code signals. The ship station shall call the coast station by speech in the manner given in § 10.(1) (see also Annex 2 to Recommendation ITU-R M.257).

§ 11.   Calls for internal communications on board ship when in territorial waters shall consist of:

  a)   From the master station:

    –   the name of the ship followed by a single letter (ALFA, BRAVO, CHARLIE, etc.) indicating the sub-station not more than three times;

    –   the words THIS IS;

    –   the name of the ship followed by the word CONTROL;

   b)   From the sub-station:

–   the name of the ship followed by the word CONTROL not more than three times;

–   the words THIS IS;

–   the name of the ship followed by a single letter (ALFA, BRAVO, CHARLIE, etc.) indicating the sub-station.

B. Frequency to Be Used for Calling
and for Preparatory Signals

B1. Bands Between 1 605 kHz and 4 000 kHz

§ 12.   (1)   A radiotelephone ship station calling a coast station should use for the call, in order of preference:

a)   a working frequency on which the coast station is keeping watch;

b)   the carrier frequency 2 182 kHz;

c)   in Regions 1 and 3 and in Greenland, the carrier frequency 2 191 kHz (assigned frequency 2 192.4 kHz) when a carrier frequency of 2 182 kHz is being used for distress;

d)   in Region 2 except for Greenland, the carrier frequency 2 191 kHz as a supplementary calling frequency in those areas of heavy usage of 2 182 kHz.

(2)   A radiotelephone ship station calling another ship station should use for the call:

a)   the carrier frequency 2 182 kHz;

b)   an intership frequency, whenever and wherever traffic density is high and prior arrangements can be made.

(3)   Subject to the provisions of § 12.(6), coast stations shall, in accordance with the requirements of their own country, call ship stations of their own nationality either on a working frequency or, when calls to individual ships are made, on the carrier frequency 2 182 kHz.

(4)   However, a ship station which keeps watch simultaneously on the carrier frequency 2 182 kHz and a working frequency should be called on the working frequency.

(5)   As a general rule, coast stations should call radiotelephone ship stations of another nationality on the carrier frequency 2 182 kHz.

(6)   Coast stations may call ship stations equipped to receive selective calls in accordance with Recommendations ITU-R M.257 and ITU-R M.541.

B2. Bands Between 4 000 kHz
and 27 500 kHz

§ 13.   (1)   A ship station calling a coast station by radiotelephony shall use either one of the calling frequencies mentioned in RR No. S52.221 [No. 4375] or the working frequency associated with that of the coast station, in accordance with RR Appendix S17, Part B Section I, [Appendix 16, Section A]

(2)   A coast station calling a ship station by radiotelephony shall use one of the calling frequencies mentioned in RR No. S52.222 [No. 4376], one of its working frequencies shown in the List of Coast Stations, or the carrier frequency 4 125 kHz or 6 215 kHz, in accordance with the provisions of RR Nos. S52.221.2 and S52.221.3 [Nos. 4375.2 and 4375.3].

(3)   The preliminary operations for the establishment of radiotelephone communications may also be carried out by radiotelegraphy using the procedure appropriate to radiotelegraphy (see Recommendation ITU-R M.1170 § 17).

(4)   The provisions of § 13.(1) and § 13.(2) do not apply to communications between ship stations and coast stations using the simplex frequencies specified in RR Appendix S17, Part B, Section I [Appendix 16, Section B].

B3. Bands Between 156 MHz and 174 MHz

§ 14.   (1)   In the bands between 156 MHz and 174 MHz, intership and coast station to ship calling should, as a general rule, be made on 156.8 MHz. However, coast station to ship calling may be conducted on a working channel or on a two-frequency calling channel which has been implemented in accordance with RR No. S52.236 [No. 4391]. Except for distress, urgency or safety communications, when 156.8 MHz should be used, ship to coast station calling should, whenever possible, be made on a working channel or on a two-frequency calling channel which has been implemented in accordance with RR No. S52.236 [No. 4391]. Ships wishing to participate in a port operations service or ship movement service should call on a port operations or ship movement working frequency, indicated in heavy type in the List of Coast Stations.

(2)   When 156.8 MHz is being used for distress, urgency or safety communications, a ship station desiring to participate in the port operations service may establish contact on 156.6 MHz, or another port operations frequency indicated in heavy type in the List of Coast Stations.

B4. Procedure for Calling a Station
Providing Pilot Service

§ 15.   A radiotelephone ship station calling a station providing pilot service should use for the call, in order of preference:

a)   an appropriate channel in the bands between 156 MHz and 174 MHz;

b)   a working frequency in the bands between 1 605 kHz and 4 000 kHz;

c)   the carrier frequency 2 182 kHz, and then only to determine the working frequency to be used.

C. Form of Reply to Calls

§ 16.   The reply to calls consists of:

–   the call sign or other identification of the calling station, not more than three times;

–   the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

–   the call sign or other identification of the station called, not more than three times.

D. Frequency for Reply

D1. Bands Between 1 605 kHz and 4 000 kHz

§ 17.   (1)   When a ship station is called on the carrier frequency 2 182 kHz, it should reply on the same carrier frequency unless another frequency is indicated by the calling station.

(2)   When a ship station is called by selective calling in accordance with Recommendation ITU-R M.257 it shall reply on a frequency on which the coast station keeps watch.

(3)   When a ship station is called on a working frequency by a coast station of the same nationality, it shall reply on the working frequency normally associated with the frequency used by the coast station for the call.

(4)   When calling a coast station or another ship station, a ship station shall indicate the frequency on which a reply is required if this frequency is not the normal one associated with the frequency used for the call.

(5)   A ship station which frequently exchanges traffic with a coast station of another nationality may use the same procedure for reply as ships of the nationality of the coast station, where this has been agreed by the administrations concerned.

(6)   As a general rule a coast station shall reply:

a)   on the carrier frequency 2 182 kHz to calls made on the carrier frequency 2 182 kHz, unless another frequency is indicated by the calling station;

b)   on a working frequency to calls made on a working frequency;

c)   on a working frequency to calls made in Regions 1 and 3 and in Greenland on the carrier frequency 2 191 kHz (assigned frequency 2 192.4 kHz).

<div align="center">

D2. Bands Between 4 000 kHz
and 27 500 kHz

</div>

§ 18.   (1)   A ship station called by a coast station shall reply either on one of the calling frequencies mentioned in RR No. S52.221 [No. 4375] or on the working frequency associated with that of the coast station, in accordance with RR Appendix S17, Part B, Section I [Appendix 16, Section A].

(2)   A coast station called by a ship station shall reply on one of the calling frequencies mentioned in RR No. S52.222 [No. 4376], or on one of its working frequencies shown in the List of Coast Stations.

(3)   When a station is called on the carrier frequency 4 125 kHz it should reply on the same frequency unless another frequency is indicated for that purpose by the calling station.

(4)   When a station is called on the carrier frequency 6 215 kHz it should reply on the same frequency unless another frequency is indicated for that purpose by the calling station.

(5)   The provisions of § 18.(1) and § 18.(2) do not apply to communication between ship stations and coast stations using the simplex frequencies specified in RR Appendix S17, Part B, Section I [Appendix 16, Section B].

<div align="center">

D3. Bands Between 156 MHz and 174 MHz

</div>

§ 19.   (1)   When a station is called on 156.8 MHz it should reply on the same frequency unless another frequency is indicated by the calling station.

(2)   When a coast station open to public correspondence calls a ship either by speech or by selective calling in accordance with Annex 2 to Recommendation ITU-R M.257, using a two-frequency channel, the ship station shall reply by speech on the frequency associated with that of the coast station; conversely, a coast station shall reply to a call from a ship station on the frequency associated with that of the ship station.

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E.   Indication of the Frequency to Be Used for Traffic

E1. Bands Between 1 605 kHz and 4 000 kHz

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§ 20.   If contact is established on the carrier frequency 2 182 kHz, coast and ship stations shall transfer to working frequencies for the exchange of traffic.

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E2. Bands Between 4 000 kHz
and 27 500 kHz

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§ 21.   After a ship station has established contact with a coast station, or another ship station, on the calling frequency of the band chosen, traffic shall be exchanged on their respective working frequencies.

E3. Bands Between 156 MHz and 174 MHz

§ 22.   (1)   Whenever contact has been established between a coast station in the public correspondence service and a ship station either on 156.8 MHz or on a two-frequency calling channel (see RR No. S52.237 [No. 4392]), the stations shall transfer to one of their normal pairs of working frequencies for the exchange of traffic. The calling station should indicate the channel to which it is proposed to transfer by reference to the frequency in MHz or, preferably, to its channel designator.

(2)   When contact on 156.8 MHz has been established between a coast station in the port operations service and a ship station, the ship station should indicate the particular service required (such as navigational information, docking instructions, etc.) and the coast station shall then indicate the channel to be used for the exchange of traffic by reference to the frequency in MHz, or, preferably, to its channel designator.

(3)   When contact on 156.8 MHz has been established between a coast station in the ship movement service and a ship station, the coast station shall then indicate the channel to be used for the exchange of traffic by reference to the frequency in MHz or, preferably, to its channel designator.

(4)   A ship station, when it has established contact with another ship station on 156.8 MHz, should indicate the intership channel to which it is proposed to transfer for the exchange of traffic by reference to the frequency in MHz or, preferably, to its channel designator.

(5)   However, a brief exchange of traffic not to exceed one minute concerning the safety of navigation need not be transmitted on a working frequency when it is important that all ships within range receive the transmission.

(6)   Stations hearing a transmission concerning the safety of navigation shall listen to the message until they are satisfied that the message is of no concern to them. They shall not make any transmission likely to interfere with the message.

F. Agreement on the Frequency to Be Used for Traffic

§ 23.   (1)   If the station called is in agreement with the calling station, it shall transmit:

a)   an indication that from that moment onwards it will listen on the working frequency or channel announced by the calling station;

b)   an indication that it is ready to receive the traffic of the calling station.

(2)   If the station called is not in agreement with the calling station on the working frequency or channel to be used, it shall transmit an indication of the working frequency or channel proposed.

(3)   For communications between a coast station and a ship station, the coast station shall finally decide the frequency or channel to be used.

(4)   When agreement is reached regarding the working frequency or channel which the calling station shall use for its traffic, the station called shall indicate that it is ready to receive the traffic.

G. Indication of Traffic

§ 24.   When the calling station wishes to exchange more than one radiotelephone call, or to transmit one or more radiotelegrams, it should indicate this when contact is established with the station called.

H. Difficulties in Reception

§ 25.   (1)   If the station called is unable to accept traffic immediately, it should reply to the call as indicated in § 16 followed by "Wait . . . minutes" (or $\overline{\text{AS}}$ spoken as ALFA SIERRA . . . (minutes) in case of language difficulties), indicating the probable duration of waiting time in minutes. If the probable duration exceeds ten minutes the reason for the delay shall be given. Alternatively the station called may indicate, by any appropriate means, that it is not ready to receive traffic immediately.

(2)   When a station receives a call without being certain that such a call is intended for it, it shall not reply until the call has been repeated and understood.

(3)   When a station receives a call which is intended for it, but is uncertain of the identification of the calling station, it shall reply immediately asking for a repetition of the call sign or other identification of the calling station.

Section IV. Forwarding (Routing) of Traffic

A. Traffic Frequency

§ 26.   (1)   Every station should transmit its traffic (radiotelephone calls or radiotelegrams) on one of its working frequencies in the band in which the call has been made.

(2)   In addition to its normal working frequency, printed in heavy type in the List of Coast Stations, a coast station may use one or more supplementary frequencies in the same band, in accordance with the provisions of RR Article S52 [Article 60].

(3)   The use of frequencies reserved for calling shall be forbidden for traffic, except distress traffic (see RR Appendix S13 [Chapter IX]).

(4)   After contact has been established on the frequency to be used for traffic, the transmission of a radiotelegram or radiotelephone call shall be preceded by:

–   the call sign or other identification of the station called;

–   the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

–   the call sign or other identification of the calling station.

(5)   The call sign or other identification need not be sent more than once.

B. Establishment of Radiotelephone Calls and Transmission of Radiotelegrams

B1. Establishment of Radiotelephone Calls

§ 27.   (1)   In setting up a radiotelephone call, the coast station should establish connection with the telephone network as quickly as possible. In the meantime, the ship station shall maintain watch on the appropriate working frequency as indicated by the coast station.

(2)   However, if the connection cannot be quickly established, the coast station shall inform the ship station accordingly. The latter station shall then either:

a)   maintain watch on the appropriate frequency until an effective circuit can be established; *or*

b)   contact the coast station later at a mutually agreed time.

(3)   When a radiotelephone call has been completed, the procedure indicated in § 29.(3) shall be applied unless further calls are on hand at either station.

B2. Transmission of Radiotelegrams

§ 28.   (1)   The transmission of a radiotelegram should be made as follows:

–   radiotelegram begins: from . . . (name of ship or aircraft);

–   number . . . (serial number of radiotelegram);

–   number of words . . . ;

–   date . . . ;

–   time . . . (time radiotelegram was handed in aboard ship or aircraft);

–   service indicators (if any);

–   address . . . ;

–   text . . . ;

–   signature . . . (if any);

–   radiotelegram ends, over.

(2)   As a general rule, radiotelegrams of all kinds transmitted by ship stations shall be numbered in a daily series; number 1 shall be given to the first radiotelegram sent each day to each separate station.

(3)   A series of numbers which has begun in radiotelegraphy should be continued in radiotelephony and vice versa.

(4)   Each radiotelegram should be transmitted once only by the sending station. However, it may, when necessary, be repeated in full or in part by the receiving or the sending station.

(5)   In transmitting groups of figures, each figure shall be spoken separately and the transmission of each group or series of groups shall be preceded by the words "in figures".

(6)   Numbers written in letters shall be spoken as they are written, their transmission being preceded by the words "in letters".

B3.   Acknowledgement of Receipt

§ 29.   (1)   The acknowledgement of receipt of a radiotelegram or a series of radiotelegrams shall be given by the receiving station in the following manner:

–   the call sign or other identification of the sending station;

–   the words THIS IS (or DE spoken as DELTA ECHO in case of language difficulties);

–   the call sign or other identification of the receiving station;

–   "Your No. . . . received, over" (or R spoken as ROMEO . . . (number), K spoken as KILO in case of language difficulties); *or*

`   –   "Your No. . . . to No. . . . received, over" (or R spoken as ROMEO . . . (numbers), K spoken as KILO in case of language difficulties).

(2)   The radiotelegram, or series of radiotelegrams, shall not be considered as cleared until this acknowledgement has been received.

(3)   The end of work between two stations shall be indicated by each of them by means of the word "Out" (or $\overline{\text{VA}}$ spoken as VICTOR ALFA in case of language difficulties).

Section V.   Duration and Control of Working

§ 30.   (1)   In communications between coast stations and ship stations, the ship station shall comply with the instructions given by the coast station in all questions relating to the order and time of transmission, to the choice of frequency, and to the duration and suspension of work.

(2)   In communications between ship stations, the station called controls the working in the manner indicated in § 30.(1) above. However, if a coast station finds it necessary to intervene, the ship stations shall comply with the instructions given by the coast station.

RECOMMENDATION ITU-R M.1172*

MISCELLANEOUS ABBREVIATIONS AND SIGNALS TO BE USED FOR RADIOCOMMUNICATIONS IN THE MARITIME MOBILE SERVICE

(1995)

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to describe miscellaneous abbreviations and signals to be used in the maritime mobile service,

recommends

1   that the use of miscellaneous abbreviations and signals for radiocommunications in the maritime mobile service be in accordance with Annex 1.

ANNEX 1

Miscellaneous abbreviations and signals to be used for radiocommunications in the maritime mobile service

Section I. Q Code

Introduction

1   The series of groups listed in this Annex range from QOA to QUZ.

2   The QOA to QQZ series are reserved for the maritime mobile service.

3   Certain Q code abbreviations may be given an affirmative or negative sense by sending, immediately following the abbreviation, the letter C or the letters NO (in radiotelephony spoken as: CHARLIE or NO).

4   The meanings assigned to Q code abbreviations may be amplified or completed by the appropriate addition of other groups, call signs, place names, figures, numbers, etc. It is optional to fill in the blanks shown in parentheses. Any data which are filled in where blanks appear shall be sent in the same order as shown in the text of the following tables.

5   Q code abbreviations are given the form of a question when followed by a question mark in radiotelegraphy and RQ (ROMEO QUEBEC) in radiotelephony. When an abbreviation is used as a question and is followed by additional or complementary information, the question mark (or RQ) should follow this information.

6   Q code abbreviations with numbered alternative significations shall be followed by the appropriate figure to indicate the exact meaning intended. This figure shall be sent immediately following the abbreviation.

7   All times shall be given in Coordinated Universal Time (UTC) unless otherwise indicated in the question or reply.

8   An asterisk * following a Q code abbreviation means that this signal has a meaning similar to a signal appearing in the International Code of Signals.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO).

Abbreviations Available for the Maritime Mobile Service

A. List of Abbreviations in Alphabetical Order

Abbre-viation	Question	Answer or Advice
QOA	Can you communicate by radio-telegraphy (500 kHz)?	I can communicate by radiotele-graphy (500 kHz).
QOB	Can you communicate by radio-telephony (2 182 kHz)?	I can communicate by radio-telephony (2 182 kHz).
QOC	Can you communicate by radiote-lephony (channel 16 – frequency 156.80 MHz)?	I can communicate by radiotele-phony (channel 16 – frequency 156.80 MHz).
QOD	Can you communicate with me in … 0. Dutch 5. Italian 1. English 6. Japanese 2. French 7. Norwegian 3. German 8. Russian 4. Greek 9. Spanish?	I can communicate with you in … 0. Dutch 5. Italian 1. English 6. Japanese 2. French 7. Norwegian 3. German 8. Russian 4. Greek 9. Spanish.
QOE	Have you received the safety signal sent by … *(name and/or call sign)*?	I have received the safety signal sent by … *(name and/or call sign)*.
QOF	What is the commercial quality of my signals?	The quality of your signals is … 1. not commercial 2. marginally commercial 3. commercial.
QOG	How many tapes have you to send?	I have … tapes to send.
QOH	Shall I send a phasing signal for … seconds?	Send a phasing signal for … sec-onds.
QOI	Shall I send my tape?	Send your tape.
QOJ	Will you listen on … kHz (*or* MHz) for signals of emergency position-indicating radiobea-cons?	I am listening on … kHz (*or* MHz) for signals of emergency posi-tion-indicating radiobeacons.

Abbre-viation	Question	Answer or Advice
QOK	Have you received the signals of an emergency position-indicating radiobeacon on … kHz (*or* MHz)?	I have received the signals of an emergency position-indicating radiobeacon on … kHz (*or* MHz).
QOL	Is your vessel fitted for reception of selective calls? If so, what is your selective call number or signal?	My vessel is fitted for the reception of selective calls. My selective call number or signal is …
QOM	On what frequencies can your vessel be reached by a selective call?	My vessel can be reached by a selective call on the following frequency/ies … (periods of time to be added if necessary).
QOO	Can you send on any working frequency?	I can send on any working frequency.
QOT	Do you hear my call; what is the approximate delay in minutes before we may exchange traffic?	I hear your call; the approximate delay is … minutes.
QRA	What is the name of your vessel (*or* station)?	The name of my vessel (*or* station) is …
QRB	How far approximately are you from my station?	The approximate distance between our stations is … nautical miles (*or* kilometres).
QRC	By what private enterprise (*or* state administration) are the accounts for charges for your station settled?	The accounts for charges of my station are settled by the private enterprise … (*or* state administration).
QRD	Where are you bound for and where are you from?	I am bound for … from …
QRE	What is your estimated time of arrival at … (*or* over …) (*place*)?	My estimated time of arrival at … (*or* over …) (*place*) is … hours.
QRF	Are you returning to … (*place*)?	I am returning to … (*place*). *or* Return to ... (*place*).

Abbre-viation	Question	Answer or Advice
QRG	Will you tell me my exact frequency (*or* that of …)?	Your exact frequency (*or* that of …) is ... kHz (*or* MHz).
QRH	Does my frequency vary?	Your frequency varies.
QRI	How is the tone of my transmission?	The tone of your transmission is … 1. good 2. variable 3. bad.
QRJ	How many radiotelephone calls have you to book?	I have … radiotelephone calls to book.
QRK	What is the intelligibility of my signals (*or* those of … *(name and/or call sign)*)?	The intelligibility of your signals (*or* those of … *(name and/or call sign)*) is … 1. bad 2. poor 3. fair 4. good 5. excellent.
QRL	Are you busy?	I am busy (*or* I am busy with … *(name and/or call sign)*). Please do not interfere.
QRM	Is my transmission being interfered with?	Your transmission is being interfered with … 1. nil 2. slightly 3. moderately 4. severely 5. extremely.
QRN	Are you troubled by static?	I am troubled by static … 1. nil 2. slightly 3. moderately 4. severely 5. extremely.

Abbre- viation	Question	Answer or Advice
QRO	Shall I increase transmitter power?	Increase transmitter power.
QRP	Shall I decrease transmitter power?	Decrease transmitter power.
QRQ	Shall I send faster?	Send faster (… words per minute).
QRR	Are you ready for automatic operation?	I am ready for automatic operation. Send at … words per minute.
QRS	Shall I send more slowly?	Send more slowly (… words per minute).
QRT	Shall I stop sending?	Stop sending.
QRU	Have you anything for me?	I have nothing for you.
QRV	Are you ready?	I am ready.
QRW	Shall I inform … that you are calling him on … kHz (*or* MHz)?	Please inform … that I am calling him on … kHz (*or* MHz).
QRX	When will you call me again?	I will call you again at … hours on … kHz (*or* MHz).
QRY	What is my turn? *(Relates to communication.)*	Your turn is Number … *(or according to any other indication). (Relates to communication.)*
QRZ	Who is calling me?	You are being called by … (on … kHz(*or* MHz)).
QSA	What is the strength of my signals (*or* those of … *(name and/or call sign))*?	The strength of your signals (*or* those of … *(name and/or call sign))* is … 1. scarcely perceptible 2. weak 3. fairly good 4. good 5. very good.

Abbre-viation	Question	Answer or Advice
QSB	Are my signals fading?	Your signals are fading.
QSC	Are you a low traffic ship station?	I am a low traffic ship station.
QSD	Are my signals mutilated?	Your signals are mutilated.
QSE*	What is the estimated drift of the survival craft?	The estimated drift of the survival craft is … *(figures and units)*.
QSF*	Have you effected rescue?	I have effected rescue and am proceeding to … base (with … persons injured requiring ambulance).
QSG	Shall I send … telegrams at a time?	Send … telegrams at a time.
QSH	Are you able to home with your direction-finding equipment?	I am able to home with my direction-finding equipment (on … *(name and/or call sign)*).
QSI		I have been unable to break in on your transmission. *or* Will you inform … *(name and/or call sign)* that I have been unable to break in on his transmission (on … kHz (*or* MHz)).
QSJ	What is the charge to be collected to … including your internal charge?	The charge to be collected to … including my internal charge is … francs.
QSK	Can you hear me between your signals and if so may I break in on your transmission?	I can hear you between my signals; break in on my transmission.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.

Abbre-viation	Question	Answer or Advice
QSM	Shall I repeat the last telegram which I sent you (*or* some previous telegram)?	Repeat the last telegram which you sent me (*or* telegram(s) number(s) …).
QSN	Did you hear me (*or* … *(name and/or call sign)*) on … kHz (*or* MHz)?	I did hear you (*or* … *(name and/or call sign)*) on … kHz (*or* MHz).
QSO	Can you communicate with … *(name and/or call sign)* direct (*or* by relay)?	I can communicate with … *(name and/or call sign)* direct (*or* by relay through …).
QSP	Will you relay to … *(name and/or call sign)* free of charge?	I will relay to … *(name and/or call sign)* free of charge.
QSQ	Have you a doctor on board (*or* is … *(name of person)* on board)?	I have a doctor on board (*or* … *(name of person)* is on board).
QSR	Shall I repeat the call on the calling frequency?	Repeat your call on the calling frequency; did not hear you (*or* have interference).
QSS	What working frequency will you use?	I will use the working frequency … kHz (*or* MHz) *(in the high frequency bands normally only the last three figures of the frequency need be given)*.
QSU	Shall I send or reply on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …)?	Send or reply on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …).
QSV	Shall I send a series of Vs (*or* signs) for adjustment on this frequency (*or* on … kHz (*or* MHz))?	Send a series of Vs (*or* signs) for adjustment on this frequency (*or* on … kHz (*or* MHz)).

Abbre-viation	Question	Answer or Advice
QSW	Will you send on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …)?	I am going to send on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …).
QSX	Will you listen to … *(name and/or call sign(s))* on … kHz (*or* MHz), or in the bands …/ channels …?	I am listening to … *(name and/or call sign(s))* on … kHz (*or* MHz), or in the bands …/ channels …
QSY	Shall I change to transmission on another frequency?	Change to transmission on another frequency (*or* on … kHz (*or* MHz)).
QSZ	Shall I send each word or group more than once?	Send each word or group twice (*or* … times).
QTA	Shall I cancel telegram (*or* message) number …?	Cancel telegram (*or* message) number …
QTB	Do you agree with my counting of words?	I do not agree with your counting of words; I will repeat the first letter or digit of each word or group.
QTC	How many telegrams have you to send?	I have … telegrams for you (*or* for … *(name and/or call sign))*.
QTD*	What has the rescue vessel or rescue aircraft recovered?	… *(identification)* has recovered… 1. … *(number)* survivors 2. wreckage 3. … *(number)* bodies.
QTE	What is my TRUE bearing from you? *or*	Your TRUE bearing from me is … degrees at … hours. *or*
	What is my TRUE bearing from … *(name and/or call sign)*? *or*	Your TRUE bearing from … *(name and/or call sign)* was … degrees at … hours. *or*

Abbre-viation	Question	Answer or Advice
QTE (cont.)	What is the TRUE bearing of … *(name and/or call sign)* from … *(name and/or call sign)*?	The TRUE bearing of … *(name and/or call sign)* from … *(name and/or call sign)* was … degrees at … hours.
QTF	Will you give me my position according to the bearings taken by the direction-finding stations which you control?	Your position according to the bearings taken by the direction-finding stations which I control was … latitude, … longitude *(or other indication of position)*, class … at … hours.
QTG	Will you send two dashes of ten seconds each (*or* carrier) followed by your call sign (*or* name) (repeated … times) on … kHz (or MHz)? *or* Will you request … *(name and/or call sign)* to send two dashes of ten seconds each (*or* carrier) followed by his call sign *(and/or name)* (repeated … times) on … kHz (*or* MHz)?	I am going to send two dashes of ten seconds each (*or* carrier) followed by my call sign (*or* name) (repeated … times) on … kHz (*or* MHz). *or* I have requested … *(name and/or call sign)* to send two dashes of ten seconds each (*or* carrier) followed by his call sign *(and/or name)* (repeated … times) on ... kHz (*or* MHz).
QTH	What is your position in latitude and longitude *(or according to any other indication)*?	My position is … latitude, … longitude *(or according to any other indication).*
QTI*	What is your TRUE course?	My TRUE course is … degrees.

Abbre-viation	Question	Answer or Advice
QTJ*	What is your speed? *(Requests the speed of a ship or aircraft through the water or air respectively.)*	My speed is … knots (*or* kilometres per hour *or* … statute miles per hour). *(Indicates the speed of a ship or aircraft through the water or air respectively.)*
QTK*	What is the speed of your aircraft in relation to the surface of the Earth?	The speed of my aircraft in relation to the surface of the Earth is … knots (*or* … kilometres per hour *or* … statute miles per hour).
QTL*	What is your TRUE heading?	My TRUE heading is … degrees.
QTM*	What is your MAGNETIC heading?	My MAGNETIC heading is … degrees.
QTN	At what time did you depart from … *(place)*?	I departed from … *(place)* at … hours.
QTO	Have you left dock (*or* port)? *or* Are you airborne?	I have left dock (*or* port). *or* I am airborne.
QTP	Are you going to enter dock (*or* port)? *or* Are you going to alight (*or* land)?	I am going to enter dock (*or* port). *or* I am going to alight (*or* land).
QTQ	Can you communicate with my station by means of the International Code of Signals (INTERCO)?	I am going to communicate with your station by means of the International Code of Signals (INTERCO).
QTR	What is the correct time?	The correct time is … hours.
QTS	Will you send your call sign (*and/or* name) for … seconds?	I will send my call sign (*and/or* name) for … seconds.
QTT		The identification signal which follows is superimposed on another transmission.

Abbre-viation	Question	Answer or Advice
QTU	What are the hours during which your station is open?	My station is open from … to … hours.
QTV	Shall I stand guard for you on the frequency of … kHz (*or* MHz) (from … to … hours)?	Stand guard for me on the frequency of … kHz (*or* MHz) (from … to … hours).
QTW*	What is the condition of survivors?	Survivors are in … condition and urgently need …
QTX	Will you keep your station open for further communication with me until further notice (*or* until … hours)?	I will keep my station open for further communication with you until further notice (*or* until … hours).
QTY*	Are you proceeding to the position of incident and if so when do you expect to arrive?	I am proceeding to the position of incident and expect to arrive at … hours (on ... *(date)*).
QTZ*	Are you continuing the search?	I am continuing the search for … (aircraft, ship, survival craft, survivors or wreckage).
QUA	Have you news of … *(name and/or call sign)*?	Here is news of … *(name and/or call sign)*.
QUB*	Can you give me in the following order information concerning: the direction in degrees TRUE and speed of the surface wind; visibility; present weather; and amount, type and height of base of cloud above surface elevation at … *(place of observation)*?	Here is the information requested: … *(The units used for speed and distances should be indicated.)*

Abbre-viation	Question	Answer or Advice
QUC	What is the number *(or other indication)* of the last message you received from me *(or* from … *(name and/or call sign))*?	The number *(or other indication)* of the last message I received from you *(or* from … *(name and/or call sign))* is …
QUD	Have you received the urgency signal sent by … *(name and/or call sign)*?	I have received the urgency signal sent by … *(name and/or call sign)* at … hours.
QUE	Can you speak in … *(language)*, with interpreter if necessary; if so, on what frequencies?	I can speak in … *(language)* on … kHz (*or* MHz).
QUF	Have you received the distress signal sent by … *(name and/or call sign)*?	I have received the distress signal sent by … *(name and/or call sign)* at … hours.
QUH*	Will you give me the present barometric pressure at sea level?	The present barometric pressure at sea level is … *(units)*.
QUM	May I resume normal working?	Normal working may be resumed.
QUN	1. *When directed to all stations:* Will vessels in my immediate vicinity … *or* (in the vicinity of … latitude, … longitude) *or* (in the vicinity of …) please indicate their position, TRUE course and speed? 2. *When directed to a single station:* Please indicate your position, TRUE course and speed.	My position, TRUE course and speed are …

Abbre-viation	Question	Answer or Advice
QUO*	Shall I search for…. 　　1. aircraft 　　2. ship 　　3. survival craft 　　in the vicinity of … latitude, 　　… longitude *(or according to any other indication)*?	Please search for … 　　1. aircraft 　　2. ship 　　3. survival craft 　　in the vicinity of … latitude, 　　… longitude *(or according to any other indication)*.
QUP*	Will you indicate your position by … 　　1. searchlight 　　2. black smoke trail 　　3. pyrotechnic lights?	My position is indicated by … 　　1. searchlight 　　2. black smoke trail 　　3. pyrotechnic lights.
QUR*	Have survivors … 　1. received survival equipment 　2. been picked up by rescue vessel 　3. been reached by ground rescue party?	Survivors ... 　1. are in possession of survival equipment dropped by … 　2. have been picked up by rescue vessel 　3. have been reached by ground rescue party.
QUS*	Have you sighted survivors or wreckage? If so, in what position?	Have sighted … 　1. survivors in water 　2. survivors on rafts 　3. wreckage 　in position … latitude, … longitude *(or according to any other indication)*.
QUT*	Is position of incident marked?	Position of incident is marked by … 　1. flame or smoke float 　2. sea marker 　3. sea marker dye 　4. … *(specify other marking)*.

Abbre-viation	Question	Answer or Advice
QUU*	Shall I home ship or aircraft to my position?	Home ship or aircraft … *(name and/or call sign)* … 1. to your position by sending your call sign and long dashes on … kHz (*or* MHz) 2. by sending on … kHz (*or* MHz) TRUE track to reach you.
QUW*	Are you in the search area designated as … *(designator or latitude and longitude)*?	I am in the … *(designation)* search area.
QUX	Do you have any navigational warnings or gale warnings in force?	I have the following navigational warning(s) or gale warning(s) in force: …
QUY*	Is position of survival craft marked?	Position of survival craft was marked at … hours by … 1. flame or smoke float 2. sea marker 3. sea marker dye 4. … *(specify other marking)*.
QUZ	May I resume restricted working?	Distress phase still in force; restricted working may be resumed.

B. List of Signals According to the Nature of Questions, Answer or Advice

Abbre-viation	Question	Answer or Advice
	Name	
QRA	What is the name of your vessel (*or* station)?	The name of my vessel (*or* station) is …
	Route	
QRD	Where are you bound for and where are you from?	I am bound for … from …
	Position	
QRB	How far approximately are you from my station?	The approximate distance between our stations is … nautical miles (*or* kilometres).
QTH	What is your position in latitude and longitude *(or according to any other indication)*?	My position is … latitude, … longitude *(or according to any other indication).*
QTN	At what time did you depart from … *(place)*?	I departed from … *(place)* at … hours.
	Quality of Signals	
QOF	What is the commercial quality of my signals?	The quality of your signals is … 1. not commercial 2. marginally commercial 3. commercial.
QRI	How is the tone of my transmission?	The tone of your transmission is… 1. good 2. variable 3. bad.

Abbre-viation	Question	Answer or Advice
	Quality of Signals (cont.)	
QRK	What is the intelligibility of my signals (*or* those of … *(name and/or call sign)*)?	The intelligibility of your signals (*or* those of … *(name and/or call sign)*) is … 1. bad 2. poor 3. fair 4. good 5. excellent.
	Strength of Signals	
QRO	Shall I increase transmitter power?	Increase transmitter power.
QRP	Shall I decrease transmitter power?	Decrease transmitter power.
QSA	What is the strength of my signals (*or* those of … *(name and/or call sign)*)?	The strength of your signals (*or* those of … *(name and/or call sign)*) is … 1. scarcely perceptible 2. weak 3. fairly good 4. good 5. very good.
QSB	Are my signals fading?	Your signals are fading.
	Keying	
QRQ	Shall I send faster?	Send faster (… words per minute).
QRR	Are you ready for automatic operation?	I am ready for automatic operation. Send at … words per minute.

Abbre-viation	Question	Answer or Advice
	Keying (cont.)	
QRS	Shall I send more slowly?	Send more slowly (… words per minute).
QSD	Are my signals mutilated?	Your signals are mutilated.
	Interference	
QRM	Is my transmission being interfered with?	Your transmission is being interfered with … 1. nil 2. slightly 3. moderately 4. severely 5. extremely.
QRN	Are you troubled by static?	I am troubled by static … 1. nil 2. slightly 3. moderately 4. severely 5. extremely.
	Adjustment of Frequency	
QRG	Will you tell me my exact frequency (*or* that of …)?	Your exact frequency (*or* that of …) is … kHz (*or* MHz).
QRH	Does my frequency vary?	Your frequency varies.
QTS	Will you send your call sign *(and/or name)* for … seconds?	I will send my call sign *(and/or name)* for … seconds.
	Choice of Frequency and/or Class of Emission	
QOO	Can you send on any working frequency?	I can send on any working frequency.

Abbre-viation	Question	Answer or Advice
	Choice of Frequency and/or Class of Emission (cont.)	
QSN	Did you hear me (*or … (name and/or call sign)*) on … kHz (*or* MHz)?	I did hear you (*or … (name and/or call sign)*) on … kHz (*or* MHz).
QSS	What working frequency will you use?	I will use the working frequency … kHz (*or* MHz) *(in the high frequency bands normally only the last three figures of the frequency need be given)*.
QSU	Shall I send or reply on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …)?	Send or reply on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …).
QSV	Shall I send a series of Vs (*or* signs) for adjustment on this frequency (*or* on … kHz (*or* MHz))?	Send a series of Vs (*or* signs) for adjustment on this frequency (*or* on … kHz (*or* MHz)).
QSW	Will you send on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …)?	I am going to send on this frequency (*or* on … kHz (*or* MHz)) (with emissions of class …).
QSX	Will you listen to … *(name and/or call sign(s))* on … kHz (*or* MHz), or in the bands …/ channels …?	I am listening to … *(name and/or call sign(s))* on … kHz (*or* MHz), or in the bands …/ channels …
	Change of Frequency	
QSY	Shall I change to transmission on another frequency?	Change to transmission on another frequency (*or* on … kHz (*or* MHz)).
	Establishing Communication	
QOA	Can you communicate by radio-telegraphy (500 kHz)?	I can communicate by radiotele-graphy (500 kHz).

Abbre-viation	Question	Answer or Advice
	Establishing Communication (cont.)	
QOB	Can you communicate by radio-telephony (2 182 kHz)?	I can communicate by radiotelephony (2 182 kHz).
QOC	Can you communicate by radio-telephony (channel 16 – frequency 156.80 MHz)?	I can communicate by radio-telephony (channel 16 – frequency 156.80 MHz).
QOD	Can you communicate with me in … 0. Dutch 5. Italian 1. English 6. Japanese 2. French 7. Norwegian 3. German 8. Russian 4. Greek 9. Spanish?	I can communicate with you in … 0. Dutch 5. Italian 1. English 6. Japanese 2. French 7. Norwegian 3. German 8. Russian 4. Greek 9. Spanish.
QOT	Do you hear my call; what is the approximate delay in minutes before we may exchange traffic?	I hear your call; the approximate delay is … minutes.
QRL	Are you busy?	I am busy (*or* I am busy with … *(name and/or call sign)*). Please do not interfere.
QRV	Are you ready?	I am ready.
QRX	When will you call me again?	I will call you again at … hours on … kHz (*or* MHz).
QRY	What is my turn? *(Relates to communication.)*	Your turn is Number … *(or according to any other indication). (Relates to communication.)*
QRZ	Who is calling me?	You are being called by … (on … kHz (*or* MHz)).
QSC	Are you a low traffic ship station?	I am a low traffic ship station.

Abbre-viation	Question	Answer or Advice
	Establishing Communication (cont.)	
QSR	Shall I repeat the call on the calling frequency?	Repeat your call on the calling frequency; did not hear you (*or* have interference).
QTQ	Can you communicate with my station by means of the International Code of Signals (INTERCO)?	I am going to communicate with your station by means of the International Code of Signals (INTERCO).
QUE	Can you speak in … *(language)*, with interpreter if necessary; if so, on what frequencies?	I can speak in … *(language)* on … kHz (*or* MHz).
	Selective Calls	
QOL	Is your vessel fitted for reception of selective calls? If so, what is your selective call number or signal?	My vessel is fitted for the reception of selective calls. My selective call number or signal is …
QOM	On what frequencies can your vessel be reached by a selective call?	My vessel can be reached by a selective call on the following frequency/ies … (periods of time to be added if necessary).
	Time	
QTR	What is the correct time?	The correct time is ... hours.
QTU	What are the hours during which your station is open?	My station is open from … to … hours.
	Charges	
QRC	By what private enterprise (*or* state administration) are the accounts for charges for your station settled?	The accounts for charges of my station are settled by the private enterprise … (*or* state administration).

Abbre-viation	Question	Answer or Advice
	Charges (cont.)	
QSJ	What is the charge to be collected to … including your internal charge?	The charge to be collected to … including my internal charge is … francs.
	Transit	
QRW	Shall I inform … that you are calling him on … kHz (*or* MHz)?	Please inform … that I am calling him on … kHz (*or* MHz).
QSO	Can you communicate with … *(name and/or call sign)* direct (*or* by relay)?	I can communicate with … *(name and/or call sign)* direct (*or* by relay through …).
QSP	Will you relay to … *(name and/or call sign)* free of charge?	I will relay to … *(name and/or call sign)* free of charge.
QSQ	Have you a doctor on board (*or* is … *(name of person)* on board)?	I have a doctor on board (*or* … *(name of person)* is on board).
QUA	Have you news of … *(name and/or call sign)*?	Here is news of … *(name and/or call sign)*.
QUC	What is the number *(or other indication)* of the last message you received from me (*or* from … *(name and/or call sign)*)?	The number *(or other indication)* of the last message I received from you (*or* from … *(name and/or call sign)*) is ...
	Exchange of Correspondence	
QOG	How many tapes have you to send?	I have … tapes to send.
QOH	Shall I send a phasing signal for … seconds?	Send a phasing signal for … seconds.

Abbre-viation	Question	Answer or Advice
	Exchange of Correspondence (cont.)	
QOI	Shall I send my tape?	Send your tape.
QRJ	How many radiotelephone calls have you to book?	I have … radiotelephone calls to book.
QRU	Have you anything for me?	I have nothing for you.
QSG	Shall I send … telegrams at a time?	Send … telegrams at a time.
QSI		I have been unable to break in on your transmission. *or* Will you inform … *(name and/or call sign)* that I have been unable to break in on his transmission (on … kHz (*or* MHz)).
QSK	Can you hear me between your signals and if so may I break in on your transmission?	I can hear you between my signals; break in on my transmission.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.
QSM	Shall I repeat the last telegram which I sent you (*or* some previous telegram)?	Repeat the last telegram which you sent me (*or* telegram(s) number(s) …).
QSZ	Shall I send each word or group more than once?	Send each word or group twice (*or* … times).
QTA	Shall I cancel telegram (*or* message) number …?	Cancel telegram (*or* message) number …
QTB	Do you agree with my counting of words?	I do not agree with your counting of words; I will repeat the first letter or digit of each word or group.

Abbre-viation	Question	Answer or Advice
	Exchange of Correspondence (cont.)	
QTC	How many telegrams have you to send?	I have … telegrams for you (*or* for … *(name and/or call sign)*).
QTV	Shall I stand guard for you on the frequency of … kHz (*or* MHz) (from … to … hours)?	Stand guard for me on the frequency of … kHz (*or* MHz) (from … to … hours).
QTX	Will you keep your station open for further communication with me until further notice (*or* until … hours)?	I will keep my station open for further communication with you until further notice (*or* until … hours).
	Movement	
QRE	What is your estimated time of arrival at … (*or* over …) *(place)*?	My estimated time of arrival at … (*or* over …) *(place)* is … hours.
QRF	Are you returning to … *(place)*?	I am returning to … *(place)*. *or* Return to … *(place)*.
QSH	Are you able to home with your direction-finding equipment?	I am able to home with my direction-finding equipment (on … *(name and/or call sign)*).
QTI*	What is your TRUE course?	My TRUE course is … degrees.
QTJ*	What is your speed? *(Requests the speed of a ship or aircraft through the water or air respectively.)*	My speed is … knots (*or* kilometres per hour *or* … statute miles per hour). *(Indicates the speed of a ship or aircraft through the water or air respectively.)*

Abbre-viation	Question	Answer or Advice
	Movement (cont.)	
QTK*	What is the speed of your aircraft in relation to the surface of the Earth?	The speed of my aircraft in relation to the surface of the Earth is … knots (*or* … kilometres per hour *or* … statute miles per hour).
QTL*	What is your TRUE heading?	My TRUE heading is … degrees.
QTM*	What is your MAGNETIC heading?	My MAGNETIC heading is … degrees.
QTN	At what time did you depart from … *(place)*?	I departed from … *(place)* at … hours.
QTO	Have you left dock (*or* port)? *or* Are you airborne?	I have left dock (*or* port). *or* I am airborne.
QTP	Are you going to enter dock (*or* port)? *or* Are you going to alight (*or* land)?	I am going to enter dock (*or* port). *or* I am going to alight (*or* land).
QUN	1. *When directed to all stations:* Will vessels in my immediate vicinity … *or* (in the vicinity of … latitude, … longitude) *or* (in the vicinity of …) please indicate their position, TRUE course and speed? 2. *When directed to a single station:* Please indicate your position, TRUE course and speed.	My position, TRUE course and speed are …

Abbre-viation	Question	Answer or Advice
	Meteorology	
QUB*	Can you give me in the following order information concerning: the direction in degrees TRUE and speed of the surface wind; visibility; present weather; and amount, type and height of base of cloud above surface elevation at … *(place of observation)*?	Here is the information requested: … *(The units used for speed and distances should be indicated.)*
QUH*	Will you give me the present barometric pressure at sea level?	The present barometric pressure at sea level is … *(units).*
QUX	Do you have any navigational warnings or gale warnings in force?	I have the following navigational warning(s) or gale warning(s) in force: …
	Radio Direction-Finding	
QTE	What is my TRUE bearing from you?	Your TRUE bearing from me is … degrees at … hours.
	or	*or*
	What is my TRUE bearing from … *(name and/or call sign)*?	Your TRUE bearing from … *(name and/or call sign)* was … degrees at … hours.
	or	*or*
	What is the TRUE bearing of … *(name and/or call sign)* from … *(name and/or call sign)*?	The TRUE bearing of … *(name and/or call sign)* from … *(name and/or call sign)* was … degrees at … hours.

Abbreviation	Question	Answer or Advice
	Radio Direction-Finding (cont.)	
QTF	Will you give me my position according to the bearings taken by the direction-finding stations which you control?	Your position according to the bearings taken by the direction-finding stations which I control was … latitude, … longitude *(or other indication of position)*, class … at … hours.
QTG	Will you send two dashes of ten seconds each (*or* carrier) followed by your call sign (*or* name) (repeated … times) on … kHz (*or* MHz)? *or*	I am going to send two dashes of ten seconds each (*or* carrier) followed by my call sign (*or* name) (repeated … times) on … kHz (*or* MHz). *or*
	Will you request … *(name and/or call sign)* to send two dashes of ten seconds each (*or* carrier) followed by his call sign (*and/or* name) (repeated … times) on … kHz (*or* MHz)?	I have requested … *(name and/or call sign)* to send two dashes of ten seconds each (*or* carrier) followed by his call sign (*and/or* name) (repeated … times) on … kHz (*or* MHz).
	Suspension of Work	
QRT	Shall I stop sending?	Stop sending.
QUM	May I resume normal working?	Normal working may be resumed.
QUZ	May I resume restricted working?	Distress phase still in force; restricted working may be resumed.
	Safety	
QOE	Have you received the safety signal sent by … *(name and/or call sign)*?	I have received the safety signal sent by … *(name and/or call sign)*.

Abbre-viation	Question	Answer or Advice
	Safety (cont.)	
QUX	Do you have any navigational warnings or gale warnings in force?	I have the following navigational warning(s) or gale warning(s) in force: …
	Urgency	
QUD	Have you received the urgency signal sent by … *(name and/or call sign)*?	I have received the urgency signal sent by … *(name and/or call sign)* at … hours.
	Distress	
QOJ	Will you listen on … kHz (*or* MHz) for signals of emergency position-indicating radiobeacons?	I am listening on … kHz (*or* MHz) for signals of emergency position-indicating radiobeacons.
QOK	Have you received the signals of an emergency position-indicating radiobeacon on … kHz (*or* MHz)?	I have received the signals of an emergency position-indicating radiobeacon on … kHz (*or* MHz).
QUF	Have you received the distress signal sent by … *(name and/or call sign)*?	I have received the distress signal sent by … *(name and/or call sign)* at … hours.
QUM	May I resume normal working?	Normal working may be resumed.
QUZ	May I resume restricted working?	Distress phase still in force; restricted working may be resumed.
	Search and Rescue	
QSE*	What is the estimated drift of the survival craft?	The estimated drift of the survival craft is … *(figures and units)*.

Abbre-viation	Question	Answer or Advice
	Search and Rescue (cont.)	
QSF*	Have you effected rescue?	I have effected rescue and am proceeding to … base (with … persons injured requiring ambulance).
QTD*	What has the rescue vessel or rescue aircraft recovered?	… *(identification)* has recovered… 1.… *(number)* survivors 2. wreckage 3. … *(number)* bodies.
QTW*	What is the condition of survivors?	Survivors are in … condition and urgently need …
QTY*	Are you proceeding to the position of incident and if so when do you expect to arrive?	I am proceeding to the position of incident and expect to arrive at … hours (on … *(date)*).
QTZ*	Are you continuing the search?	I am continuing the search for … (aircraft, ship, survival craft, survivors or wreckage).
QUN	1. *When directed to all stations:* Will vessels in my immediate vicinity … *or* (in the vicinity of … latitude, … longitude) *or* (in the vicinity of …) please indicate their position, TRUE course and speed? 2. *When directed to a single station:* Please indicate your position, TRUE course and speed.	My position, TRUE course and speed are …

Abbre-viation	Question	Answer or Advice
	Search and Rescue (cont.)	
QUO*	Shall I search for … 1. aircraft 2. ship 3. survival craft in the vicinity of … latitude, … longitude *(or according to any other indication)*?	Please search for … 1. aircraft 2. ship 3. survival craft in the vicinity of … latitude, … longitude *(or according to any other indication)*.
QUP*	Will you indicate your position by … 1. searchlight 2. black smoke trail 3. pyrotechnic lights?	My position is indicted by … 1. searchlight 2. black smoke trail 3. pyrotechnic lights.
QUR*	Have survivors … 1. received survival equipment 2. been picked up by rescue vessel 3. been reached by ground rescue party?	Survivors … 1. are in possession of survival equipment dropped by … 2. have been picked up by rescue vessel 3. have been reached by ground rescue party.
QUS*	Have you sighted survivors or wreckage? If so, in what position?	Have sighted … 1. survivors in water 2. survivors on rafts 3. wreckage in position … latitude, … longitude *(or according to any other indication)*.
QUT*	Is position of incident marked?	Position of incident is marked by … 1. flame or smoke float 2. sea marker 3. sea marker dye 4. … *(specify other marking)*.

Abbre-viation	Question	Answer or Advice
	Search and Rescue (cont.)	
QUU*	Shall I home ship or aircraft to my position?	Home ship or aircraft … *(name and/or call sign)* … 1. to your position by sending your call sign and long dashes on ... kHz (*or* MHz) 2. by sending on … kHz (*or* MHz) TRUE track to reach you.
QUW*	Are you in the search area designated as … *(designator or latitude and longitude)*?	I am in the … *(designation)* search area.
QUY*	Is position of survival craft marked?	Position of survival craft was marked at … hours by … 1. flame or smoke float 2. sea marker 3. sea marker dye 4. … *(specify other marking)*.
QUZ	May I resume restricted working?	Distress phase still in force; restricted working may be resumed.
	Identification	
QTT		The identification signal which follows is superimposed on another transmission.

Section II. Miscellaneous Abbreviations and Signals

Abbre-viation or signal	Definition
AA	All after … *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
AB	All before … *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
ADS	Address *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
$\overline{\text{AR}}$	End of transmission.
$\overline{\text{AS}}$	Waiting period.
BK	Signal used to interrupt a transmission in progress.
BN	All between … and … *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
$\overline{\text{BQ}}$	A reply to an RQ.
$\overline{\text{BT}}$	Signal to mark the separation between different parts of the same transmission.
C	Yes *or* "The significance of the previous group should be read in the affirmative".
CFM	Confirm (*or* I confirm).
CL	I am closing my station.
COL	Collate (*or* I collate).
CORREC-TION	Cancel my last word *or* group. The correct word *or* group follows *(used in radiotelephony, spoken as KOR-REK-SHUN).*
CP	General call to two or more specified stations *(see Recommendation ITU-R M.1170).*
CQ	General call to all stations.
CS	Call sign *(used to request a call sign).*

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Note: When used in radiotelegraphy, a bar over the letters composing a signal denotes that the letters are to be sent as one signal.

Abbre-viation or signal	Definition
DE	"From …" *(used to precede the name or other identification of the calling station).*
DF	Your bearing at … hours was … degrees, in the doubtful sector of this station, with a possible error of … degrees.
DO	Bearing doubtful. Ask for another bearing later *(or at … hours).*
DSC	Digital selective calling.
E	East (cardinal point).
ETA	Estimated time of arrival.
INTERCO	International Code of Signals groups follow *(used in radiotelephony, spoken as IN-TER-CO).*
K̄	Invitation to transmit.
KA	Starting signal.
KTS	Nautical miles per hour *(knots).*
MIN	Minute *(or* Minutes*).*
MSG	Prefix indicating a message to or from the master of a ship concerning its operation or navigation.
MSI	Maritime safety information.
N	North (cardinal point).
NBDP	Narrow-band direct-printing telegraphy.
NIL	I have nothing to send to you.
NO	No *(negative).*
NW	Now.
NX	Notice to Mariners *(or* Notice to Mariners follows*).*
OK	We agree *(or* It is correct*).*
OL	Ocean letter.
P	Prefix indicating a private radiotelegram.
PBL	Preamble *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
PSE	Please.
R	Received.

Abbre-viation or signal	Definition
RCC	Rescue coordination centre.
REF	Reference to … (*or* Refer to …).
RPT	Repeat (*or* I repeat) (*or* Repeat …).
RQ	Indication of a request.
S	South (cardinal point).
SAR	Search and Rescue.
SIG	Signature *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
SLT	Radiomaritime Letter.
SVC	Prefix indicating a service telegram.
SYS	Refer to your service telegram.
TFC	Traffic.
TR	Used by a land station to request the position and next port of call of a mobile station; used also as a prefix to the reply.
TU	Thank you.
TXT	Text *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
$\overline{\text{VA}}$	End of work.
W	West (cardinal point).
WA	Word after … *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
WB	Word before … *(used after a question mark in radiotelegraphy or after RQ in radiotelephony (in case of language difficulties) or after RPT, to request a repetition).*
WD	Word(s) *or* Group(s).
WX	Weather report (*or* Weather report follows).
XQ	Prefix used to indicate the transmission of a service note.
YZ	The words which follow are in plain language.

RECOMMENDATION ITU-R M.1173*

**TECHNICAL CHARACTERISTICS OF SINGLE-SIDEBAND TRANSMITTERS USED IN
THE MARITIME MOBILE SERVICE FOR RADIOTELEPHONY IN THE BANDS
BETWEEN 1 606.5 kHz (1 605 kHz REGION 2) AND 4 000 kHz
AND BETWEEN 4 000 kHz AND 27 500 kHz**

(1995)

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to describe the technical characteristics of single-sideband transmitters for the bands 1 606.5 kHz (1 605 kHz Region 2) to 4 000 kHz and 4 000 kHz to 27 500 kHz,

recommends

1   that single-sideband transmitters used in the maritime mobile service for radiotelephony in the bands between 1 606.5 kHz (1 605 kHz Region 2) and 4 000 kHz and between 4 000 kHz and 27 500 kHz should be designed to meet the technical characteristics shown in Annex 1.

ANNEX 1

**Technical characteristics of single-sideband transmitters used in
the maritime mobile service for radiotelephony in the bands
between 1 606.5 kHz (1 605 kHz Region 2) and 4 000 kHz
and between 4 000 kHz and 27 500 kHz**

1   Power of the carrier:

For class J3E emissions the power of the carrier shall be at least 40 dB below the peak envelope power.

2   Coast and ship stations shall use only the upper sideband.

3   The transmitter audio-frequency band shall be 350 Hz to 2 700 Hz with a permitted amplitude variation of 6 dB.

4   The carrier frequencies shall be maintained within the tolerances specified in Recommendation ITU-R SM.1137.

5   The unwanted frequency modulation of the carrier shall be sufficiently low to prevent harmful distortion.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO).

Note by the Secretariat: The references made to the Radio Regulations (RR) in this Recommendation refer to the RR as revised by the World Radiocommunication Conference 1995. These elements of the RR will come into force on 1 June 1998. Where applicable, the equivalent references in the current RR are also provided in square brackets.

6   When class H3E or J3E emissions are used, the power of any unwanted emission supplied to the antenna transmission line on any discrete frequency shall, when the transmitter is driven to full peak envelope power, be in accordance with the following Tables:

    a)   Transmitters installed before 2 January 1982:

Separation Δ between the frequency of the unwanted emission [1] and the assigned frequency [4] (kHz)	Minimum attenuation below peak envelope power
$1.6 < \Delta \le 4.8$	28 dB
$4.8 < \Delta \le 8$	38 dB
$8 \ \ < \Delta$	43 dB without the unwanted emission power exceeding the power of 50 mW

    Transmitters using suppressed carrier emission may, as far as concerns out-of-band emissions [2] and those spurious emissions [3] which are a result of the modulation process but do not fall in the spectrum of out-of-band emissions [2], be tested for compliance with this regulation by means of a two-tone-audio input signal with a frequency separation between the tones such that all intermodulation products occur at frequencies at least 1.6 kHz removed from the assigned frequency [4].

    b)   Transmitters installed after 1 January 1982:

Separation Δ between the frequency of the unwanted emission [1] and the assigned frequency [4] (kHz)	Minimum attenuation below peak envelope power
$1.5 < \Delta \le 4.5$	31 dB
$4.5 < \Delta \le 7.5$	38 dB
$7.5 < \Delta$	43 dB without the unwanted emission power exceeding the power of 50 mW

    Transmitters using suppressed carrier emission may, as far as concerns out-of-band emissions [2] and those spurious emissions [3] which are a result of the modulation process but do not fall in the spectrum of out-of-band emissions [2], be tested for compliance with this regulation by means of a two-tone-audio input signal with a frequency separation between the tones such that all intermodulation products occur at frequencies at least 1.5 kHz removed from the assigned frequency [4].

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[1]   *Unwanted emission:* see RR No. S1.146 [No. 140].

[2]   *Out-of-band emission:* see RR No. S1.144 [No. 138].

[3]   *Spurious emission:* see RR No. S1.145 [No. 139].

[4]   The assigned frequency is 1 400 Hz higher than the carrier frequency: see RR No. S.52.177 [No. 4325].

RECOMMENDATION ITU-R M.1174-2*

Technical characteristics of equipment used for on-board vessel communications in the bands between 450 and 470 MHz

(1995-1998-2004)

Summary

This Recommendation describes the technical characteristics for equipment operating in the maritime mobile services in accordance with the provisions of No. 5.287 of the Radio Regulations (RR) for on-board vessel communications. Provision is made for 25 kHz or 12.5 kHz channel spacing.

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to describe the characteristics of equipment for on-board vessel communications in the bands between 450 and 470 MHz;

b)   that changes have recently been made to the frequency availability;

c)   Resolution 341 (WRC-97),

recommends

1   that transmitters and receivers used in the maritime mobile service for on-board vessel communications in the bands between 450 and 470 MHz should conform to the technical characteristics shown in Annex 1.

Annex 1

Technical characteristics of equipment used for on-board vessel communications in the bands between 450 and 470 MHz

1   The equipment should be fitted with sufficient channels for satisfactory operation in the area of intended use.

2   The effective radiated power should be limited to the maximum required for satisfactory operations, but should in no case exceed 2 W. Wherever practicable the equipment should be fitted with a suitable device to reduce readily the output power by at least 10 dB.

3   In the case of equipment installed at a fixed point on the ship, the height of its antenna should not be more than 3.5 m above the level of the bridge.

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*   This Recommendation should be brought to the attention of the International Maritime Organization (IMO) and the International Maritime Radio Committee (CIRM).

	25 kHz channels	**12.5 kHz channels**
4	Only frequency modulation with a pre-emphasis of 6 dB/octave (phase modulation) should be used.	Only frequency modulation with a pre-emphasis of 6 dB/octave (phase modulation) should be used.
5	The frequency deviation corresponding to 100% modulation should approach ±5 kHz as nearly as practicable. In no event should the frequency deviation exceed ±5 kHz.	The frequency deviation corresponding to 100% modulation should approach ±2.5 kHz as nearly as practicable. In no event should the frequency deviation exceed ±2.5 kHz.
6	The frequency tolerance should be 5 parts in 10^6.	The frequency tolerance should be 2.5 parts in 10^6.
7	The audio-frequency band should be limited to 3 000 Hz.	The audio-frequency band should be limited to 2 550 Hz.

8 Control, telemetry and other non-voice signals such as paging, should be coded in such a manner as to minimize the possibility of false response to interfering signals. The frequencies specified in RR No. 5.287 for on-board communications may be used for single frequency and two-frequency simplex operation.

9 When used in the duplex mode the base transmitter frequency should be selected from the lower range for improved operability.

10 If the use of a repeater station is required on board a ship, the following frequency pairs should be used (see RR No. 5.287 and 5.288):

457.525 MHz   and 467.525 MHz

457.550 MHz   and 467.550 MHz

457.575 MHz   and 467.575 MHz

457.5375 MHz   and 467.5375 MHz

457.5625 MHz   and 467.5625 MHz.

11   Frequencies

The frequencies specified in RR No. 5.287 (subject to national regulations) may be used:

For 25 or 12.5 kHz channel spacing:

457.525 MHz

457.550 MHz

457.575 MHz

467.525 MHz

467.550 MHz

467.575 MHz.

For equipment designed to operate with 12.5 kHz channel spacing the additional frequencies referred to in RR No. 5.287 are:

457.5375 MHz

457.5625 MHz

467.5375 MHz

467.5625 MHz.

RECOMMENDATION ITU-R M.1187-1

A method for the calculation of the potentially affected region for a mobile-satellite service network in the 1-3 GHz range using circular orbits

(Questions ITU-R 83/8 and ITU-R 201/8)

(1995-2006)

Scope

This Recommendation defines the term "active service arc" and provides a method for the calculation of an "affected region" when assigning frequencies to space stations of MSS systems operating between 1 and 3 GHz and for giving assistance in the identification of administrations whose assignments may be included within this "affected region".

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to develop Recommendations on coordination methods, the necessary orbital data relating to non-geostationary (non-GSO) satellite systems, and sharing criteria;

b)   that non-GSO satellite systems implementing these MSS allocations may have different constellations, with different altitudes, and different inclination angles;

c)   that "active service arc" needs to be defined;

d)   that there is a need to define the area where other services, including MSS, might be affected and where coordination may be performed for which the relevant criteria and methods are not defined in this Recommendation;

e)   that there is a need to further define the concept of an "affected region" (which is not to be confused with the "coordination area") for MSS operating between 1 and 3 GHz,

recognizing

1   that Chapter III of the Radio Regulations (RR) which includes the procedure for effecting coordination for MSS systems for certain bands within the Table of Frequency Allocations of the Radio Regulations within the frequency range of 1-3 GHz,

recommends

1   that "active service arc" should be defined as: the locus of orbital points in an MSS constellation that describes where the satellites are transmitting or receiving. The MSS operator calculates the arc utilizing those system specific characteristics such as the constellations orbits, spacecraft antenna characteristics, e.i.r.p., which achieves its service objectives for a particular service area;

2   that when a specific active service arc is published, the methodology in Annex 1 could be used to assist in the identification of administrations whose assignments may be included in the "affected region" as defined in Annex 1 (see Note 1).

NOTE 1 – This methodology could be further improved by taking into account more precise technical characteristics of the MSS system.

Annex 1

A method for the calculation of the potentially affected region for an MSS network in the 1-3 GHz range using circular orbits

1   Introduction

This Annex defines a methodology for calculating the "affected region". This affected region should be used to identify co-frequency MSS and other services with equal or higher status in other administrations that might be affected by operation of the MSS network. First, the locus of points of the satellite's orbital arc are plotted that correspond to points where the satellite would be active in order to cover its service area. Then, the corresponding sub-satellite locations are plotted on the Earth's surface. The affected region is then defined to be these areas on the Earth within visibility of the spacecraft and referenced to the perimeter of the sub-satellite locus.

This methodology to calculate the affected region identifies the administrations whose co-frequency assignments might be affected.

It is recognized that another methodology of determining affected frequency assignments of other administrations with respect to an MSS space station and its associated service area could be used and that the incorporation of this methodology into an ITU-R Recommendation would not make its use mandatory.

Use of this methodology for calculating an affected region does not change the status (primary or secondary) of the radio services within that region.

2   Calculation of the affected region

Let the quadrilateral A depicted in Fig. 1 represent the active sub-satellite area needed to serve an administration for a representative MSS system. Note that the sub-satellite area is not necessarily coincident with the borders of the administration. The distance, D, depicted in Fig. 1 is the distance from the outer perimeter of A to the field of view (FOV) point from the satellite. The FOV is defined as extending to the limits of the visible horizon as seen from the satellite. The total affected region is then the total area calculated from the edges of the sub-satellite area out to the distance D. For circular constellations distance D will be a constant great circle distance which increases with increasing satellite altitudes.

2.1   Calculation of width of affected region envelope

This section presents a methodology to calculate the distance that should be used to draw the outer perimeter around the active sub-satellite areas to create the affected region.

Figure 2 illustrates the calculation of the outer perimeter distance D, which is the distance from the edge of the sub-satellite area A to the FOV of the satellite at the active area outer edge. The affected region is defined as follows:

Affected region: an area on the Earth's surface calculated by defining a distance from the perimeter of the active sub-satellite area A, a distance D from the perimeter of the active sub-satellite sub-area, corresponding to the maximum field of view from the satellites at the perimeter of the active service arc. The region also includes administrations within the active sub-satellite area.

Active service arc and active sub-satellite area are defined as follows:

Active service arc: see the definition in *recommends* 1.

Active sub-satellite area: the projection down the nadir from the active service arc to points on the Earth's surface. The perimeter of this area is defined in geocentric coordinates (latitude/longitude).

FIGURE 1

**Representation of an active sub-satellite area required to serve
an administration and its corresponding affected region**
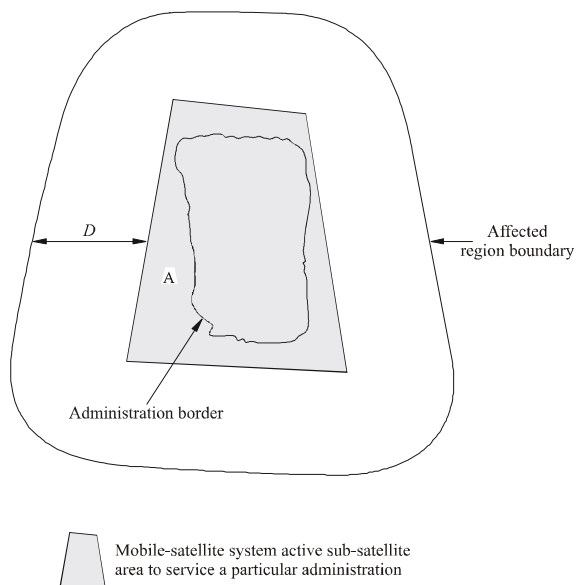
1187-01

FIGURE 2

Geometry required to calculate *D*, envelope distance around sub-satellite area
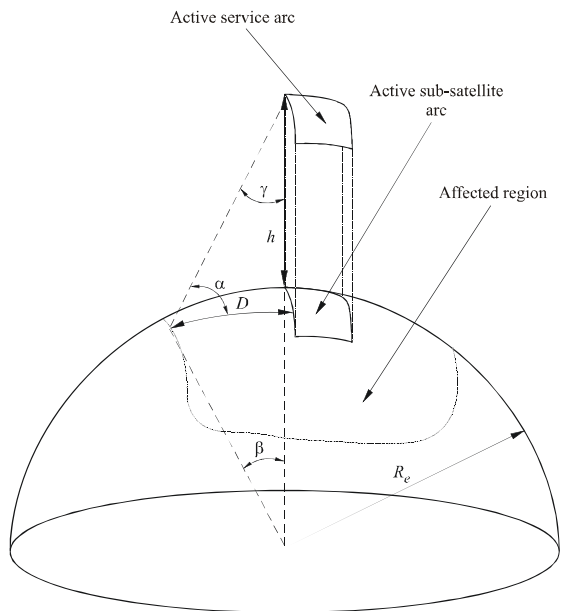
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Definition of variables:

R_e :   Earth radius

h :   satellite altitude

γ :   nadir angle from satellite at sub-satellite perimeter edge to its field of view distance

β :   geocentric angle from sub-satellite area edge to field of view distance

α :   elevation angle

D :   Earth distance from active sub-satellite area perimeter to 0° elevation angle point (maximum field of view limits).

The necessary formulae to calculate the distance D:

$$\beta = \cos^{-1} [R_e/(R_e + h)] \tag{1}$$

$$D = R_e \beta \qquad \text{rad} \tag{2}$$

Once D has been calculated, it can be used to determine the affected region in conjunction with the sub-satellite area.

2.2   Example calculation of an affected region

This section gives an example of how to calculate the affected region for a mobile-satellite system intending to provide service within the territory of an administration. The example administration is Italy, and Fig. 3 illustrates the sub-satellite area for servicing Italy for the LEO A (see Recommendation ITU-R M.1184) mobile-satellite system.

FIGURE 3

Hypothetical sub-satellite active area for Italy

The necessary parameters to calculate the affected region are:

Satellite altitude: 780 km

Earth radius: 6 367 km

Sub-satellite area width: 1 140 km

Sub-satellite area length: 1 625 km

Note that the sub-satellite active area was chosen assuming the service area was the Italian administration and is only an example. The actual sub-satellite area for Italy of any mobile-satellite system may be quite different depending on the satellite networks system specific characteristics.

Using equations (1) and (2) for this case, $\beta = 27°$ and $D = 3\,000$ km, so the distance D to add around the sub-satellite area is 3 000 km. Therefore, for the example sub-satellite area in Fig. 3, the affected region would extend into North-Western Sudan, Western Russia (including Moscow), Northern Norway and Mauritania.

RECOMMENDATION ITU-R S.1256

**METHODOLOGY FOR DETERMINING THE MAXIMUM AGGREGATE POWER
FLUX-DENSITY AT THE GEOSTATIONARY-SATELLITE ORBIT IN THE BAND
6 700-7 075 MHz FROM FEEDER LINKS OF NON-GEOSTATIONARY
SATELLITE SYSTEMS IN THE MOBILE-SATELLITE SERVICE
IN THE SPACE-TO-EARTH DIRECTION**

(Question ITU-R 206/4)

(1997)

The ITU Radiocommunication Assembly,

considering

a)   that the band 6 700-7 075 MHz is allocated to the fixed-satellite service (FSS), in the space-to-Earth direction, on a primary basis, for the use by feeder links of non-geostationary satellite networks in the mobile-satellite service (MSS);

b)   that the band 6 700-7 075 MHz is also allocated to the FSS in the Earth-to-space direction, on a primary basis, and the band 6 725-7 025 MHz is subject to the Allotment Plan of Appendix 30B of the Radio Regulations (RR) for geostationary satellite networks;

c)   that, under No. S22.5A of the RR, the maximum aggregate power flux-density (pfd) produced within $\pm 5°$ of the geostationary-satellite orbit (GSO) by a non-geostationary satellite system in the FSS shall not exceed -168 dB(W/m^2) in any 4 kHz band;

d)   that Resolution 115 of the World Radiocommunication Conference (Geneva, 1995) (WRC-95) invites ITU-R to establish a methodology to determine the maximum aggregate power flux-density at the GSO from a non-geostationary satellite network;

e)   that non-geostationary satellite networks of the mobile-satellite service have orbital and transmission parameters available as specified in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95),

recommends

1   that the methodology given in Annex 1 shall be followed to determine the maximum level of aggregate power flux-density (dB(W/m^2) in any 4 kHz band), at any location within $\pm 5°$ inclination of the GSO, from the feeder links of a non-geostationary satellite network operating in the band 6 700-7 075 MHz, in the space-to-Earth direction.

ANNEX 1

Methodology

1   Description of methodology

To calculate the aggregate pfd from a non-geostationary orbiting satellite (non-GSO) network to a single test location at the GSO, computer modelling of the full non-GSO constellation and a test location at the GSO is needed.

Basically, noting that in an ordinary situation a GSO satellite will orbit the geostationary orbit with a period of about T_{GSO} = 24 h and that the orbital period of a non-GSO satellite ($T_{non-GSO}$) is not necessarily a submultiple of T_{GSO}, extensive time-consuming statistical simulations may be needed to assess the worst-case scenario that would lead to the maximum pfd level at the GSO location.

A simple and very much less time-consuming simulation can be performed to assess the maximum pfd at any GSO location. Instead of a real orbiting GSO satellite, a fixed test location at the GSO is considered whose orbital position is fixed with respect to a 0xyz Cartesian reference system (see Fig. 1) but not with respect to the rotating Earth reference system. With this in mind, since the non-GSO satellites have an orbital period $T_{non\text{-}GSO}$, it implies that the position of the non-GSO satellites, as seen from the fixed GSO test location (see Fig. 1), will be repeated at least once every orbital period $T_{non\text{-}GSO}$. Moreover, in the case where the non-GSO satellites are uniformly distributed on each orbital plane, the same geometrical disposition of the non-GSO satellites will be repeated with a period equal to $T_{non\text{-}GSO}/N_s$ (where N_s is the number of non-GSO satellites uniformly distributed on one plane). With these basic considerations, the aggregate pfd level (aggregated over the visible non-GSO satellites) at the GSO test location will have values that will be repeated within this period.

FIGURE 1
GSO/non-GSO constellation geometry to calculate pfd: $\Delta\Omega = 0°$
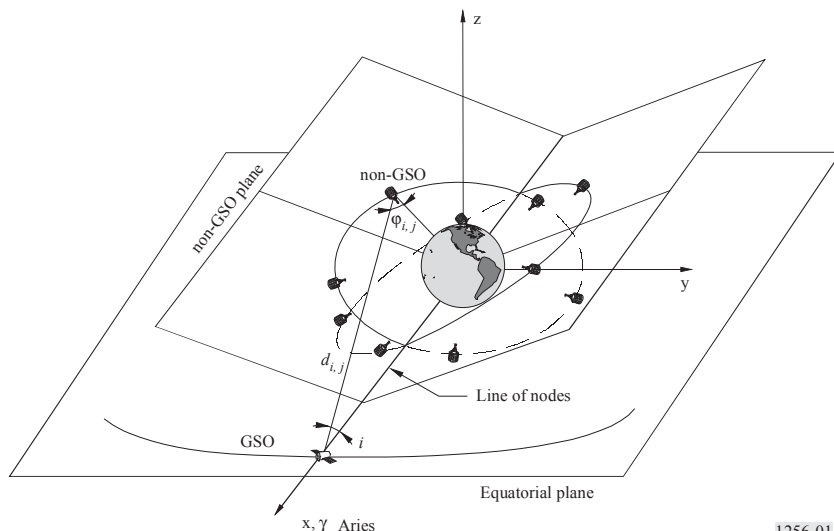
The aggregate pfd can be calculated for each time step and a maximum aggregate pfd, for the chosen GSO test location, can be derived during the simulation period from T_0 to $T_0 + T_{non\text{-}GSO}/N_s$.

The value found for the particular GSO test location in Fig. 1 is not necessarily the maximum pfd level. In order to find the highest possible maximum aggregate pfd level, the same procedure must be repeated to the other GSO test locations by incrementing the angle $\Delta\Omega$ (see Fig. 2) between the GSO test location and the non-GSO line of nodes. This second iteration will be done for angles of $\Delta\Omega$ between 0° and $\Delta\Omega_{max} = 360°/N_p$, where N_p is the number of non-GSO satellite orbital planes. In cases where N_p is even (as per LEO-F and LEO-D) then $\Delta\Omega_{max} = 180°/N_p$.

The method can also apply to any non-GSO constellation which does not meet the orbital requirements as stated above (e.g. non-uniform satellite distribution, elliptical orbits). In such cases the time simulation will be performed for a period of time equal to the minimum repeatability period of the constellation configuration, which in many cases is equal to the constellation period $T_{non\text{-}GSO}$.

The § 2 reports all the basic equations needed to arrive at the aggregate pfd level from a given non-GSO network to a given test location at the GSO and Fig. 3 shows the flow chart for the software implementation of the methodology here described.

FIGURE 2

GSO/non-GSO constellation geometry to calculate pfd: ΔΩ ≠ 0°
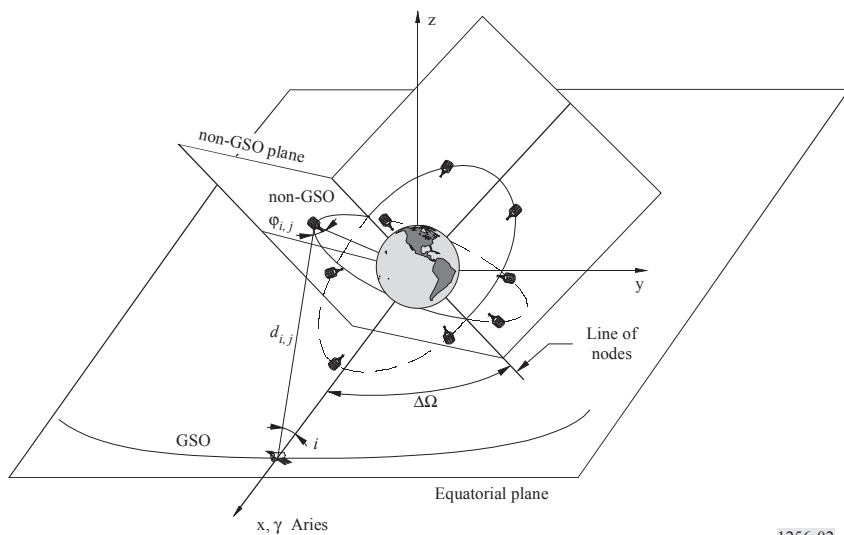
1256-02

FIGURE 3

Methodology flow chart

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- 326 -
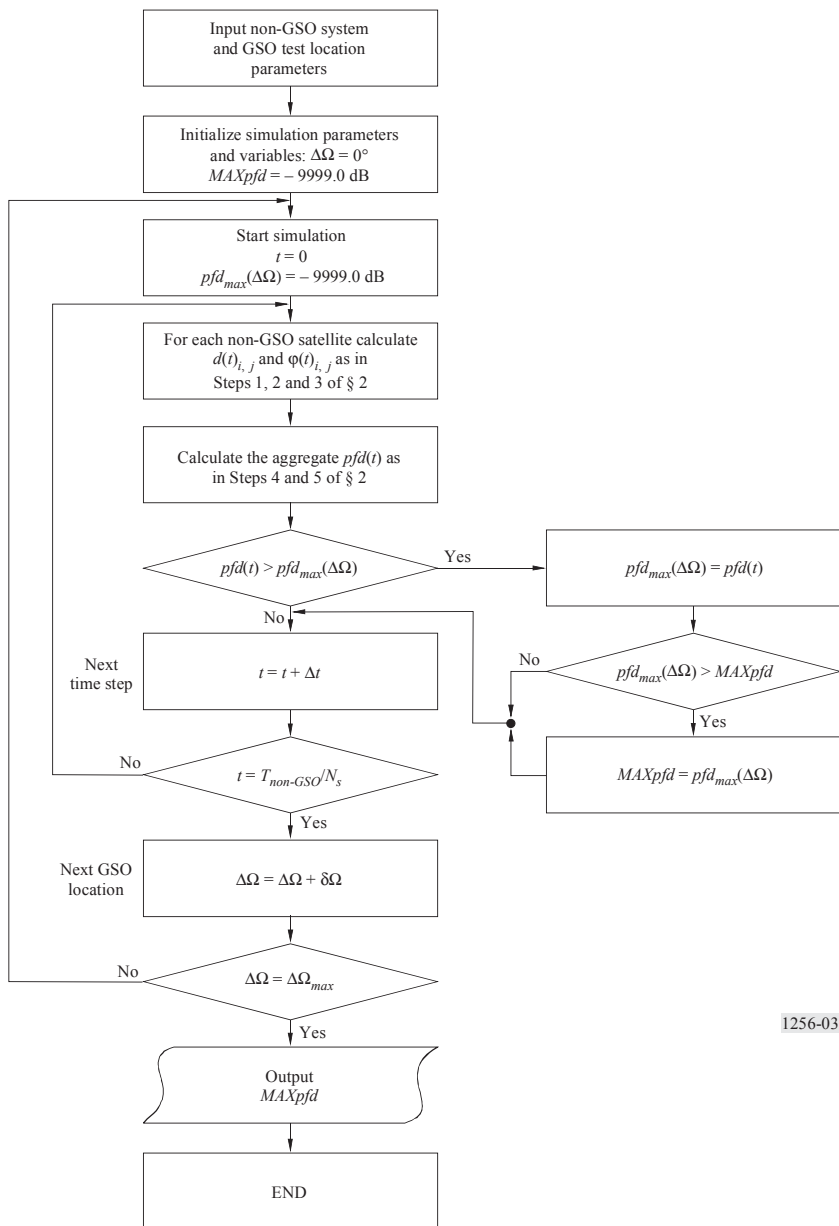
2 Basic simulation steps

Step 1: Orbital position of the non-GSO satellites

FIGURE 4

Non-GSO orbit and reference systems

1256-04
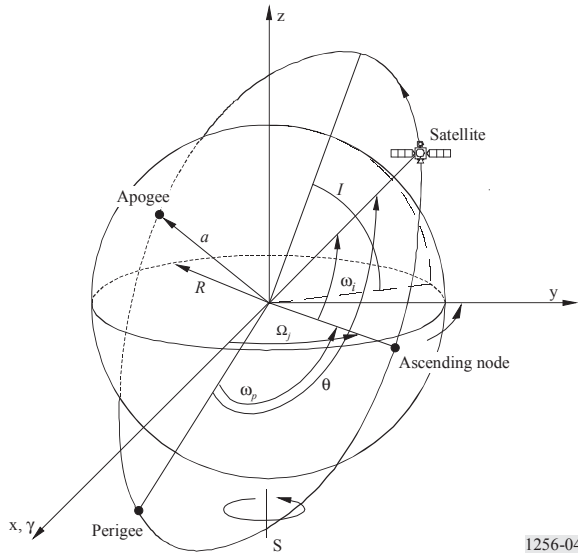
Figure 4 indicates the various parameters that are needed to fully assess at any instant the position of any non-GSO satellite on its orbit. These parameters are referenced in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95):

a : semi-major axis, in case of a circular orbit the semi-major axis is constant and equal to the orbit radius;

I : inclination of the orbit relative to the equatorial plane

Ω_j : right ascension of the ascending node for the j-th orbital plane, measured counter-clockwise in the equatorial plane from the direction of the vernal equinox to the point where the satellite makes its south-to-north crossing of the equatorial plane ($0° \leq \Omega_j < 360°$)

ω_p : argument of perigee, for a circular orbit, the perigee is equal to the apogee and thus ω_p can be put to 0°

ω_i : initial phase angle of the i-th satellite in its orbital plane at reference time $t=0$, measured from the point of ascending node ($0° \leq \omega_i < 360°$)

θ : true anomaly of the satellite.

For a constellation of non- GSO satellites using circular orbits, a and I will be constant and ω_p will be equal to zero, then the variation of the position of each satellite will be defined by Ω and θ.

For a circular orbit, the angular velocity of a satellite is constant, the angular position of a satellite is then equal to its true anomaly and is given by:

$$\theta(t)_{i,j} = \frac{360°}{T} \, t + \omega_{i,j} \tag{1}$$

for $i = 1$ to N_s and $j = 1$ to N_p where N_s is the number of satellites in each orbital plane, N_p is the number of orbital planes and T is the orbital period in seconds given by:

$$T = 2 \pi \sqrt{a^3/\mu} \tag{2}$$

where μ is the geocentric gravitational constant and is equal to 3.986 E14(m^{3}s^{-2}).

The various values of Ω_j will depend on the geometry of the constellation and will be given in the set of elements found in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95). The same principal applies to the values of $\omega_{i,j}$.

Knowing for each satellite its true anomaly $\theta_{i,j}(t)$ and the right ascension of its ascending node Ω_j, its geocentric coordinates are given by:

$$x(t)_{i,j} = a\left[\cos \Omega_j \, \cos \theta(t)_{i,j} - \cos I \sin \Omega_j \, \sin \theta(t)_{i,j}\right] \tag{3}$$

$$y(t)_{i,j} = a\left[\sin \Omega_j \, \cos \theta(t)_{i,j} + \cos I \cos \Omega_j \, \sin \theta(t)_{i,j}\right] \tag{4}$$

$$z(t)_{i,j} = a\left[\sin I \, \sin \theta(t)_{i,j}\right] \tag{5}$$

The position of the GSO test location with respect to the line of nodes of the non-GSO constellation is determined by $\Delta\Omega$ (see § 1). Hence, in equations (3), (4) and (5) $\Omega_j = \Omega_{j,0} + \Delta\Omega$, where $\Delta\Omega$ ranges from 0 to $\Delta\Omega_{max}$ (see § 1) and $\Omega_{j,0} = \Omega_j$ for $\Delta\Omega = 0$.

Step 2:   Distance between the non-GSO satellite and the test location at the GSO

x_{GSO}, y_{GSO} and z_{GSO} are the geocentric coordinates of the GSO test location given by:

$$x_{GSO} = a_{GSO} \cdot \cos I_{GSO} \tag{6}$$

$$y_{GSO} = 0 \tag{7}$$

$$z_{GSO} = a_{GSO} \cdot \sin I_{GSO} \tag{8}$$

where:

   a_{GSO}: semi-major axis of the geostationary orbit (42 164 km)

   I_{GSO}: inclination of the geostationary orbit ($-5° \leq I_{GSO} \leq 5°$).

These equations remain constant during the simulation since it is simpler to vary Ω_j in equations (3), (4) and (5) by incrementing the offset $\Delta\Omega$.

The distance between a non-GSO satellite and the GSO test location can then be calculated using Pythagora's theorem:

$$d(t)_{i,j} = \sqrt{\left(x_{GSO} - x(t)_{i,j}\right)^2 + y(t)_{i,j}^2 + \left(z_{GSO} - z(t)_{i,j}\right)^2} \tag{9}$$

Step 3:　　Calculation of the non-GSO antenna off-axis angle to the test location at the GSO

Fig. 5 shows the geometry, represented in a two-dimensional diagram, of the non-GSO satellite off-axis angle relative to the test location at the GSO.

FIGURE 5

Calculation of $\varphi_{i,j}$

1256-05

The non-GSO antenna off-axis angle can be determined using Carnot's theorem (known also as the "cosine" theorem):

$$\varphi(t)_{i,j} = \text{arc cos}\left(\frac{a^2 + d(t)_{i,j}^2 - a_{GSO}^2}{2\,a\,d(t)_{i,j}}\right) \tag{10}$$

Step 4:　　Calculation of the non-GSO off-axis antenna gain toward the test location at the GSO

Taken the off-axis angle calculated in equation (10), for each visible satellite it is possible to calculate the off-axis antenna gain $G(\varphi(t)_{i,j})$. However, as seen in Fig. 5, this is only necessary if $\varphi(t)_{i,j}$ is higher than a minimum value of φ_{min} given by:

$$\varphi_{min} = \text{arc sin}\left(R/a\right) \tag{11}$$

Step 5:　　Calculation of the aggregate pfd level towards the GSO test location

The aggregate pfd level can be expressed as:

$$pfd(t) = \frac{P_{peak,\,4\,kHz}}{4\pi} \sum_{i\cdot j=1 \text{ to } N(t)_v} \frac{G\left(\varphi(t)_{i,j}\right)}{d(t)_{i,j}^2} \qquad \text{for } \varphi(t)_{i,j} \geq \varphi_{min} \tag{12}$$

where:

$P_{peak,\,4\,kHz}$:　　peak power in the worst 4 kHz band at the input of the non-GSO satellite antenna, assumed constant and equal for all the non-GSO satellites

$N(t)_v$:　　number of visible non-GSO satellites from the GSO test location at the time *t*.

3 Total number of simulation steps and simulation step increments

Two simulation steps are needed to perform the calculation of the maximum aggregate pfd toward the GSO from a non-GSO network, the time step Δt and the right ascension step $\delta\Omega$.

Since there is no direct in-line interference from the non-GSO satellites (either they use isoflux low gain antenna or interference comes from the side lobes of the transmitting antenna), various simulations (for LEO-D and LEO-F) have shown that an angular step of no more than 0.5° is sufficient to get valid results. The calculation steps will then be:

$$\Delta t = \frac{T\,(\mathrm{s}) \times 0.5°}{360°}$$

$$\delta\Omega = 0.5°$$

The total simulation time for each GSO test location and the total number of GSO test locations are given in § 1.

————————————

RECOMMENDATION ITU-R RS.1260-1*, **

Feasibility of sharing between active spaceborne sensors and other services in the range 420-470 MHz

(Question ITU-R 218/7)

(1997-2003)

The ITU Radiocommunication Assembly,

considering

a)   that synthetic aperture radars (SARs) can measure soil moisture, forest biomass, can detect buried geologic structures such as faults, fractures, synclines and anticlines, and can map and measure the depth of Antarctic ice, and hydrogeological properties of arid and semiarid regions;

b)   that experimental SARs mounted on aircraft have demonstrated the potential for making these measurements;

c)   that these spaceborne SARs must operate at frequencies below 500 MHz in order to penetrate dense vegetation and the Earth's surface on a worldwide repetitive basis;

d)   that the need for monitoring forests was emphasized at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, 1992;

e)   that Resolution 727 (Rev.WRC-2000) seeks provision of up to 6 MHz of frequency spectrum to the Earth exploration-satellite service (active) in the frequency range 420-470 MHz in order to meet the Earth exploration-satellite service (active) requirements;

f)   that frequency bands between 420-470 MHz are currently allocated to the radiolocation, fixed, amateur, space operations and mobile services;

g)   that within the amateur service weak-signal operations (including Earth-Moon-Earth) are conducted centred around 432 MHz, and amateur-satellite operations (both uplink and downlink) are conducted in the band 435-438 MHz;

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*   NOTE – The following Administrations – Saudi Arabia, Djibouti, Egypt, United Arab Emirates, Jordan, Kuwait, Morocco, Mauritania, Syrian Arab Republic, Tunisia and Yemen – object to the approval of this Recommendation. For more details, please refer to the appropriate Summary Record of RA-03.

**   Radiocommunication Study Group 7 made editorial amendments to this Recommendation.

h)   that other uses are made of portions of these bands including:

–   wind profilers in the range 440-450 MHz, and in case of incompatibility between wind profiler radars and other applications, in the bands 420-435 MHz and 438-440 MHz (Resolution 217 (WRC-97));

–   launch vehicle range safety command destruct receivers in the band 449.75-450.25 MHz (No. 5.286 of the Radio Regulations (RR)), as well as around 421.0, 425.0, 427.0, 440.0 and 445.0 MHz in the United States of America and Brazil and, in the French Overseas Departments in Region 2 and India, the band 433.75-434.25 MHz (RR No. 5.281);

j)   that certain spaceborne SARs could produce pfd's at the Earth's surface in excess of the pfd levels that may be required to protect the fixed service and the land mobile service allocated in this frequency range;

k)   that co-frequency sharing with wind profilers is likely to be unfeasible due to interference to the spaceborne active sensor;

l)   that SARs and the amateur service (primary in Region 1 and secondary in Regions 2 and 3, except as in RR No. 5.278) can coexist in the band 430-440 MHz, by taking appropriate technical and operational measures defined in Annex 1 to this Recommendation;

m)   that in addition, the provisions of RR Nos. 5.274, 5.275, 5.276, 5.277, 5.278, 5.281 and 5.283 list countries that have defined portions of the band between 430 and 440 MHz as having primary status for the fixed, mobile, space operation and/or the amateur services;

n)   that some sharing studies have indicated that co-frequency sharing between the amateur services and some proposed SARs in the Earth exploration-satellite service (EESS) is possible for some amateur modes of transmission such as FM and time division multiple access (TDMA), but would be difficult with continuous wave and single sideband modes of operation;

o)   that Recommendation ITU-R M.1462 contains the technical and operational characteristics of, and protection criteria for, radars (airborne, shipborne, and space object tracking) operating in the radiolocation service operating in the band 420-450 MHz;

p)   that there is a potential for unacceptable interference from some spaceborne SARs to terrestrial space object tracking radars operating in the band 420-450 MHz if the spaceborne SAR radar is within the view of the terrestrial radars (i.e. above the radars' visible horizon);

q)   that some spaceborne SARs will be tracked by terrestrial space object tracking radars, and that the resultant unwanted received power level at a spaceborne SAR can approach its maximum power-handling capability;

r)   that there is a potential for unacceptable interference from some spaceborne SARs to airborne and shipborne radars operating in 420-450 MHz, the probability and severity of which is highly dependent upon the characteristics of the SARs;

s)   that any harmful interference, even for very short periods, by SARs into launch vehicle command destruct receivers could impede the safety of life and property;

t)   that given the complexity of the EESS (active) instruments implementation in these low frequencies, very few such platforms are expected to be in orbit at the same time,

recommends

1   that active spaceborne sensors operating in the bands used by the amateur service, the amateur satellite service, the fixed, radiolocation, space operation, mobile services and the MSS in the range 420-470 MHz, respect the technical and operational constraints provided in Annex 1 to this Recommendation;

2   that spaceborne active sensors operating in the range 420-450 MHz not be put into operation within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, on a case-by-case basis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing have been performed to confirm compatibility with the mutual agreement of the affected administrations;

3   that a spaceborne SAR intended for operation in the 420-450 MHz band be designed to tolerate the unwanted signal power levels that will result from being tracked by terrestrial space object tracking radars;

4   that sufficient frequency and geographical separation between spaceborne SARs and wind profilers operating in the ranges 420-432 MHz and 438-450 MHz may need to be provided;

5   that spaceborne active sensor frequency bands be selected in such a way as not to overlap with launch vehicle range safety command destruct receive frequency bands listed in *considering* h);

6   that in cases where *recommends* 5 becomes difficult to implement, spaceborne active sensors operating in the frequency ranges allocated for launch vehicle range safety command destruct receive frequency bands should not be put into operation within the specific distance of locations where launch vehicle commands are used, in order to avoid interference from spaceborne active sensors into launch vehicle receivers.

Annex 1

Technical and operational constraints for EESS (active)
operating in the range 420-470 MHz

For the purposes of protecting stations operating in the existing services, SAR transmissions from stations in the EESS (active) operating in the frequency range 420-470 MHz are subject to the technical and operational constraints specified in this Annex.

The following constraints are based on ITU-R studies. Annex 2 provides information on the feasibility of sharing between active spaceborne sensors and other services in the range of 420-470 MHz.

1   Technical constraints

TABLE 1

**Technical constraints for EESS (active) instruments
in the range 420-470 MHz**

Parameter	Value
Peak pfd on Earth's surface from antenna main lobe	-140 dB(W/(m^2 · Hz))
Maximum mean pfd on Earth's surface from antenna main lobe	-150 dB(W/(m^2 · Hz))
Maximum mean pfd on Earth's surface from 1st antenna side lobe	-170 dB(W/(m^2 · Hz))

2   Operational constraints

EESS (active) operating in the band 420-450 MHz shall not transmit within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing, have been performed to confirm compatibility.

As a consequence of the above constraints, EESS (active) instruments shall be designed in such a way as to allow programmable turning off of all RF emissions over geographical areas or countries where ITU regulations or national regulations do not allow their operations.

The EESS (active) instruments operation profile shall be campaign-oriented, targeted to specific geographical areas and shall limit the instrument active time to the minimum required to achieve the campaign objectives. Thus, the measurements carried out by the instrument do not require continuous operation of the instrument, and intervals of months between successive measurements on the same area can be expected.

The operational duty cycle in campaign-mode will be 15% maximum (typically 10%). While not in campaign-mode, the instrument will be switched off.

FIGURE 1
Example of exclusion zone around space object tracking radars for a SAR in a 550 km orbit

1260-01
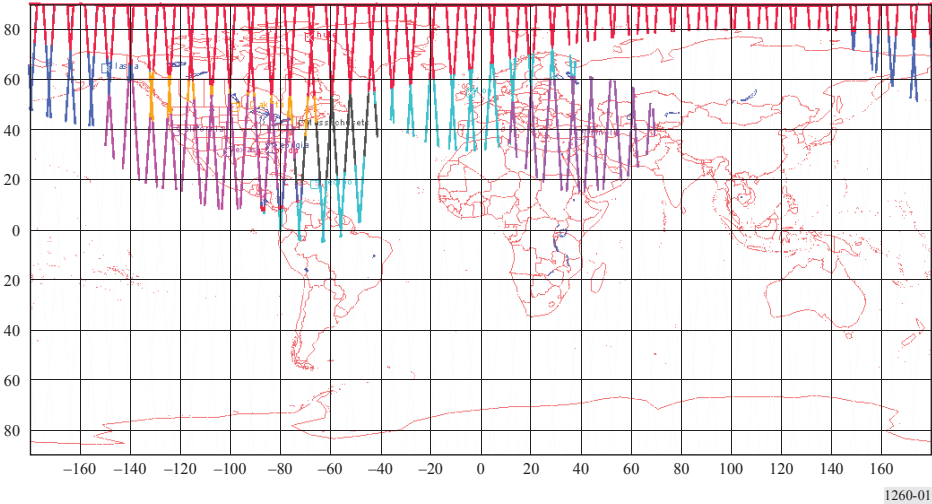
TABLE 2

Space object tracking radars operating in 430-440 MHz

Radar location	Latitude	Longitude
Massachusetts (United States of America)	41.8º N	70.5º W
Texas (United States of America)	31.0º N	100.6º W
California (United States of America)	39.1º N	121.5º W
Georgia (United States of America)	32.6º N	83.6º W
Florida (United States of America)	30.6º N	86.2º W
North Dakota (United States of America)	48.7º N	97.9º W
Alaska (United States of America)	64.3º N	149.2º W
Thule (Greenland)	76.6º N	68.3º W
Fylingdales Moor (United Kingdom)	54.5º N	0.4º W
Pirinclik (Turkey)	37.9º N	40.0º E

3   Protection criteria for existing services in the frequency range 420-470 MHz

Not all protection criteria mentioned in this section are contained in ITU-R Recommendations. Therefore, some of these protection criteria have been derived from information provided in ITU-R studies. Table 3 reflects the information available at the time of the development of this Recommendation.

It should be noted that any future Recommendation describing the protection criteria for any given service, has preference above the value listed in the table as derived from ITU-R studies.

TABLE 3

Protection criteria for services in the range 420-470 MHz

Frequency range (MHz)	ITU-R services	The time percentages and criteria in columns 4 and 5 are to be applied only in the following geographical areas	Maximum percentage of time that the criteria may be exceeded[1]	Interference criteria at receiving stations	Sources
430-440	Amateur	Within line-of-sight (LoS) of terrestrial amateur stations located in regions defined in *considering* l)	1%	pfd = -204 dB(W/(m$^2 \cdot$ Hz))[2]	ITU-R studies
435-438	Amateur satellite	Within LoS of satellite amateur earth stations located in regions defined in *considering* l)	1%	pfd = -197 dB(W/(m$^2 \cdot$ Hz))	ITU-R studies
435-438	Amateur satellite	Within LoS of receivers of amateur space stations	1%	pfd = -187 dB(W/(m$^2 \cdot$ Hz))	ITU-R studies
420-470[3]	Fixed	Within LoS of stations of the fixed service including stations located in regions defined in *considering* m)	Not applicable	$(I/N)_{MEAN} = -20$ dB (equivalent to 1% fractional degradation in performance)	Recs. ITU-R F.758 and ITU-R F.1108
420-432 and 438-450	Radio-location	Within LoS of wind profiler radars	[4]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Space operation	Within LoS of launch vehicle command destruct receivers located in regions defined in *considering* m)	Frequency or geographical separation required		ITU-R studies

TABLE 3 (*end*)

Frequency range (MHz)	ITU-R services	The time percentages and criteria in columns 4 and 5 are to be applied only in the following geographical areas	Maximum percentage of time that the criteria may be exceeded[1]	Interference criteria at receiving stations	Sources
420-450	Radio-location	Within LoS of terrestrial space object tracking radars[5]	[4]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Radio-location	Within LoS of shipborne radars	[4]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-450	Radio-location	Within LoS of airborne radars	[4]	$(I/N)_{PEAK} = -6$ dB	Rec. ITU-R M.1462
420-470[3]	Mobile	Within LoS of mobile stations including stations located in Regions defined in *considering* m)	0.1%	pfd = -204 dB(W/(m^2 · Hz))[2]	ITU-R studies

[1]   Considering all active SARs in this frequency range.

[2]   The maximum aggregate pfd specified for the band 430-440 MHz has been based on the maximum acceptable interference level received by the average side lobe of an amateur receiving antenna.

[3]   In the frequency range 430-440 MHz, the fixed and mobile services are allocated only in some countries by footnote.

[4]   The criterion given in Recommendation ITU-R M.1462 is based on the protection of radiolocation systems from noise-like interference. Sharing may be possible between radiolocation systems and spaceborne active sensors at interference levels greater than those given in Recommendation ITU-R M.1462 through the use of signal processing techniques to filter out unwanted pulsed emissions. Recommendation ITU-R M.1372 provides a description of some of these interference suppression techniques.

[5]   The EESS (active) operating in the band 420-450 MHz shall not transmit within view of the terrestrial space object tracking radars listed in Table 2, unless detailed analysis, on a case-by-case basis, to include consideration of the effects of the radars' receiver processing upon unwanted SAR signals, and possibly field testing, have been performed to confirm compatibility with the mutual agreement of the affected administrations.

Annex 2

Methodology for interference assessment and mitigation

1   Introduction

A methodology is presented that allows an estimate to be made as to whether or not the unwanted signal received by other services in the band 420-470 MHz from an active spaceborne sensor may cause difficulties if operated in common frequency bands. Much of the content of this Annex has been extracted from Annex 1 of Recommendation ITU-R RS.1280 – Selection of active spaceborne sensor emission characteristics to mitigate the potential for interference to terrestrial radars operating in frequency bands 1-10 GHz. The calculations highlight a number of parameters of the sensor that can be chosen such that the sharing situation is improved.

2 Calculation of interference to other services

The average interfering signal pfd, I_{pfd} (dB(W/(m^2 · Hz))) and average interfering signal power level, I (dBW), received by the other services from spaceborne active sensors is calculated from the following:

$$I_{pfd} = 10 \log P_t + 10 \log (\tau\, PRF) + G_t - (130.99 + 20 \log R + 10 \log B) + OTR - PG \qquad (1a)$$

and

$$I = 10 \log P_t + 10 \log (\tau\, PRF) + G_t + G_r - (32.44 + 20 \log (f R)) + OTR - PG \qquad (1b)$$

where:

P_t : peak space borne sensor transmitter power (W)

τ : spaceborne sensor pulse width (s)

PRF : spaceborne sensor pulse repetition frequency (Hz)

G_t : spaceborne sensor antenna gain towards other service (dBi)

R : slant range between sensor and radar (km)

B : bandwidth of sensor (MHz)

OTR : receiver on-tune rejection (dB)

PG : processing gain (dB), rejection of unwanted signals due to receiver signal processing (assumed to be zero if not known)

f : frequency (MHz).

Equation (1a) gives the average interference signal pfd level and equation (1b) gives the average interference signal power level. The average interference power level is used when it can be determined that such use is appropriate. For example, a radar that performs a fast Fourier transform (FFT) on the received signal will "smear" the dissimilar pulsed signal across a number of bins, resulting in an averaged interfering signal level. The on-tune rejection term is calculated from:

$$OTR = 10 \log (B_r/B_t) \qquad \text{for } B_r \le B_t \qquad (2a)$$

$$= 0 \qquad \text{for } B_r > B_t \qquad (2b)$$

where:

B_r : receiver bandwidth

B_t : bandwidth of the transmitted interfering signal.

If the peak interfering signal is of interest, then the second term of equation (1) should be left out, and on-tune rejection is calculated from the following:

Input pulse with no frequency modulation:

$$OTR = 20 \log (B_r \tau) \qquad \text{for } B_r \tau < 1 \qquad (3a)$$

$$= 0 \qquad \text{for } B_r \tau > 1 \qquad (3b)$$

Input pulse with frequency modulation:

$$OTR = 10 \log \left(\frac{B_r^2 \tau}{B_c} \right) \qquad \text{for } \frac{B_r^2 \tau}{B_c} < 1 \qquad (4a)$$

$$= 0 \qquad \text{for } \frac{B_r^2 \tau}{B_c} > 1 \qquad (4b)$$

where:

B_r: other service receiver IF bandwidth

B_c: chirp bandwidth of spaceborne sensor

τ: sensor pulse width.

3 Interference criteria for other services

Specific criteria for specific systems in the other services are given in Table 1 in terms of the maximum aggregate pfd limits at the receiving stations (dB(W/(m² · Hz))) and also the maximum percentage of time that the pfd limits may be exceeded. There are several instances where a different criteria is used as follows.

3.1 Surveillance radars in radiolocation service

It will be assumed that the received S/N of the surveillance radars may not be degraded by more than 0.5 dB longer than a single scan time, taken to be 10 s. This equates to an I/N power ratio of −9 dB at the receiver IF stage. The average interfering signal power level is considered to be of interest in the case of the surveillance radars.

3.2 Tracking radars in radiolocation service

Tracking radars often use "range gates" to exclude all returns other than those at specific ranges of interest. An important consideration in determining the susceptibility of a tracking radar to an interfering pulse train is the fraction of interfering pulses that are coincident with the range gate. The coincidence of interfering pulses with the range gate will depend upon whether the desired and undesired PRFs are related by integer multiples (Case I) or not (Case II). The fraction of coinciding pulses, f_c, is found from:

$$f_c = \frac{GCF(PRF_i, PRF_g)}{PRF_g} \qquad \text{for Case I} \qquad (5a)$$

$$f_c = PRF_i(\tau_g + \tau_i) \qquad \text{for Case II} \qquad (5b)$$

where:

PRF_i: interfering PRF

PRF_g: gate PRF

$GCF(PRF_i, PRF)_g$: greatest common factor of PRF_i and PRF_g

τ_i: interfering pulse width

τ_g: gate width.

Note that when $\tau_i > \tau_g$ and the desired and undesired PRFs are not related by integer multiples (Case II), f_c is approximately the duty cycle of the interfering pulses. This situation is considered to be the typical case, and is used in the following determination of degradation threshold for a tracking radar.

To obtain highly accurate position data on objects of interest, tracking radars use high gain antennas with well-defined, narrow mainbeams. A servo mechanism attempts to keep the boresight of the antenna mainbeam on the target; the servo mechanism is driven by an error signal generated by the angle error between the target and the antenna boresight. Undesired signals entering the radar can increase this bias error.

A degradation threshold for a tracking radar, expressed as an allowed fraction of coincident interfering pulses, f_c, as a function of the S/I ratio at the IF output is given as:

$$f_c = \frac{a^2 - 1}{\dfrac{90 B_r \tau}{(S/I - 1)} - 1} \qquad \text{when } S/I > 1 \qquad (6a)$$

$$f_c = \frac{a^2 - 1}{\dfrac{90 B_r \tau}{(S/I - 1)} - 1} \qquad \text{when } S/I < 1 \qquad (6b)$$

where:

a : factor associated with total tracking error, with degradation due to interference included (e.g. $a = 1.1$ allows a 0.1%, or 10% increase due to interference)

B_r : 3 dB bandwidth of the radar IF filter

τ : length of the target pulses (note $B_r \tau \cong 1$ for a tracking radar)

S/I : S/I power ratio at the radar IF output (not in dB).

Figure 2 is a plot of the fraction of coincident pulses versus S/I at the radar IF output, allowing a 10% increase in the radar tracking error due to interference. The fraction of coincident pulses is approximately the sensor's duty cycle (6%), so an S/I of 13 dB corresponds to a 10% tracking error. It will be assumed that the S/I must be ≥ 13 dB for periods of time longer than 3 s. (Since the interference criterion has been developed based upon an interfering pulse being coincident with the radar's range gate, the peak interfering signal power should be used.)

FIGURE 2

**Radar *S/I* as a function of fraction of coincident interfering pulses
(10% increase in tracking error)**

1260-02
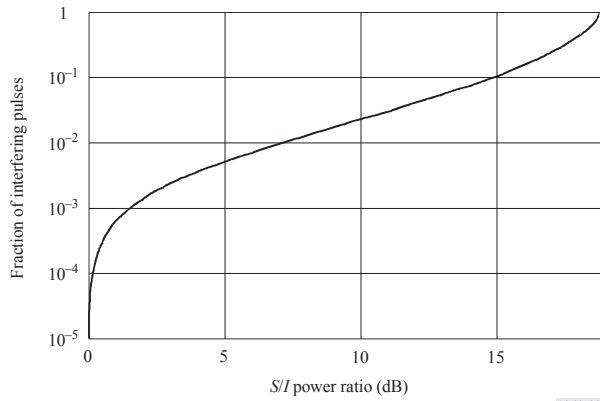
4 Example analysis of the unwanted signal from a spaceborne sensor to other services

4.1 Technical characteristics

4.1.1 Spaceborne sensor

Table 4 gives the technical characteristics of the representative spaceborne sensor used in the following analysis.

TABLE 4

Spaceborne SAR1 characteristics

Parameter	Value
Orbit height (km)	750
Orbit inclination (degrees)	98.4
Peak radiated RF power (W)	400
Average radiated RF power (W)	4.4
Pulse width (µs)	50
PRF (Hz)	2 200
Modulation of pulse	Linear FM
Pulse bandwidth (MHz)	4.8
Antenna peak gain (dB)	27.9
Antenna orientation (degrees)	37 from nadir
Antenna 1st side lobe (dB)	−17.6 from peak
Antenna 5th side lobe (dB)	−34 from peak

4.1.2   Airborne radars

Recommendation ITU-R M.1462 provides the characteristics and protection criteria for radars operating in the frequency band 420-450 MHz. Previous analyses concluded that spaceborne active sensors are not technically compatible with highly sensitive land-based space object tracking radars.

The computer simulation analysis considered the compatibility of spaceborne SARs with airborne radars in this frequency band. Shipboard radar results are similar to those of the airborne radar. The draft revision to the Recommendation lists the airborne receiver bandwidth as 1 MHz, and the radar antenna as a 22 dBi gain planar array. For the purposes of analysis, the antenna was assumed to be scanning in azimuth at a 0º elevation angle. The protection criterion for the radars is an I/N of −6 dB.

4.2   Analysis approach and results

4.2.1   Computer simulations

4.2.1.1   Processing gain

The analysis of the potential interference from spaceborne SARs into the radiolocation service receivers assumed no processing gain (that is, ability to reject the interference due to receiver signal processing). For the radiolocation systems, it may be appropriate to examine the potential response of the receiver to pulsed interfering signals such as from the SARs.

The details of a radar's resistance to interfering pulsed signals are generally not published. However, many modern radar receivers, particularly those which need to perform a surveillance function in the presence of significant clutter, will do digital Doppler processing in order to resolve targets against the clutter background. The effect of the FFT on the incoming pulsed interference will be to "smear" the peak pulse power over the neighbouring range/Doppler bins, and result in an averaged interfering power effect.

4.2.1.2   Radar interference criterion

An I/N equal to −6 dB is given as the protection criterion for the airborne radars in Recommendation ITU-R M.1462. No per cent of time or duration of time is given as permissible for interference to exceed this value. It is not appropriate to apply the concept of an allowed per cent of time that interference can exceed this value to radars, and particularly to surveillance radars such as the airborne radars considered in this analysis. The concept of data loss or permitted "outage" can be applied to a communications link or sensor system, but target detection – a basic and critical radar system function – occurs at an instant in time, and thus long-term outages are not relevant.

An approach used in a number of similar analyses in ITU-R, is to examine the simulation results with the assumption that a surveillance radar cannot be degraded for a period of time exceeding a single antenna scan. This means that a target may go undetected during the first scan period that detection may otherwise have successfully been accomplished. The airborne radars in this analysis have antenna rotation times on the order of 10 s. Thus, interference should not exceed $I/N = −6$ dB for longer than 10 s. (Under this assumption, a target with an 800 km/h velocity approaches another

~2 km after detection should have happened in the absence of interference. This may or may not be acceptable, depending upon the situation.) Upon examination of the results of the simulations (using both peak as well as average interfering power into the radars), it is evident that frequency sharing may be difficult between the spaceborne SARs and the radars.

4.2.1.3 Computer simulation results

Simulations were performed using the SAR1 type (see Table 5). Table 6 provides the results of computer simulations of the expected interference environment from spaceborne SAR1 into radiolocation service systems. All simulations were conducted in 2s time increments over a 60-day period. Note that two results with respect to the per cent of time that interference occurs are also given in Table 6.

The first is the per cent of time that the interference criterion is exceeded during periods when one or more SARs are visible (i.e. above the horizon) to the earth station(s); the second is the per cent of time that the interference criterion is exceeded out of the entire period simulated (i.e. including the times when no SAR is visible on some portions of the Earth).

TABLE 5

**Peak/average pfd interference from main lobes and side lobes
of P-band SAR1 at Earth's surface**

Parameter	Value	dB
Transmitted power (W)	400.00	26.02
Peak main lobe antenna gain (dBi)	27.90	27.90
Antenna side-lobes level (dBi)	−6.10	−6.10
$1/(4\pi)$	7.96×10^{-2}	−10.99
$1/(\text{distance})^2$ (km)	972.80	−119.76
1/Bandwidth (MHz)	1/4.80	−66.81
Pulse width (μs)	50	
PRF (Hz)	2 200	
Peak power density in main lobe (dBW)		−75.86
Peak power density in side lobe (dBW)		−109.86
Peak pfd in main lobe (dB(W/(m² · Hz)))		−143.6
Average pfd in main lobe (dB(W/(m² · Hz)))		−153.2
Peak pfd in side lobes (dB(W/(m² · Hz)))		−177.6
Average pfd in side lobes (dB(W/(m² · Hz)))		−187.2

TABLE 6

Computer simulation results

Receiver	Criterion	SAR1
Airborne radar	I/N, worst (dB)	36.2
	I/N, average (dB)	–4.4
	Per cent of time I/N > –6 dB (SAR visible) (%)	12.0
	Per cent of time I/N > –6 dB (All times) (%)	0.6
	Maximum time I/N > –6 dB (min)	4.8
	Average time I/N > –6 dB (s)	7.3
	Number of times I/N > –6 dB (events)	3 823

5 Procedure to use methodology

The average pfd of an active spaceborne sensor should be examined during the design stages. Equations (1) to (4) can be examined to determine parameters that can potentially be adjusted during the design of the spaceborne sensor, in order to improve sharing with the other services. Transmitter power, antenna gain (particularly side-lobe levels), pulse width and repetition rate, and chirp bandwidth are all likely candidates for adjustment.

When compatibility between a spaceborne sensor and a particular service system is analysed, the processing gain, if any, of the receiving system should be considered since the analysis assumed that there was none. This assumption is valid for the general case since not all receiving stations have processing gain.

For example, consider two radars operating in 420-450 MHz:

– a tracking radar with a 0.1 MHz IF bandwidth (radar 1)

– an airborne intercept radar with a 1 MHz IF bandwidth (radar 2).

If the spaceborne sensor of Table 4 can be operated with a different pulse width and chirp bandwidth such as in Table 7, then a significant reduction in the unwanted signal power level can be achieved.

TABLE 7

**Example of reduction in received unwanted sensor power,
via changes in sensor pulse width and chirp bandwidth**

	New parameter values for SAR1		ΔOTR (dB)	ΔP_{avg} (dB)	ΔI (dB)
	τ (µs)	B_c (MHz)			
Radar 1	25	6	−4.0	Not available[1]	−4.0
Radar 2	25	6	−0.0	−3.0	−3.0

[1] It has been deemed appropriate to use average interference signal power for the airborne radar, and peak interference signal power for the tracking radar.

6   Conclusion

It has been demonstrated that it should be possible to reduce the pfd to improve the emission characteristics of active spaceborne sensor in order to enhance the compatibility with other services. Sensor transmitter power, antenna gain pattern, pulse width, PRF, and chirp bandwidth (if frequency modulation is used) are all possible characteristics that can be adjusted to improve compatibility.

RECOMMENDATION ITU-R BO.1293-2

**Protection masks and associated calculation methods for
interference into broadcast-satellite systems
involving digital emissions**

(Question ITU-R 223/11)

(1997-2000-2002)

The ITU Radiocommunication Assembly,

considering

a)   that protection ratios and associated protection masks are essential characteristics for the television signals in the broadcasting-satellite service (BSS) and associated feeder links;

b)   that the Radio Regulations (RR) Appendices 30 and 30A Plans have been developed by using values of protection ratio and interference calculation methods based on fixed frequency offsets and given types of signal;

c)   that new systems submitted to the Radiocommunication Bureau (BR) for implementation in these plans propose to use new types of signals for which no protection masks and only limited interference calculation methods are available;

d)   that the BR has requested Radiocommunication Study Group 6 to provide additional methodologies and protection criteria to assess interference from and to these new types of signals;

e)   that the definition of protection masks and associated calculation methods provides very useful technical information when revising the RR Appendices 30 and 30A Plans for Regions 1 and 3;

f)   that several studies have now been carried out by various administrations and organisations that validate the proposed interference calculation method,

recognizing

a)   that protection masks extend the usefulness of protection ratios, which are themselves associated with fixed frequency offsets;

b)   that appropriate protection masks for interference calculation between digital emissions can be derived by using the methodology provided in Annex 3;

c)   that the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000) has established new BSS and associated feeder-link plans for Regions 1 and 3, based on digital modulation, and new Regions 1 and 3 Lists, thus updating Appendices 30 and 30A;

d)   that Administrations are entitled to implement their Plan assignments at any time without any further restrictions with respect to the characteristics on which the plans are based,

recommends

1   that for any EPM/OEPM compatibility analysis carried out under Articles 4 and 5 of Appendices 30 and 30A, Annex 1 should be applied;

2   that the associated interference calculation methods of EPM/OEPM provided in Annex 2, should be used for the compatibility analyses referred to in *recommends* 1.

NOTE 1 – The calculation method to generate protection masks provided in Annex 3 for BSS networks employing all types of digital phase shift keyed emissions may be applied in compatibility analyses for bilateral coordination between administrations.

NOTE 2 – Further studies are needed to develop masks for interference between other types of emission (i.e. for analogue into analogue, digital into analogue and analogue into digital interference). Until such time as these masks are available, the method described in Annex 1 should be used when calculating interference between emissions when the interference is digital.

ANNEX 1

Calculation of digital interference in the absence of appropriate protection masks

When applying the calculation method of Annex 2, it is desirable to apply the most appropriate protection mask for the digital interference situation under consideration (i.e. the most appropriate value for $D_i(fo_i)$ in Annex 2). For example, for digital interference into a digital emission, this mask can be derived using the calculation method given in Annex 3.

Further studies are required to derive suitable generic protection masks for the case of digital into analogue interference.

Until such time as these masks are available, the method given below should be used to calculate the interference between two emissions, where the interferer is a digital emission.

The value for $D(fo)$ is calculated as follows:

$$D(fo) = 10 \log_{10}(B/b(fo)) + K$$

where:

$b(fo)$:   overlapping bandwidth between the interfering carrier and the wanted carrier (MHz)

B :   necessary bandwidth of the interfering digital carrier (MHz)

K :   positive weighting coefficient.

In general, a protection mask calculation method such as that given in Annex 3 quantifies the value K which may vary depending upon the wanted and interfering signal parameters and the frequency offset between the two signals (in fact, the method of Annex 3 does not explicitly calculate the factor K but rather calculates directly the value $-D(fo)$).

In the absence of suitable protection masks which quantify the factor K, either directly or indirectly, it should be assumed that $K = 0$ which corresponds to the worst case.

ANNEX 2

Interference calculation methods associated with Annexes 1 and 3*

1 Introduction

The purpose of this Annex is to define a generic method to calculate the interference situation in the BSS Plans, taking into account different categories of interference (e.g. co-channel, adjacent-channel, etc.).

The generic interference calculation method defined below, associated with the appropriate protection mask calculation methods, should be applied to establish the values necessary to assess the interference situation between different emissions of the BSS Plans.

2 Terminology, symbols and operators

In order to simplify this Annex and to facilitate its understanding, the following terminology, symbols and operators are defined:

Single entry, se: a single interfering carrier is considered

Aggregate, ag: all interfering carriers are considered

Equivalent, eq: combination of co-frequency and frequency offset interference

Overall, ov: combination of feeder-link (up) and downlink (dn) interference

fo: frequency offset = difference between the centre frequencies of two carriers

C/I: carrier-to-interference ratio (dB)

PR: protection ratio (dB)

EPM: equivalent protection margin (dB)

OEPM: overall equivalent protection margin (dB)

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* This method has been developed to carry out the compatibility analysis of assignments, submitted to the BR under the provision of RR Appendices 30 and 30A, with parameters different from those used in the establishment of the Plans (channel bandwidth, centre frequency, type of emission, etc.).

X: reduction of the overall C/I due to interference in the feeder link (dB)

Operator $\oplus$: $A \oplus B = -10 \log\left(10^{-A/10} + 10^{-B/10}\right)$

Operator $\copyright$: $A \copyright B = -10 \log\left(10^{-A/10} - 10^{-B/10}\right)$

Operator $\Sigma\oplus$: $\displaystyle\sum_{n=1}^{N} \oplus A_n = -10\log\left(10^{-A_1/10} + 10^{-A_2/10} + ... + 10^{-A_n/10}\right)$

3   Interference calculation methods

In order to calculate the interference situation of an assignment, two major elements are needed:

–   the equivalent aggregate carrier to interference ratio, $C/I_{eq,\,ag}$, on both up and downlinks, $C/I_{eq,\,ag,\,up}$, $C/I_{eq,\,ag,\,dn}$, respectively;

–   the overall co-channel (or co-frequency) protection ratios of the wanted carrier, PR_{ov}.

In addition, definitions for the EPM (see Note 1) and OEPM are required.

NOTE 1 – EPM is not needed in case of application of this method to the Region 2 BSS Plan.

3.1   The first elements, i.e. the equivalent aggregate carrier to interference ratios, are calculated as follows for both the up and downlinks:

$$C/I_{eq,\,ag,\,up} = \sum_{i=1}^{m} \oplus \left(C/I_{i,\,se,\,up} + D_i(fo_i)\right)$$

$$C/I_{eq,\,ag,\,dn} = \sum_{i=1}^{n} \oplus \left(C/I_{i,\,se,\,dn} + D_i(fo_i)\right)$$

where:

         m: number of interfering carriers on the feeder link

         n: number of interfering carriers on the downlink

         fo: frequency offset between the centre frequencies of the wanted carrier and one interfering carrier; a positive or negative value (MHz)

    $D(fo)$:   difference (dB) between the appropriate protection mask's value with no frequency offset (i.e. the centre value at 0 MHz) and the protection mask's value with a frequency offset of fo MHz.

For the case of a digital wanted carrier and a digital interfering carrier, the value $D(fo) = -I(fo)$, where $I(fo)$ ($\equiv I(\Delta f)$) is defined in Annex 3 assuming a linear or non-linear channel.

For other combinations of wanted and interfering carrier types (digital into analogue interference) appropriate masks remain to be defined. Until such time as these masks are available, the model given in Annex 1 should be applied to evaluate $D(fo)$.

From these first elements the overall equivalent aggregate carrier-to-interference ratio (denoted $C/I_{ov, eq, ag}$) can be calculated as follows:

$$C/I_{ov, eq, ag} = C/I_{eq, ag, up} \oplus C/I_{eq, ag, dn}$$

3.2 The second major element, i.e. the overall protection ratio, PR_{ov}, is associated to the type of the wanted carriers.

In addition to this second element, a feeder-link protection ratio and a downlink protection ratio, PR_{up} and PR_{dn} respectively, can be defined. Assuming a given increase, X, in the downlink protection ratio to allow for interference in the feeder link, PR_{up} and PR_{dn} are defined as follows:

$$PR_{dn} = PR_{ov} + X$$

$$PR_{up} = PR_{ov} \copyright PR_{dn}$$

3.3 EPM_{up}, EPM_{dn} **and OEPM definitions**

$$OEPM = C/I_{ov, eq, ag} - PR_{ov}$$

$$EPM_{up} = C/I_{eq, ag, up} - PR_{up}$$

$$EPM_{dn} = C/I_{eq, ag, dn} - PR_{dn}$$

ANNEX 3

**Calculation of protection masks for interference
between various types of digital carriers**

1 Method

It is assumed that the interfering digital carrier can, for interference calculation purposes, be modelled as a white noise source followed by a square-root, raised cosine pulse shaping filter. The roll-off factor, α_i, of this filter may be freely specified in the range $0 \leq \alpha_i \leq 1$ (0% to 100% roll-off). The filter's 3 dB bandwidth is specified by the transmitted symbol rate, R_i, for the interfering digital signal.

The level of digital interference affecting the wanted digital signal is dependent upon:

– the frequency offset between the wanted and interfering signals, Δf;

– the characteristics of the receiver's filter;

– the characteristics of the transmission channel that carries the interfering signal.

The receiver's filter is also modelled as a square-root, raised cosine filter with a roll-off factor, α_w, where $(0 \le \alpha_w \le 1)$, and a 3 dB bandwidth specified by the wanted signal symbol rate R_w.

High power amplification of the interfering signal causes spectral side lobe re-growth. The interference contributed by the side lobes is negligible for low values of Δf, but becomes increasingly significant as the frequency offset is increased.

Only the first two side lobes need to be considered. The interference contribution from higher order side lobes is negligible in all practical transmission scenarios.

The level of each side lobe is adjusted with respect to the main spectral lobe to reflect the characteristics of the non-linear channel. The relative level of each side lobe comprises two components L_s and X:

– A value L_s that is dependent upon the non-linear characteristics of the high power amplifier (HPA) and upon the amplifier's drive level (backoff). The value of L_s is different for each side lobe.

– A value X that represents the effect of filtering at the output of the HPA. This attenuation value is assumed to be the same for all spectral side lobes. This approach is conservative, since the gain of the post-HPA filter is not flat, but rolls off with increasing frequency offset from the channel centre frequency.

The parameters L_s and X are expressed in decibels.

The parameters R_i and R_w are expressed in Msymbol/s. The total bandwidths of the wanted and interfering signals are given by $R_w(1 + \alpha_w)$ MHz and $R_i(1 + \alpha_i)$ MHz respectively. The frequency difference parameter Δf is expressed in MHz. The interference at the output of the receiver filter is assumed to be noise-like.

A common algorithm is used to calculate the wanted signal power at the input to the receiver and the interference power contributions from the main spectral lobe and from each of the spectral side lobes. The procedure for calculating each power contribution is as follows (see § 3 for definitions of the terms used below):

a) set the input parameters (R_i, R_w, α_i, α_w, δf, L_s and X) to the appropriate values for the power contribution to be calculated (wanted signal, interfering signal main spectral lobe or interfering signal spectral side lobe);

b) calculate the nine pairs of limits (U_n, L_n, $n = 1, …, 9$);

c) calculate the five power contribution terms (C_m, $m = 1, …, 5$);

d) calculate the total received power, P:

$$P = 10^{\frac{L_s - X}{10}} \sum_{m=1}^{5} C_m$$

The level of interference power $I(\Delta f)$, measured at the output of the receiver's filter and expressed relative to the wanted carrier power for a reference link C/I of 0 dB (i.e. assuming equal wanted and interfering carrier powers), is calculated as follows.

Step 1: Calculate the wanted signal power, P_w, at the output of the receiver filter using the above algorithm and setting the input parameter values as follows:

$$R_i = R_w, \quad \alpha_i = \alpha_w, \quad \delta f = 0, \quad L_s = 0, \quad X = 0$$

Step 2: Calculate the interfering signal power contribution from the main spectral lobe, P_0, at the output of the receiver filter using the same algorithm and setting the input parameters as follows:

$$\delta f = \Delta f, \quad L_s = 0, \quad X = 0$$

Step 3: Calculate the interfering signal power contribution from the first spectral side lobe, P_1, with the input parameters set as follows:

$$\delta f = |\Delta f| - R_i, \quad L_s = L_1 \neq 0, \quad X \neq 0$$

The value for L_s depends upon the non-linear characteristics of the HPA and its drive level. The value of X depends upon the out-of-band attenuation characteristics of the post-HPA filter.

Step 4: Calculate the interfering signal power contribution from the second spectral side lobe, P_2, with the input parameters set as follows:

$$\delta f = |\Delta f| - 2R_i, \quad L_s = L_2 \neq L_1 \neq 0, \quad X \neq 0$$

The value for L_s again depends upon the non-linear characteristics of the HPA and its drive level. The value of X is the same as in Step 3.

Step 5: Calculate the relative interference power for the given signal parameters and frequency offset:

$$I(\Delta f) = 10 \log \left(\frac{P_0 + P_1 + P_2}{P_w} \right) \qquad \text{dB}$$

2   Example calculation of a protection mask

As an (arbitrary) example, it is assumed that the wanted and interfering signal parameters are as follows:

Wanted digital signal:

Symbol rate, $R_w = 27.5$ Msymbol/s

Roll-off factor, $\alpha_w = 0.35$ (35% cosine roll-off).

Interfering digital signal:

Symbol rate, $R_i = 27.5$ Msymbol/s

Roll-off factor, $\alpha_i = 0.35$ (35% cosine roll-off).

Side lobe levels:

First side lobe level, $L_{s1} = -17.0$ dB

Second side lobe level, $L_{s2} = -27.5$ dB.

Post-HPA filtering:

Side lobe attenuation, $X_f = 12.0$ dB.

The frequency offset between the wanted and interfering signals, Δf, is assumed to be 38.36 MHz. The application of the calculation method described in § 1 of this Annex, and detailed in § 3 of this Annex, gives the following:

Step 1: Calculate the wanted signal power, P_w, at the output of the receiver filter:

$$R_i = R_w, \quad \alpha_i = \alpha_w, \quad L_s = 0, \quad X = 0, \quad \delta f = 0$$

$$L_1 = U_8 = U_9 = -8.937$$

$$U_1 = L_2 = U_2 = L_3 = U_3 = L_4 = U_4 = L_5 = U_5 = L_6 = L_7 = L_8 = L_9 = 8.937$$

$$U_6 = U_7 = 18.563$$

$$C_1 = 0.825, \quad C_2 = 0, \quad C_3 = 0, \quad C_4 = 0.088, \quad C_5 = 0$$

$$P_w = 0.913$$

Step 2: Calculate the interfering signal power, P_0, due to the main spectral lobe at the output of the receiver filter:

$$L_s = 0, \quad X = 0, \quad \delta f = \Delta f$$

$$L_1 = L_3 = L_4 = 29.422, \quad U_1 = L_2 = L_5 = L_7 = 8.937, \quad L_6 = L_9 = 47.297, \quad L_8 = -18.563$$

$$U_9 = -8.937, \quad U_2 = U_5 = -29.422, \quad U_3 = U_4 = U_6 = 18.563, \quad U_7 = U_8 = -19.797$$

$$C_1 = 0, \quad C_2 = 0, \quad C_3 = 0, \quad C_4 = 0, \quad C_5 = 0$$

$$P_0 = 0$$

Step 3: Calculate the interfering signal power, P_1, due to the first spectral side lobe at the output of the receiver filter:

$$L_s = L_{s1}, \quad X = X_f, \quad \delta f = |\Delta f| - R_i$$

$$L_1 = 1.923, \quad U_1 = L_2 = L_3 = L_4 = L_5 = L_7 = 8.937, \quad U_2 = U_5 = L_8 = -1.923$$

$$U_3 = U_4 = U_6 = 18.563, \quad L_6 = L_9 = 19.797, \quad U_7 = 7.703, \quad U_8 = U_9 = -8.937$$

$$C_1 = 0.605, \quad C_2 = 0, \quad C_3 = 0, \quad C_4 = 0, \quad C_5 = 0$$

$$P_1 = 7.618 \times 10^{-4}$$

Step 4: Calculate the interfering signal power, P_2, due to the second spectral side lobe at the output of the receiver filter:

$$L_s = L_{s2}, \quad X = X_f, \quad \delta f = |\Delta f| - 2R_i$$

$$L_1 = U_8 = U_9 = -8.937, \quad U_1 = U_3 = U_4 = L_9 = -7.703, \quad L_2 = L_3 = L_4 = L_5 = L_6 = 8.937$$

$$U_2 = U_5 = U_7 = 18.563, \quad L_7 = L_8 = 25.578, \quad U_6 = 1.922$$

$$C_1 = 0.395, \quad C_2 = 0, \quad C_3 = 0, \quad C_4 = 0, \quad C_5 = 0$$

$$P_2 = 4.431 \times 10^{-5}$$

Step 5: Calculate the total interference power relative to the wanted signal power:

$$I(\Delta f) = -30.5$$

Following this procedure for a range of frequency offsets results in the example protection mask given in Fig. 1.

FIGURE 1
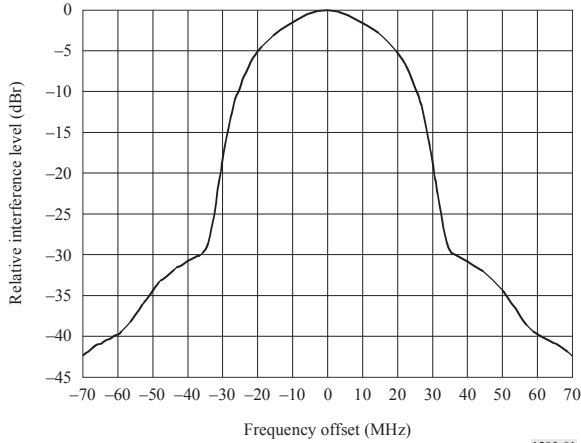
1293-01

3 Algorithms: Calculation of the received (wanted or interfering) signal power

3.1 Limits

$$A = (1 - \alpha_w)\frac{R_w}{2} \qquad B = (1 + \alpha_w)\frac{R_w}{2} \qquad C = (1 - \alpha_i)\frac{R_i}{2} \qquad D = (1 + \alpha_i)\frac{R_i}{2}$$

$L_1 = max\,(-A;\, \delta f - C)$	$L_4 = max\,(A;\, \delta f - C)$	$L_7 = max\,(A;\, -\delta f + C)$
$U_1 = min\,(A;\, \delta f + C)$	$U_4 = min\,(B;\, \delta f + C)$	$U_7 = min\,(B;\, -\delta f + D)$
$L_2 = max\,(-A - \delta f;\, C)$	$L_5 = max\,(A;\, -\delta f - C)$	$L_8 = max\,(-B;\, -\delta f + C)$
$U_2 = min\,(A - \delta f;\, D)$	$U_5 = min\,(B;\, -\delta f + C)$	$U_8 = min\,(-A;\, -\delta f + D)$
$L_3 = max\,(-A + \delta f;\, C)$	$L_6 = max\,(A;\, \delta f + C)$	$L_9 = max\,(-B;\, \delta f + C)$
$U_3 = min\,(A + \delta f;\, D)$	$U_6 = min\,(B;\, \delta f + D)$	$U_9 = min\,(-A;\, \delta f + D)$

NOTE 1:

$max\,(a;\, b)$: maximum value of a and b

$min\,(a;\, b)$: minimum value of a and b

δf = frequency of interfering signal − frequency of wanted signal.

3.2   Functions

When $1 \leq n \leq 3$:

$$
\begin{aligned}
p_n(a,b) &= f_n(a) - f_n(b) && \text{for } a > b \\
&= 0 && \text{for } a \leq b
\end{aligned}
$$

$$
f_1(x) = \left(\frac{x}{R_i}\right) \qquad\qquad f_2(x) = \frac{\alpha_i}{2\pi} \cos\left(\frac{\pi}{2} \frac{2x - R_i}{\alpha_i R_i}\right) \qquad\qquad f_3(x) = \frac{\alpha_w R_w}{2\pi R_i} \cos\left(\frac{\pi}{2} \frac{2x - R_w}{\alpha_w R_w}\right)
$$

When $4 \leq n \leq 5$:

$$
\begin{aligned}
p_n(a,b,\delta f) &= f_n(a,\delta f) - f_n(b,\delta f) && \text{for } a > b \\
&= 0 && \text{for } a \leq b
\end{aligned}
$$

$$
\begin{aligned}
f_4(x,y) &= f_{4a}(x,y) && \text{for } \alpha_w R_w = \alpha_i R_i \\
&= f_{4b}(x,y) && \text{for } \alpha_w R_w \neq \alpha_i R_i
\end{aligned}
\qquad\qquad
\begin{aligned}
f_5(x,y) &= f_{5a}(x,y) && \text{for } \alpha_w R_w = \alpha_i R_i \\
&= f_{5b}(x,y) && \text{for } \alpha_w R_w \neq \alpha_i R_i
\end{aligned}
$$

$$
f_{4a}(x,y) = \frac{1}{16\pi R_i}\left(2\pi x \cos\left(\frac{\pi}{2} \frac{2y + R_i - R_w}{\alpha_i R_i}\right) - \alpha_i R_i \sin\left(\frac{\pi}{2} \frac{4x - 2y - R_i - R_w}{\alpha_i R_i}\right)\right)
$$

$$
f_{4b}(x,y) = \frac{\alpha_i \alpha_w R_w}{4\pi\left(\alpha_i^2 R_i^2 - \alpha_w^2 R_w^2\right)}\left(\alpha_i R_i \cos\left(\frac{\pi}{2}\frac{2x - R_w}{\alpha_w R_w}\right)\sin\left(\frac{\pi}{2}\frac{2y - 2x + R_i}{\alpha_i R_i}\right) + \alpha_w R_w \sin\left(\frac{\pi}{2}\frac{2x - R_w}{\alpha_w R_w}\right)\cos\left(\frac{\pi}{2}\frac{2y - 2x + R_i}{\alpha_i R_i}\right)\right)
$$

$$
f_{5a}(x,y) = \frac{1}{16\pi R_i}\left(\alpha_i R_i \sin\left(\frac{\pi}{2}\frac{4x - 2y - R_i + R_w}{\alpha_i R_i}\right) - 2\pi x \cos\left(\frac{\pi}{2}\frac{2y + R_i + R_w}{\alpha_i R_i}\right)\right)
$$

$$
f_{5b}(x,y) = \frac{\alpha_i \alpha_w R_w}{4\pi\left(\alpha_i^2 R_i^2 - \alpha_w^2 R_w^2\right)}\left(\alpha_i R_i \cos\left(\frac{\pi}{2}\frac{2x + R_w}{\alpha_w R_w}\right)\sin\left(\frac{\pi}{2}\frac{2x - 2y - R_i}{\alpha_i R_i}\right) - \alpha_w R_w \sin\left(\frac{\pi}{2}\frac{2x + R_w}{\alpha_w R_w}\right)\cos\left(\frac{\pi}{2}\frac{2x - 2y - R_i}{\alpha_i R_i}\right)\right)
$$

3.3   Power contributions

$$
C_1 = p_1(U_1, L_1) + \frac{1}{2}\sum_{n=2}^{5} p_1(U_n, L_n) + \frac{1}{4}\sum_{n=6}^{9} p_1(U_n, L_n)
$$

$$
\begin{aligned}
C_2 = &\ p_2(U_2, L_2) + p_2(U_3, L_3) + \\
&\frac{1}{2}\left[p_2(U_6 - \delta f, L_6 - \delta f) + p_2(U_7 + \delta f, L_7 + \delta f) + p_2(U_8 + \delta f, L_8 + \delta f) + p_2(U_9 - \delta f, L_9 - \delta f)\right]
\end{aligned}
$$

$$
C_3 = p_3(U_4, L_4) + p_3(U_5, L_5) + \frac{1}{2}\left[p_3(U_6, L_6) + p_3(U_7, L_7) + p_3(-L_8, -U_8) + p_3(-L_9, -U_9)\right]
$$

$$
C_4 = p_4(U_6, L_6, \delta f) + p_4(U_7, L_7, -\delta f)
$$

$$
C_5 = p_5(U_8, L_8, -\delta f) + p_5(U_9, L_9, \delta f)
$$

3.4   Total received signal power

$$\text{Power} = 10^{\frac{L_s - X}{10}} \sum_{m=1}^{5} C_m$$

APPENDIX 1

TO ANNEX 3

Notification of parameters associated to digital emissions

Application of the method described in Annex 3 for calculation of protection masks for interference between digital emissions requires the notification of parameters associated with each digital emission. These parameters are:

–   the digital modulation type (this method is applicable only to phase shift keyed signals);

–   the transmitted symbol rate (Msymbol/s);

–   the roll-off factor of the digital pulse shaping filter (assumed to be a cosine roll-off filter or an approximation thereof), a value in the range 0 to 1;

–   the relative levels of the first and second side lobes, L_{s1} and L_{s2} (dB);

–   the side lobe attenuation, X (dB) resulting from post-HPA filtering.

The first three of these items are already required by RR Appendix 4. In addition, the last two items are recommended to be provided to be added to RR Appendix 4 by a future competent conference.

Most downlink digital TV carriers occupy the whole of the transponder bandwidth and the transponder is operated at saturation for maximum downlink power. Studies have shown that, under these conditions, suitable side lobe relative levels are –18 dB and –30 dB respectively. Furthermore, since there is always filtering (an output multiplexer) at the output of the on-board HPA (travelling wave tube amplifier (TWTA), the parameter X is non-zero. The precise value of X will vary from system to system. A value of 12 dB seems to be a conservative minimum value that should be exceeded by all new systems implementing contiguous co-polar channels.

For uplinks there is typically no post-HPA filter but the HPA is operated with a backoff to control the out-of-band side lobe levels. Side lobe levels of –29 dB and –39.5 dB are unlikely to be exceeded in feeder links to BSS systems.

RECOMMENDATION ITU-R S.1340*,**

Sharing between feeder links for the mobile-satellite service and the aeronautical radionavigation service in the Earth-to-space direction in the band 15.4-15.7 GHz

(Question ITU-R 243/4)

(1997)

The ITU Radiocommunication Assembly,

considering

a)   that Resolution 117 of the World Administrative Radio Conference (Geneva, 1995) (WARC-95) calls for studies by the ITU-R of the sharing situation between feeder links (Earth-to-space) for the mobile-satellite service (MSS) and the aeronautical radionavigation service in the band 15.45-15.65 GHz;

b)   that the band 15.4-15.7 GHz is allocated to the aeronautical radionavigation service on a primary basis and that No. S4.10 of the Radio Regulations (RR) applies;

c)   that the WRC-95 has added an allocation to the fixed-satellite service (FSS) in the band 15.45-15.65 GHz for feeder links of non-geostationary (non-GSO) satellite networks in the MSS in the Earth-to-space direction;

d)   that the requirements for feeder links (Earth-to-space) of non-GSO satellite systems in the MSS need to be accommodated in this band;

e)   that emissions from stations in the aeronautical radionavigation service can cause unacceptable interference to satellites;

f)   that administrations operating stations in the aeronautical radionavigation service are urged to limit the average e.i.r.p. to 42 dBW in order to limit interference to non-GSO satellites; this value is subject to review and study by the ITU-R (see RR No. S5.511C);

g)   that coordination of emissions from aeronautical radionavigation stations with feeder-link space stations is not considered practical;

h)   that emissions from feeder-link earth stations propagated along the Earth's surface can cause harmful interference to aeronautical radionavigation stations;

j)   that certain limitations have been placed on the fixed-satellite service for the protection of the aeronautical radionavigation service in accordance with RR No. S5.511C;

k)   that there is fairly extensive use of this band by the aeronautical radionavigation service for airborne, land and ocean based stations;

l)   that aircraft stations are not permitted to transmit in the band 15.45-16.45 GHz in accordance with RR No. S5.511B;

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*   This Recommendation should be brought to the attention of Radiocommunication Study Group 8.

**   Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

m)   that the technical and operational characteristics of the aeronautical radionavigation stations are reasonably well known;

n)   that the technical and operational characteristics of feeder links are not well defined;

o)   that methods are needed to determine the coordination and separation distances required between feeder-link earth stations and aeronautical radionavigation stations in order to protect the aeronautical radionavigation stations;

p)   that studies have been made with respect to the preceding *considerings*,

recommends

1   that feeder links for the MSS should be limited to the band 15.43-15.63 GHz (see Note 1);

2   that the emissions expressed as effective e.i.r.p. (E_{eff}) from aeronautical radionavigation stations should not exceed the following:

2.1   for aircraft landing systems and for feeder-link bandwidths greater than 3 MHz:

$$E_{eff} = \begin{cases} 53 & \text{dBW} & \text{for} & 0 \le \varphi < 8 \\ 53 - 0.833\,(\varphi - 8) & \text{dBW} & \text{for} & 8 \le \varphi < 14 \\ 48 & \text{dBW} & \text{for} & 14 \le \varphi < 32 \\ 48 - 9\,(\varphi - 32) & \text{dBW} & \text{for} & 32 \le \varphi < 34 \\ 30 & \text{dBW} & \text{for} & 34 \le \varphi < 40 \\ 30 - 0.2\,(\varphi - 40) & \text{dBW} & \text{for} & 40 \le \varphi \le 90 \end{cases}$$

2.2   for general purpose aircraft radars and for feeder-link bandwidths greater than 1 MHz:

$$E_{eff} = \begin{cases} 62 & \text{dBW} & \text{for} & 0 \le \varphi < 20 \\ 62 - 0.56\,(\varphi - 20)^2 & \text{dBW} & \text{for} & 20 \le \varphi < 25 \\ 48 & \text{dBW} & \text{for} & 25 \le \varphi < 29 \\ 71.86 - 25 \log\,(\varphi - 20) & \text{dBW} & \text{for} & 29 \le \varphi < 68 \\ 29.8 & \text{dBW} & \text{for} & 68 \le \varphi \le 90 \end{cases}$$

where:

$$E_{eff} = E_p - 15 \log\,(1 + 5/PW) \qquad \text{dBW}$$

E_{eff} :   e.i.r.p. which causes the same level of interference to a phase modulated signal as a continuous noise like interferer

E_p :   peak pulse e.i.r.p. (dBW) of the aeronautical radionavigation station

PW :   pulse duration (µs) of the aeronautical radionavigation station

φ :   angle of elevation (degrees) above the local horizontal plane;

3   that feeder links in the Earth-to-space direction should be designed to operate in the interference environment defined in *recommends* 2;

4   that with *recommends* 2 and 3 coordination of emissions from aeronautical radionavigation stations with satellite receiving stations is not required;

5 that the e.i.r.p. transmitted toward the local horizontal plane by a feeder-link earth station should not exceed 54 dB(W/MHz) (see Note 2);

6 that surface based radars as described in Annex 1 should not operate in the 15.43-15.63 GHz band;

7 that the coordination distances required to protect the aeronautical radionavigation stations from harmful interference from feeder-link earth station emissions are:

– 515 km from the aircraft landing surface for aircraft landing systems (ALS);

– 600 km from aircraft using general purpose radars (MPR);

– 270 km from the aircraft landing for radar sensing and measurement systems;

8 that additional information is contained in Annexes 1, 2 and 3.

NOTE 1 – The frequency band given in *recommends* 1 is slightly different to that allocated by the WRC-95. This difference is recommended to facilitate sharing between the non-GSO MSS feeder links and the aeronautical radionavigation service. *recommends* 1 will be reviewed at a later date in accordance with the outcome of a future WRC.

NOTE 2 – Additional design and operational constraints may be placed on MSS Earth-to-space feeder links in order to take into account the threshold levels for the radio astronomy service given in Recommendation ITU-R RA.769.

ANNEX 1

Aeronautical radionavigation systems in the 15.4-15.7 GHz band

1 Surface based radars (SBR)

The land and ship based SBR are used for the detection, location and movement of aircraft and other vehicles on the surface of airports and other aircraft landing areas.

1.1 Antenna patterns

– Nominal 3 dB beamwidth: <3.5° vertical, inverted
  cosecant to –31°
  0.35° horizontal

– Frequency range: 15.65-16.7 GHz

– Polarization: circular

– Typical gain: 43 dBi

– Maximum side-lobe level: 25 dB below peak gain

– Maximum back-lobe level: 35 dB below peak gain

– Vertical tilt range: ±1.5°

– Maximum horizontal scan range: 360°.

1.1.1 Antenna elevation envelope pattern

Based on measured data and side-lobe level specifications and with the peak gain directed at $+1.5°$, an elevation envelope gain pattern is defined as follows where φ is the elevation angle (degrees):

$$G(\varphi) = \begin{cases} 43 & \text{dBi} & \text{for} & 0 \le \varphi < 4 \\ 43 - 5\,(\varphi - 4) & \text{dBi} & \text{for} & 4 \le \varphi < 9 \\ 18 & \text{dBi} & \text{for} & 9 \le \varphi < 16 \\ 43.2 - 21 \log \varphi & \text{dBi} & \text{for} & 16 \le \varphi < 48 \\ 8 & \text{dBi} & \text{for} & 48 \le \varphi \le 90 \end{cases}$$

1.1.2 Antenna azimuth envelope pattern

Based on measured data and side-lobe level specifications, the azimuth gain pattern is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 43 - 110\,\varphi^2 & \text{dBi} & \text{for} & 0 \le \varphi < 0.4767 \\ 18 & \text{dBi} & \text{for} & 4.4767 \le \varphi < 0.72 \\ 17.07 - 6.5 \log \varphi & \text{dBi} & \text{for} & 0.72 \le \varphi < 48 \\ 8 & \text{dBi} & \text{for} & 48 \le \varphi \le 180 \end{cases}$$

1.2 Other characteristics

1.2.1 Transmitting

– Peak e.i.r.p.: 86 dBW

– Pulse repetition frequency: 8 192 Hz

– Pulse duration: 0.04 μs

– Pulse 3.5 dB bandwidth: 25 MHz.

1.2.2 Receiving

– Typical antenna gain: 43 dBi

– Typical noise figure: 6.2-6.9 dB.

2 Aircraft landing systems (ALS)

These ALS are general purpose systems and are used on ships, as portable or permanent land based systems and for shuttle landings. The microwave scanning beam landing system (MSBLS) is one such system. Some of the characteristics vary with the particular applications.

2.1 Surface based station antenna patterns

The antenna patterns are similar for all applications including the MSBLS. The scanning ranges vary with application. The scanning ranges given below cover all applications.

The antenna complement of the ALS consists of an elevation antenna and an azimuth antenna.

The elevation antenna portion of the ALS is used to transmit vertical angle data to the aircraft.

– nominal 3 dB beamwidths: 1.3° vertical
40° horizontal

– frequency range: 15.4-15.7 GHz

– polarization: horizontal and vertical

– typical gain: 28 dBi

– maximum side-lobe level: 17 dB below peak gain in both planes

– maximum vertical scan range: 0 to 30°.

The azimuth antenna portion of the ALS is used to transmit azimuth information to the aircraft.

– nominal 3 dB beamwidths: 2.0° horizontal
6.5° vertical

– the vertical pattern is spoiled to achieve at least a 20 dBi gain at 20° above the horizon

– frequency range: 15.4-15.7 GHz

– polarization: horizontal and vertical

– typical gain: 33 dBi

– maximum side-lobe level: 17 dB below peak gain in both planes

– maximum horizontal scan range: ±35°.

2.1.1 Combined antenna elevation envelope pattern

A combined vertical envelope gain pattern based on measured data is defined as follows where φ is the elevation angle (degrees):

$$G(\varphi) = \begin{cases} 33 & \text{dBi} & \text{for} & 0 \le \varphi < 8 \\ 33 - 0.833\,(\varphi - 8) & \text{dBi} & \text{for} & 8 \le \varphi < 14 \\ 28 & \text{dBi} & \text{for} & 14 \le \varphi < 32 \\ 28 - 9\,(\varphi - 32) & \text{dBi} & \text{for} & 32 \le \varphi < 34 \\ 10 & \text{dBi} & \text{for} & 34 \le \varphi < 40 \\ 10 - 0.2\,(\varphi - 40) & \text{dBi} & \text{for} & 40 \le \varphi \le 90 \end{cases}$$

2.1.2 Azimuth antenna patterns

The azimuth envelope pattern of the elevation antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 28 - 0.0062\,\varphi^2 & \text{dBi} & \text{for} & 0 \le \varphi < 70 \\ -2.37 & \text{dBi} & \text{for} & 70 \le \varphi \le 180 \end{cases}$$

The azimuth envelope pattern of the azimuth antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 33 - 2\,\varphi^2 & \text{dBi} & \text{for} & 0 \le \varphi < 3 \\ 15 & \text{dBi} & \text{for} & 3 \le \varphi < 5 \\ 32.5 - 25\log\varphi & \text{dBi} & \text{for} & 5 \le \varphi < 48 \\ -9.53 & \text{dBi} & \text{for} & 48 \le \varphi \le 180 \end{cases}$$

2.2   Other characteristics

2.2.1   Transmitting
–   Peak e.i.r.p.: 71 dBW
–   Pulse repetition frequency: 3 334 Hz
–   Pulse duration: 0.333 µs
–   Pulse 3.5 dB bandwidth: 3 MHz.

2.2.2   Receiving
–   Typical antenna gain: 8 dBi
–   Typical noise figure: 8 dB.

3   Aircraft multipurpose radars (MPR)

The aircraft MPR is a radionavigation, radiolocation and weather radar.

3.1   Antenna patterns

The antenna is a parabola of approximately 0.3 m diameter which is scanned vertically and horizontally with respect to the heading and attitude of the aircraft:

–   nominal 3 dB beamwidth: 4.5°
–   frequency range: 15.4-15.7 GHz
–   polarization: vertical
–   typical gain: 30 dBi
–   maximum horizontal scan range: ±45°
–   maximum vertical scan range: ±20°.

The envelope pattern of the antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 30 & \text{dBi} & \text{for} & 0 \le \varphi < 20 \\ 30 - 0.56\,(\varphi - 20)^2 & \text{dBi} & \text{for} & 20 \le \varphi < 25 \\ 16 & \text{dBi} & \text{for} & 25 \le \varphi < 29 \\ 39.86 - 25\log(\varphi - 20) & \text{dBi} & \text{for} & 29 \le \varphi < 68 \\ -2.17 & \text{dBi} & \text{for} & 68 \le \varphi \le 180 \end{cases}$$

3.2   Other characteristics

3.2.1   Transmitting

–   Peak e.i.r.p.: 70 dBW

–   Pulse repetition frequency: 800 Hz

–   Pulse duration: 2 µs

–   Pulse 3.5 dB bandwidth: 0.5 MHz.

3.2.2   Receiving

–   Typical antenna gain: 30 dBi

–   Typical noise figure: 8 dB.

4   Radar sensing and measurement system (RSMS)

Measurement techniques using radar technology at 15 GHz are particularly suited to smaller aircraft, including helicopters, offering the benefits of compact, light, equipment with good antenna directivity and more than adequate performance for many operational radionavigation applications which are not practicable at lower frequencies due to propagation or other reasons. For use in a height measurement mode this higher frequency band confers system design benefits, such as lower cross coupling and absence of triangulation effects, which are particularly important for accurate measurement at very low (metric) separations. For some operational applications they present the only viable technical solution.

Systems using these techniques are widely used in certain parts of the world where they make an important contribution to the safety of aircraft operation. Measurement of height and ground clearance is one of the most critical parameters in the operation of aircraft when used to assist the final stages in a landing. High accuracy and interference free operation are vital to success and the enhancement of safety.

RSMS are essentially used in low level operations up to a nominal height of around 1 500 m. An antenna mounting which transmits and receives vertically downwards would be used in the great majority of applications. Power reduction proportional to height above terrain is employed to reduce scatter and other undesirable effects.

4.1   RSMS characteristics

4.1.1   Transmitter

–   Frequency range: 15.63-15.65 GHz

–   Peak power: 30 dBmW

–   Antenna gain: 13 dBi, back lobes < 5 dBi

–   PRF (pulse repetition frequency): 58 kHz

–   Pulse length (max.): 500 ns

–   Duty cycle (max.): 3%

–   Pulse 3.5 dB bandwidth: 2 MHz.

4.1.2   Receiver

–   Antenna gain: 13 dBi, back lobes < 5 dBi

–   Noise figure: 6 dB.

ANNEX 2

**Emission criteria for the aeronautical radionavigation service and
sharing feasibility with feed links for the MSS (Earth-to-space)
in the 15.4-15.7 GHz band**

1   Introduction

A basic method for protecting non-GSO satellites from unacceptable interference is to establish maximum limits on the e.i.r.p. from aeronautical radionavigation stations and minimum e.i.r.p. limits on the emissions from the feeder-link earth stations.

Alternatively, only maximum e.i.r.p. limits on the aeronautical radionavigation stations can be established which define the interference environment in which the feeder links must be able to operate. This alternative appears more attractive in that it is simpler and allows maximum freedom for the design and operation of feeder links. This approach is addressed in the following sections.

Either of these methods is an effective way to eliminate the need for coordination. Coordination is not practical for this case.

2   Characteristics of aeronautical radionavigation systems

Several systems are identified that operate in this band. These include surface based radars (SBR) used on land and ships for the detection, location and movement of aircraft and other vehicles on aircraft landing areas, ALS, MPR and RSMS. The antenna patterns of these systems is an important element in determining the e.i.r.p. as a function of elevation angle. Antenna envelope gain patterns and other pertinent characteristics are given in Annex 1.

3   Analyses

3.1   Pulsed interference into digital carriers

Task Group 4/4 studied the interference from radars into digital carriers. Measurements were made over a wide range of pulse repetition frequencies (PRF), (1-100 kHz) and duty cycles, d, (0.01%-100%) for radar and data rates from 2 Mbit/s to 45 Mbit/s for 3/4 rate forward error correction (FEC) coded QPSK digital carriers operating at a bit error rate (BER) of 1×10^{-6}. An

empirical equation was developed from the measurement data which can be used to relate the peak pulsed radar e.i.r.p., E_p, to an effective e.i.r.p., E_{eff}, i.e., an e.i.r.p. which would cause the same level of interference (see Recommendation ITU-R S.1068). The actual average e.i.r.p., E_{ave}, is equal to the peak e.i.r.p. times the duty cycle. Under these conditions the empirical equation is:

$$E_{eff} = E_p - 15 \log (1 + 0.5(PRF/d)) \qquad \text{dBW} \qquad (1)$$

where PRF is in kHz and d is in per cent.

Since the pulse width, PW, is equal to (d/PRF), equation (1) can be expressed as:

$$E_{eff} = E_p - 15 \log (1 + 5/PW) \qquad \text{dBW} \qquad (2)$$

where PW is in microseconds.

With a $[(\sin x)/x]^2$ power spectral density function the peak power density is approximately 3.5 dB greater than the power density averaged over a $2/PW$ bandwidth. The 3.5 dB bandwidth (BW) (MHz) is approximately $1/PW$. With this, the effective e.i.r.p. density E_{eff}/MHz, for feeder-link carrier bandwidths (BW) (MHz) that are less than $1/PW$ is:

$$E_{eff}/\text{MHz} = E_p - 10 \log (2/PW) + 3.5 - 15 \log (1 + 5/PW) \qquad \text{dBW} \qquad (3)$$

and for (BW) equal to or greater than ($1/PW$) the (E_{eff}/MHz) averaged over (BW) is:

$$E_{eff}/\text{MHz} = E_p - 10 \log (2/PW) + 3.5 - 15 \log (1 + 5/PW) - 10 \log [(BW)(PW)] \qquad \text{dBW} \qquad (4)$$

3.2 Emission limits on aeronautical radionavigation stations

The SBRs can be accommodated in the band 15.63-15.7 GHz. By shifting the 15.45-15.65 GHz band to 15.43-15.63 GHz, interference to feeder links in the Earth-to-space direction does not need to be considered.

The dominant area of operation of the MPR is over the ocean which in most cases will be beyond the coordination distance of feeder-link earth stations, and thus would not require coordination with feeder-link earth stations. Therefore, the operation of the MPR in the 15.4-15.7 GHz band would be permitted even though geographical constraints would apply (see Annex 3). The RSMS currently operates in the 15.4-15.7 GHz band and geographical constraints may also apply.

The parameter values for equations (2), (3) and (4) for the ALS, MPR and RSMS aeronautical radionavigation systems are given in Annex 1 along with the antenna envelope gain functions. With this information the values of E_{eff} can be computed as a function of the elevation angle. The peak e.i.r.p. and PW are limited by equations (2), (3) and (4). The elevation angle, φ, is in degrees.

3.2.1   ALS E_{eff} limits

For feeder-link carrier bandwidths greater than 3 MHz:

$$E_{eff} = \begin{cases} 53 & \text{dBW} & \text{for} & 0 \le \varphi < 8 \\ 53 - 0.833\,(\varphi - 8) & \text{dBW} & \text{for} & 8 \le \varphi < 14 \\ 48 & \text{dBW} & \text{for} & 14 \le \varphi < 32 \\ 48 - 9\,(\varphi - 32) & \text{dBW} & \text{for} & 32 \le \varphi < 34 \\ 30 & \text{dBW} & \text{for} & 34 \le \varphi < 40 \\ 30 - 0.2\,(\varphi - 40) & \text{dBW} & \text{for} & 40 \le \varphi \le 90 \end{cases}$$

This function is shown in Fig. 1.

FIGURE 1

ALS effective e.i.r.p., E_{eff}, limits

Elevation angle with respect to the surface of the Earth (degrees)
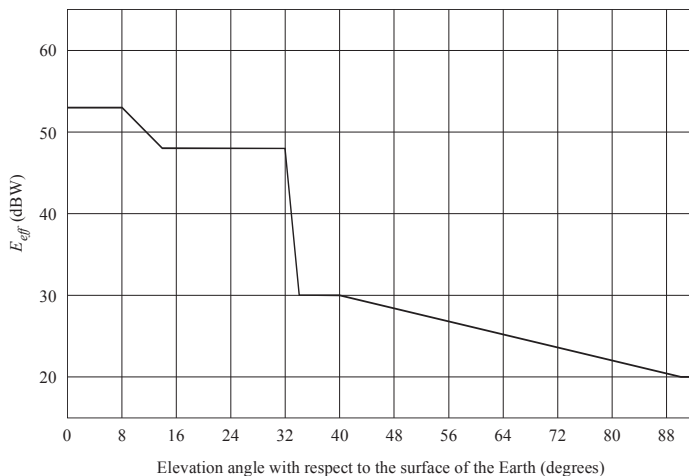
1340-01

3.2.2   MPR E_{eff} limits

For feeder-link carrier bandwidths greater than 1 MHz:

$$E_{eff} = \begin{cases} 62 & \text{dBW} & \text{for} & 0 \le \varphi < 20 \\ 62 - 0.56\,(\varphi - 20)^2 & \text{dBW} & \text{for} & 20 \le \varphi < 25 \\ 48 & \text{dBW} & \text{for} & 25 \le \varphi < 29 \\ 71.86 - 25 \log\,(\varphi - 20) & \text{dBW} & \text{for} & 29 \le \varphi < 68 \\ 29.8 & \text{dBW} & \text{for} & 68 \le \varphi \le 90 \end{cases}$$

This function is shown in Fig. 2.

The E_{eff} for the RSMS for elevation angles above 0° is −13.1 dBW.

FIGURE 2

MPR effective e.i.r.p., E_{eff}, limits
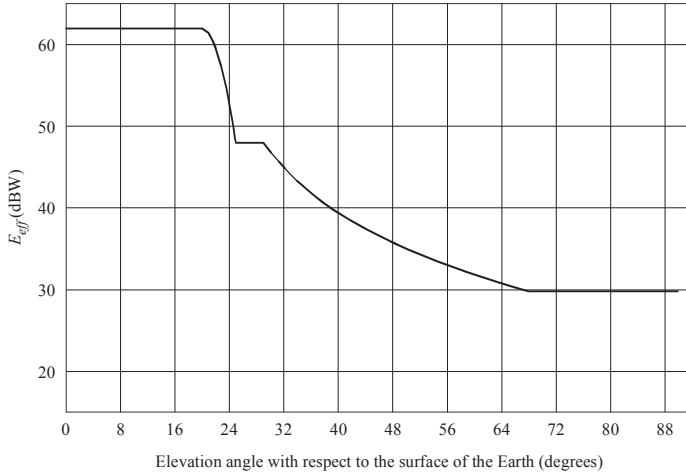
1340-02

3.3 Impact on feeder link up path e.i.r.p.

Protection from up-path interference due to aeronautical radionavigation stations can be achieved by providing adequate up-path e.i.r.p. from the earth station.

For the case of interference to a rate 3/4 FEC QPSK carrier, the carrier-to-interference, C/I, ratio for a 1×10^{-6} BER was about 9 dB for the measurements described in Section 3.1. This C/I is for the condition where interference from other sources is not significant. Since the percentage of time that a radionavigation station is operating and the −3 dB contour of its antenna is in conjunction with a satellite is very low, it is assumed that a C/I of 9 dB can be tolerated for this small percentage of time. For an uncoded QPSK carrier the C/I is about 12 dB.

The up-path e.i.r.p. required to overcome these interference envelopes as a function of the feeder-link carrier bandwidth can be computed by assuming that only one entry of one type will occur at any one time. In general, e.i.r.p. values in the 60 to 70 dBW range may be required.

4   Summary

–   The effective e.i.r.p. limits given in § 3.2 are consistent with the operation of currently existing aeronautical radionavigation systems.

–   Specifying the maximum interference environment which must be accepted by MSS feeder links allows the feeder-link designers and operators maximum flexibility to meet their service requirements and eliminates any need to specify orbit altitudes, satellite antenna pattern etc., which may be involved in specifying minimum e.i.r.p.s.

–   The minimum feeder-link earth station e.i.r.p.s required to operate in the maximum interference environment given in § 3.3 in the Earth-to-space direction are readily achievable.

ANNEX 3

Coordination distances between feeder-link earth stations in the MSS operating in the Earth-to-space direction and stations in the aeronautical radionavigation service in the band 15.4-15.7 GHz

1   Aeronautical radionavigation system characteristics

Several systems are identified that operate in this band. These include aircraft landing systems (ALS) and airborne multipurpose radars (MPR). The characteristics and analyses necessary to determine coordination distances are given in the following section.

2   Coordination distances

2.1   Analyses

The coordination distance, D_c, necessary to ensure protection against interference from feeder-link earth stations in the MSS into stations operating in the aeronautical radionavigation service is computed as shown in the following paragraphs.

$$D_c = D_{fsl} + D_{oth} + D_{as} \qquad \text{km} \qquad (5)$$

where:

D_{fsl} :   total radio line-of-sight distance (km)

D_{oth} :   over-the-horizon distance corresponding to the necessary over the horizon loss (km)

D_{as} :   distance from aircraft to landing surface (km) (applies to ALS and RSMS)

$$D_{fsl} = (2r\,h_1)^{0.5} + (2r\,h_2)^{0.5} \qquad \text{km} \qquad (6)$$

where:

r : radius of the Earth taken as 4/3 geometric to account for atmospheric refraction (8 500 km)

h_1 : ARNS station height (km)

h_2 : feeder-link earth station height (km)

$$L_{oth} = E_{esd} + 168.6 - L_{fsl} + G/T - I/N \qquad \text{dB} \qquad (7)$$

where:

L_{oth} : over-the-horizon propagation loss added to L_{fsl} (dB) (this function is shown in below and in Fig. 1 which is derived from the 5% functions for 15 GHz in Recommendation ITU-R P.528; i.e. loss exceeded 95% of the time)

E_{esd} : maximum e.i.r.p. density of the feeder-link earth station toward the horizon (this is taken as 54 dB(W/MHz))

L_{fsl} : free space loss computed for D_{fsl} (dB)

G/T : gain/noise temperature of the ARNS station (dB)

I/N : acceptable interference/noise of the ARNS station (dB).

The values of L_{oth} as a function of D_{oth} are as indicated in Table 1.

TABLE 1

D_{oth} (km)	L_{oth} (dB)	D_{oth} (km)	L_{oth} (dB)	D_{oth} (km)	L_{oth} (dB)
0	0	175	78	350	104
25	24	200	82	375	107
50	45	225	86	400	110
75	57	250	90	425	113
100	64	275	94	450	116
125	69	300	98	475	118
150	74	325	101	500	120

Values of D_{oth} for values of L_{oth} between those given may be extrapolated by:

$$D_{oth} = D_{ith} + 25[(L_{oth} - L_{ith})/(L_{jth} - L_{ith})] \qquad \text{km} \qquad (8)$$

where:

L_{ith} : next lower value of L_{oth} in Table 1, from L_{oth} determined by equation (7)

L_{jth} : next higher value of L_{oth} in Table 1, from L_{oth} determined by equation (7).

2.2   Computed coordination distances

Given the equations and computation methods plus some parameter values in § 2.1 and the other necessary parameter values, coordination values are computed as indicated in Table 2:

TABLE 2

Parameter	ALS	MPR	RSMS
h_1 (km)	7.6	15	1.5
h_2 (km)	0.01	0.01	0.01
D_{fsl} (km)	372	518	172.7
D_{as} (km)	100	0	40
L_{fsl} (dB)	167.7	170.6	160.9
G/T (dB)	–22.7	–2.0	–24.4
I/N (dB)	–10	–10	–10
L_{oth} (dB)	42.2	60	47.3
D_{oth} (km)	46.7	85.7	54.8
D_c (km)	518.7	603.7	267.5

A coordination distance of 600 km can be used for the MPR. The dominant mode of operation of the MPR is over ocean areas, which in most cases will be beyond 600 km of feeder-link earth stations and this would not require coordination. If feeder-link earth stations were located inland the areas of operation over the ocean would be enhanced.

2.3   Reduction of earth station limits

Reducing the maximum e.i.r.p. density limit toward the horizon of the feeder-link earth station should reduce the coordination distance. Using the function in Fig. 3, coordination distances versus E_{esd} are as indicated in Table 3:

TABLE 3

E_{esd} (dB(W/MHz))	ALS (km)	MPR (km)	RSMS (km)
54	519	604	268
44	507	573	254
34	495	561	242
24	485	549	231

It is evident that the coordination distance for the ALS, MPR and RSMS where the distance is largely line-of-sight is not very sensitive to the e.i.r.p. density radiated toward the horizon.

FIGURE 3

Loss added to free space loss at line-of-sight
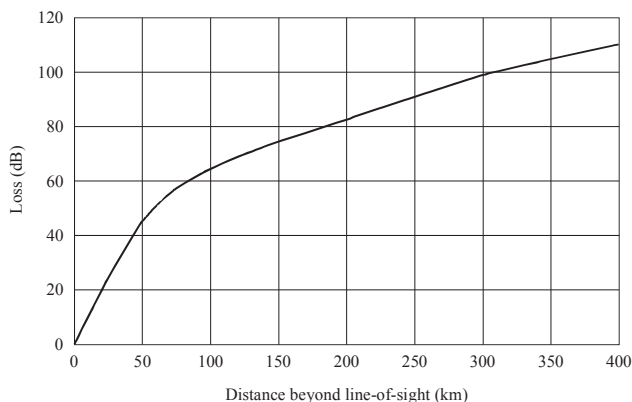
1340-03

3   Summary

–   The maximum emissions from a feeder-link earth station in the local horizontal plane should be limited to 54 dB(W/MHz).

–   With this limit a coordination threshold distance of about 515 km is needed to protect ALS stations operating in the aeronautical radionavigation service from unacceptable interference from feeder-link earth station emissions. The distance is about 600 km for the MPR and 270 km for the RSMS.

–   The coordination threshold distance for the ALS, MPR and RSMS are not significantly reduced by reducing the maximum allowable emissions from feeder-link earth stations.

The method above can be used in conjunction with other mitigation techniques to minimize the separation distances during coordination.

4   Mitigation factors for reducing the separation distance within the coordination distance

The following considerations should be taken into account where it is necessary for a feeder-link earth station operating in the Earth-to-space direction to be located within the coordination distance:

–   Typically, feeder-link earth stations will have antenna beamwidths of less than 1° and operate at elevation angles of more than 5°. This will reduce the e.i.r.p. towards the aeronautical radionavigation station and thus reduce the separation distance.

–   If the horizontal scan limits of the ALS aircraft landing system do not include the azimuth toward the feeder-link earth station, the air space for the aircraft landing system in not in line with the feeder-link earth station which potentially could reduce the separation distance by up to 100 km.

–   Use of an earth mound specifically constructed around the feeder-link earth station antenna(s) to provide additional isolation toward the aeronautical radionavigation station.

–   The geographical location of the feeder-link earth station can be considered to take advantage of natural terrain blocking which will increase the propagation path loss.

–   Any aircraft antenna discrimination that would exist when the aircraft is in the air space of the aircraft landing system and is using the landing system.

RECOMMENDATION ITU-R S.1341*

SHARING BETWEEN FEEDER LINKS FOR THE MOBILE-SATELLITE SERVICE AND THE AERONAUTICAL RADIONAVIGATION SERVICE IN THE SPACE-TO-EARTH DIRECTION IN THE BAND 15.4-15.7 GHz AND THE PROTECTION OF THE RADIO ASTRONOMY SERVICE IN THE BAND 15.35-15.4 GHz

(Question ITU-R 242/4)

(1997)

The ITU Radiocommunication Assembly,

considering

a)   that Resolution 116 (WRC-95) of the World Radiocommunication Conference (Geneva, 1995) calls for studies by the ITU-R of the sharing situation between feeder links (space-to-Earth) for the mobile-satellite service (MSS) and the aeronautical radionavigation service in the band 15.4-15.7 GHz;

b)   that the band 15.4-15.7 GHz is allocated to the aeronautical radionavigation service on a primary basis and that No. 953 (S4.10) of the Radio Regulations (RR) applies;

c)   that the WRC-95 has added an allocation to the fixed-satellite service in this band for feeder links of non-geostationary (non-GSO) networks in the MSS in the space-to-Earth direction;

d)   that the requirements for feeder links (space-to-Earth) of non-GSO satellite systems need to be accommodated in this band;

e)   that emissions from satellites can cause harmful interference to stations in the aeronautical radionavigation service;

f)   that power flux-density (pfd) limitations have been placed on the emissions from non-geostationary space stations to protect the aeronautical radionavigation service in accordance with No. S5.511A of the RR, which are subject to review by the ITU-R;

g)   that the coordination of satellite emissions with aeronautical radionavigation stations is not considered practical;

h)   that emissions from aeronautical radionavigation stations propagated along the Earth's surface can cause unacceptable interference to feeder-link earth stations;

j)   that methods are needed to determine the coordination and separation distances required between feeder-link earth stations and aeronautical radionavigation stations in order to protect the feeder-link earth stations;

k)   that aircraft stations are not permitted to transmit in the band 15.45-15.65 GHz in accordance with No. S5.511B of the RR;

l)   that there is fairly extensive use of this band by the aeronautical radionavigation service for airborne, land and ocean based stations;

m)   that the technical and operational characteristics of the aeronautical radionavigation stations are reasonable well defined;

n)   that the technical and operational characteristics of feeder links are not well defined;

o)   that satellite systems in this frequency range usually do not operate with low earth station antenna elevation angles;

p)   that studies have been made with respect to § o;

_____

*   This Recommendation should be brought to the attention of Radiocommunication Study Groups 7 and 8.

q)   that the adjacent band 15.35-15.4 GHz is allocated to the radio astronomy service and other passive services and that protection from harmful interference due to emissions from space stations is needed (see No. S5.511A of the RR);

r)   that all emissions are prohibited in the band 15.35-15.4 GHz in accordance with No. S5.340 except those provided for in No. S5.341;

s)   that Recommendation ITU-R RA.769 provides threshold levels of detrimental interference for the radio astronomy service,

recommends

1   that feeder links for the MSS should be limited to the band 15.43-15.63 GHz (Note 1);

2   that provisionally the pfd at the Earth's surface produced by emissions from the feeder links of a space system of non-GSO satellites for all conditions and for all methods of modulation should not exceed the values given in 2.1 under the condition given in § 2.2 (Note 2);

2.1   in the frequency band 15.43-15.63 GHz, where φ is the angle of arrival (degrees) above the local horizontal plane:

$$
\begin{array}{llll}
-127 & \text{dB(W/m}^2\text{) in 1 MHz} & \text{for} & 0 \le \varphi < 20 \\
-127 + 0.56\,(\varphi - 20)^2 & \text{dB(W/m}^2\text{) in 1 MHz} & \text{for} & 20 \le \varphi < 25 \\
-113 & \text{dB(W/m}^2\text{) in 1 MHz} & \text{for} & 25 \le \varphi < 29 \\
-136.9 + 25 \log (\varphi - 20) & \text{dB(W/m}^2\text{) in 1 MHz} & \text{for} & 29 \le \varphi < 31 \\
-111 & \text{dB(W/m}^2\text{) in 1 MHz} & \text{for} & 31 \le \varphi \le 90
\end{array}
$$

2.2   that these limits relate to the pfd which would be obtained under assumed free-space propagation conditions;

3   that with the pfd limits given in *recommends* 2 coordination of satellite emissions with receiving stations in the aeronautical radionavigation service is not required;

4   that surface based radars as described in Annex 1 should not operate in the band 15.43-15.63 GHz;

5   that the threshold distance for the coordination of emissions from stations in the aeronautical radionavigation service with respect to feeder-link earth stations for the MSS based on an earth station antenna gain in the local horizontal plane of 11.5 dBi are:

–   150 km from the ground segment for aircraft landing system (ALS);

–   600 km from aircraft using general purpose radars;

–   60 km from the aircraft landing surface for radar sensing and measurement systems;

6   that feeder-link earth stations should limit their operation to angles above the local horizontal plane of at least 5°;

7   that emissions from the feeder links of a space system of non-GSO satellites for all conditions and all methods of modulation should take into account the threshold levels for the radio astronomy service given in Recommendation ITU-R RA.769 for the band 15.35-15.4 GHz (see Note 3);

8   that additional information is contained in Annexes 1, 2, and 3.

NOTE 1 – The bandwidth given in *recommends* 1 is smaller than that allocated by WRC-95 for non-GSO MSS feeder links. This difference is recommended to facilitate sharing between the non-GSO MSS feeder links and the aeronautical radionavigation service. *Recommends* 1 will be reviewed at a later date in accordance with the outcome of a future WRC.

NOTE 2 – The feasibility to design and operate feeder links in the space-to-Earth direction with the provisional pfd limits given in *recommends* 2.1 has not yet been studied. Further, the provisional pfd values given in *recommends* 2.1 should be reviewed to ensure protection to the ARNS.

NOTE 3 – Additional design and operational constraints may be placed on MSS space-to-Earth feeder links in order to take into account the threshold levels for the radio astronomy service given in ITU-R RA.769 per *recommends* 7.

Aeronautical radionavigation systems in the 15.4-15.7 GHz band

1   Surface based radars (SBR)

The land and ship based SBR are used for the detection, location, and movement of aircraft and other vehicles on the surface of airports and other aircraft landing areas.

1.1   Antenna patterns

–   Nominal 3 dB beamwidth: <3.5° vertical, inverted cosecant to –31°
                                                0.35° horizontal;

–   Frequency range: 15.65-16.7 GHz;

–   Polarization: circular;

–   Typical gain: 43 dBi;

–   Maximum side-lobe level: 25 dB below peak gain;

–   Maximum back-lobe level: 35 dB below peak gain;

–   Vertical tilt range: ± 1.5°;

–   Maximum horizontal scan range: 360°

1.1.1   Antenna elevation envelope pattern

Based on measured data and side-lobe level specifications and with the peak gain directed at +1.5°, an elevation envelope gain pattern is defined as follows where φ is the elevation angle (degrees):

$$G(\varphi) = \begin{cases} 43 & \text{dBi} & \text{for} & 0 \le \varphi < 4 \\ 43 - 5(\varphi - 4) & \text{dBi} & \text{for} & 4 \le \varphi < 9 \\ 18 & \text{dBi} & \text{for} & 9 \le \varphi < 16 \\ 43.2 - 21\log\varphi & \text{dBi} & \text{for} & 16 \le \varphi < 48 \\ 8 & \text{dBi} & \text{for} & 48 \le \varphi \le 90 \end{cases}$$

1.1.2   Antenna azimuth envelope pattern

Based on measured data and side-lobe level specifications, the azimuth gain pattern is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 43 - 110\,\varphi^2 & \text{dBi} & \text{for} & 0 \le \varphi < 0.4767 \\ 18 & \text{dBi} & \text{for} & 0.4767 \le \varphi < 0.72 \\ 17.07 - 6.5\log\varphi & \text{dBi} & \text{for} & 0.72 \le \varphi < 48 \\ 8 & \text{dBi} & \text{for} & 48 \le \varphi \le 180 \end{cases}$$

1.2   Other characteristics

1.2.1   Transmitting

–   Peak e.i.r.p.: 86 dBW

–   Pulse repetition frequency: 8 192 Hz

–   Pulse duration: 0.04 µs

–   Pulse 3.5 dB bandwidth: 25 MHz.

1.2.2   Receiving

–   Typical antenna gain: 43 dBi

–   Typical noise figure: 6.2-6.9 dB.

2   Aircraft landing systems (ALS)

These ALS are general purpose systems and are used on ships, as portable or permanent land based systems and for shuttle landings. The microwave scanning beam landing system (MSBLS) is one such system. Some of the characteristics vary with the particular applications.

2.1   Surface based station antenna patterns

The antenna patterns are similar for all applications including the MSBLS. The scanning ranges vary with application. The scanning ranges given below cover all applications.

The antenna complement of the ALS consists of an elevation antenna and an azimuth antenna.

The elevation antenna portion of the ALS is used to transmit vertical angle data to the aircraft.

–   Nominal 3 dB beamwidths: 1.3° vertical
                                               40° horizontal

–   frequency range: 15.4-15.7 GHz

–   polarization: horizontal and vertical

–   typical gain: 28 dBi

–   maximum side-lobe level: 17 dB below peak gain in both planes

–   maximum vertical scan range: 0° to 30°.

The azimuth antenna portion of the ALS is used to transmit azimuth information to the aircraft:

–   Nominal 3 dB beamwidths: 2.0° horizontal
                                               6.5° vertical

–   the vertical pattern is spoiled to achieve at least a 20 dBi gain at 20 degrees above the horizon

–   frequency range: 15.4-15.7 GHz

–   polarization: horizontal and vertical

–   typical gain: 33 dBi

–   maximum side-lobe level: 17 dB below peak gain in both planes

–   maximum horizontal scan range: ± 35°.

2.1.1   Combined antenna elevation envelope pattern

A combined vertical envelope gain pattern based on measured data is defined as follows where φ is the elevation angle (degrees):

$$G(\varphi) = \begin{cases} 33 & \text{dBi} \quad \text{for} \quad 0 \le \varphi < 8 \\ 33 - 0.833\,(\varphi - 8) & \text{dBi} \quad \text{for} \quad 8 \le \varphi < 14 \\ 28 & \text{dBi} \quad \text{for} \quad 14 \le \varphi < 32 \\ 28 - 9\,(\varphi - 32) & \text{dBi} \quad \text{for} \quad 32 \le \varphi < 34 \\ 10 & \text{dBi} \quad \text{for} \quad 34 \le \varphi < 40 \\ 10 - 0.2\,(\varphi - 40) & \text{dBi} \quad \text{for} \quad 40 \le \varphi \le 90 \end{cases}$$

2.1.2 Azimuth antenna patterns

The azimuth envelope pattern of the elevation antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 28 - 0.0062\,\varphi^2 & \text{dBi} \quad \text{for} \quad 0 \le \varphi < 70 \\ -2.37 & \text{dBi} \quad \text{for} \quad 70 \le \varphi \le 180 \end{cases}$$

The azimuth envelope pattern of the azimuth antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 33 - 2\,\varphi^2 & \text{dBi} \quad \text{for} \quad 0 \le \varphi < 3 \\ 15 & \text{dBi} \quad \text{for} \quad 3 \le \varphi < 5 \\ 32.5 - 25\log\varphi & \text{dBi} \quad \text{for} \quad 5 \le \varphi < 48 \\ -9.53 & \text{dBi} \quad \text{for} \quad 48 \le \varphi \le 180 \end{cases}$$

2.2 Other characteristics

2.2.1 Transmitting

– Peak e.i.r.p.: 71 dBW

– Pulse repetition frequency: 3 334 Hz

– Pulse duration: 0.333 µs

– Pulse 3.5 dB bandwidth: 3 MHz.

2.2.2 Receiving

– Typical antenna gain: 8 dBi

– Typical noise figure: 8 dB.

3 Aircraft multipurpose radars (MPR)

The aircraft MPR is a radionavigation, radiolocation and weather radar.

3.1 Antenna patterns

The antenna is a parabola of approximately 0.3 m diameter which is scanned vertically and horizontally with respect to the heading and attitude of the aircraft:

– nominal 3 dB beamwidth: 4.5°

– frequency range: 15.4-15.7 GHz

– polarization: vertical

– typical gain: 30 dBi

– maximum horizontal scan range ± 45°

– maximum vertical scan range ± 20°.

The envelope pattern of the antenna is defined as follows where φ is the relative azimuth angle (degrees):

$$G(\varphi) = \begin{cases} 30 & \text{dBi} \quad \text{for} \quad 0 \le \varphi < 20 \\ 30 - 0.56\,(\varphi - 20)^2 & \text{dBi} \quad \text{for} \quad 20 \le \varphi < 25 \\ 16 & \text{dBi} \quad \text{for} \quad 25 \le \varphi < 29 \\ 39.86 - 25\log(\varphi - 20) & \text{dBi} \quad \text{for} \quad 29 \le \varphi < 68 \\ -2.17 & \text{dBi} \quad \text{for} \quad 68 \le \varphi \le 180 \end{cases}$$

3.2   Other characteristics

3.2.1   Transmitting

–   Peak e.i.r.p.: 70 dBW

–   Pulse repetition frequency: 800 Hz

–   Pulse duration: 2 µs

–   Pulse 3.5 dB bandwidth: 0.5 MHz.

3.2.2   Receiving

–   Typical antenna gain: 30 dBi

–   Typical noise figure: 8 dB.

4   Radar sensing and measurement system (RSMS)

Measurement techniques using radar technology at 15 GHz are particularly suited to smaller aircraft, including helicopters, offering the benefits of compact, light, equipment with good antenna directivity and more than adequate performance for many operational radionavigation applications which are not practicable at lower frequencies due to propagation or other reasons. For use in a height measurement mode this higher frequency band confers system design benefits, such as lower cross coupling and absence of triangulation effects, which are particularly important for accurate measurement at very low (metric) separations. For some operational applications they present the only viable technical solution.

Systems using these techniques are widely used in certain parts of the world where they make an important contribution to the safety of aircraft operation. Measurement of height, and ground clearance, is one of the most critical parameters in the operation of aircraft when used to assist the final stages in a landing. High accuracy and interference free operation are vital to success and the enhancement of safety.

RSMS are essentially used in low level operations up to a nominal height of around 1 500 m. An antenna mounting which transmits and receives vertically downwards would be used in the great majority of applications. Power reduction proportional to height above terrain is employed to reduce scatter, and other undesirable effects.

4.1   RSMS characteristics

4.1.1   Transmitter

–   Frequency range: 15.63-15.65 GHz

–   Peak power: 30 dBmW

–   Antenna gain: 13 dBi, back lobes <5 dBi

–   PRF: 58 kHz

–   Pulse length (max.): 500 ns

–   Duty cycle (max.): 3%

–   Pulse 3.5 dB bandwidth: 2 MHz.

4.1.2   Receiver

–   Antenna gain: 13 dBi, back lobes < 5 dBi

–   Noise figure: 6 dB.

ANNEX 2

**Protection criteria for the aeronautical radionavigation service and sharing feasibility with
feeder links for the MSS (space-to-Earth) in the 15.4-15.7 GHz band and protection of
the radio astronomy service in the band 15.35-15.4 GHz (Surface based radars (SBR),
used on land and ships for the detecting, location and movement of aircraft and
other vehicles on aircraft landing areas)**

1   Characteristics of aeronautical radionavigation systems

Several systems are identified that operate in this band. These include land and ship based surface detection radars
(SBR), ALS, MPR, and RSMS. The antenna patterns of these systems are an important element in determining the pfd as
a function of elevation angle. Antenna envelope gain patterns and the other pertinent characteristics are given in
Annex 1.

2   Analyses

2.1   Worst case pfd limits

The general expression for the calculation of a pfd limit for this case is:

$$pfd \leq -217.6 + 10 \log B - 20 \log \lambda - G/T + I/N \qquad \text{dB}(\text{W/m}^2) \text{ in } B \qquad (1)$$

where:

   B :   bandwidth (Hz)

   λ :   wave length (m)

   G/T :   antenna gain/noise temperature (dB)

   I/N :   allowable interference/noise (dB)

Since these systems operate in the ARNS and are considered as Safety Service systems, the protection requirements may
be more severe than for other services. Assuming an I/N limit of −10 dB, the solution of equation (1) for the SBR
parameters given in Annex 1 results in a pfd limit of −146 dB(W/m^2) in 1 MHz. Solution of equation (1) for the systems
parameters given in Annex 1 results in a pfd limit of −111 dB(W/m^2) in 1 MHz for the ALS and RSMS, and
−133 dB(W/m^2) in 1 MHz for the MPR. These values are based on the maximum antenna gains for these systems.

The pfd limit of −146 dB(W/m^2) in 1 MHz implies the use of very large earth station antennas (larger than 15 m
diameter) which are not considered practical (see § 2.3). However, the SBRs can be accommodated in the 15.63-
15.7 GHz band and this would remove this restriction in a feeder-link band of 15.43-15.63 GHz.

The dominant area of operation of the MPR is over the ocean which in most cases will be beyond the coordination
distance of feeder-link earth stations, and thus would not require coordination with feeder-link earth stations. Therefore,
the operation of the MPR in the 15.4-15.7 GHz band would be permitted even though geographical constraints would
apply (see Annex 3).

The RSMS imposes no significant pfd restriction, but geographical constraints may apply.

A pfd limit of -133 dB(W/m^2) in 1 MHz at low elevation angles of arrival may unduly constrain the implementation of
MSS feeder-link earth stations. A pfd of −127 dB(W/m^2) in 1 MHz results in earth station antenna diameters that are
one-half those imposed by a pfd of −133 dB(W/m^2) in 1 MHz. (See 2.3.) Since the MPR uses a narrow beam scanning

antenna, interference will occur for short periods of time when its main beam is directed at a satellite. Additionally, normal operation of the MPR need not be considered as a Safety Service. Thus an increase in system noise of up to 40 per cent could be tolerated for short periods of time, which results in a pfd limit of -127 dB(W/m^2) in 1 MHz.

2.2   pfd limits versus angle of arrival

From 2.1 the ALS and MPR would operate in the 15.4-15.7 GHz band including the 15.43-15.63 GHz band shared with feeder links.

Combining the pfd values in 2.1 with the antenna gain functions given in Sections 2 and 3 of Annex 1 results in the pfd limits given below and shown in Fig. 1, where φ is in degrees, i.e.;

$$pfd \begin{cases} \leq -127 & \text{dB(W/m}^2) \text{ in 1 MHz} & \text{for} & 0 \leq \varphi < 20 \\ \leq -127 + 0.56\,(\varphi - 20)^2 & \text{dB(W/m}^2) \text{ in 1 MHz} & \text{for} & 20 \leq \varphi < 25 \\ \leq -113 & \text{dB(W/m}^2) \text{ in 1 MHz} & \text{for} & 25 \leq \varphi < 29 \\ \leq -136.9 + 25 \log\,(\varphi - 20) & \text{dB(W/m}^2) \text{ in 1 MHz} & \text{for} & 29 \leq \varphi < 31 \\ \leq -111 & \text{dB(W/m}^2) \text{ in 1 MHz} & \text{for} & 31 \leq \varphi \leq 90 \end{cases}$$

FIGURE 1

Maximum satellite pfd limits (ALS, MPR and RSMS)
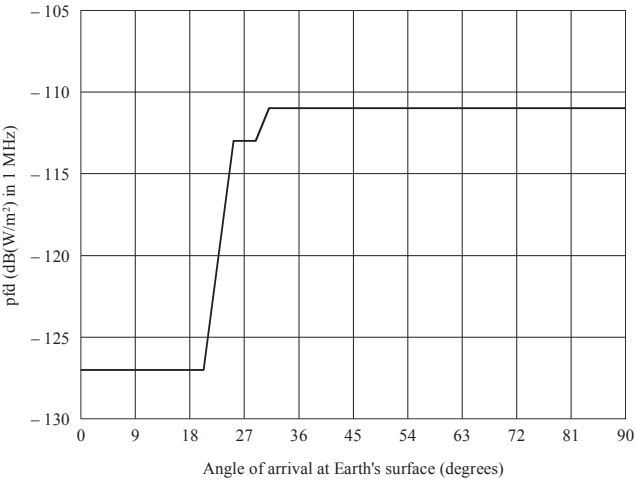
1341-01

2.3 Impact on feeder-link parameters

Satellite emissions will always occur at low angles of arrival at the surface of the Earth. At low angles the pfd limit is −127 dB(W/m^2) in 1 MHz. The diameter of an earth station antenna, D, for a given pfd may be computed by:

$$D = \left[(C/N)_t \,(k\,T\,B\,/\,pfd)\,(4M\,/\,\pi\,\eta)\right]^{0.5} \qquad \text{m} \qquad (2)$$

where:

$(C/N)_t$: threshold carrier-to-noise ratio

k: Boltsman's constant

T: receiving system noise temperature (K)

B: bandwidth in (Hz) as used in pfd

M: margin

η: antenna aperture efficiency.

MSS feeder-link earth stations are typically designed to provide link availability of around 99.99%. For operation at elevation angles below 20° (depending on the rain climatic zone of operation) the rain fade margin requirement combined with the requirement to meet the −127 dB(W/m^2) in 1 MHz pfd limit may constrain the implementation of MSS feeder-link earth stations in the 15.43-15.63 GHz frequency band.

Assuming a $(C/N)_t$ of 12 dB, a value of T of 24 dB(K), a η of 0.6 and values of pfd of −127 dB(W/m^2) in 1 MHz, −133 dB(W/m^2) in 1 MHz, and −146 dB(W/m^2) in 1 MHz in equation (2) results in the following values of D:

TABLE 1

M (dB)	pfd		
	−127 dB(W/m^2) in 1 MHz	−133 dB(W/m^2) in 1 MHz	−146 dB(W/m^2) in 1 MHz
	D (m)	D (m)	D (m)
7	1.7	3.4	15
10	2.4	4.8	22
13	3.4	6.8	30.4
16	4.8	9.6	43
19	6.8	13.6	61
22	9.6	19.2	86
25	13.6	27.1	121
28	19.2	38.3	171

2.4 Interference from non-GSO satellites into radio astronomy receivers in the 15.35-15.4 GHz band

Recommendation ITU-R RA.769 provides threshold levels of detrimental interference for the primary radio astronomy service in the band 15.35-15.4 GHz. These levels are −156 dB(W/m^2) in 1 MHz and −233 dB(W/m^2) in 1 Hz at the surface of the Earth. Assuming that the per Hz value can be extrapolated to one MHz, this would be −173 dB(W/m^2) in 1 MHz. A value of −127 dB(W/m^2) in 1 MHz applies for angles of arrival up to about 20°, rising to −111 dB(W/m^2) in

1 MHz above about 30° in the 15.43-15.63 GHz band. This requires about 46 dB discrimination at 15.4 GHz rising to 62 dB above 30°. A value of 62 dB is achievable with a 6 pole (0.1 dB ripple) filter in 30 MHz with a 50 MHz passband. Operation of space-to-Earth links very near 15.4 GHz does not seem possible. However, if the 15.4-15.43 GHz band is not used by feeder links there would be a 30 MHz guard band in which band pass filters and other means could be employed to protect the radio astronomy service in the 15.35-15.4 GHz band.

The out-of-band emission levels of the feeder links should take into account the needs of the radio astronomy service in the band 15.35-15.4 GHz.

3   Summary

The pfd limits given in Section 2.2 are necessary for the protection of the aeronautical radionavigation service from interference from feeder links operating in the space-to-Earth direction in the 15.4-15.7 GHz band.

ANNEX 3

Coordination distances between feeder-link earth stations in the MSS operating in the space-to-Earth direction and stations in the aeronautical radionavigation service in the band 15.4-15.7 GHz

1   Aeronautical radionavigation system characteristics

Several systems are identified that operate in this band. These include ALS and MPR. The characteristics and analyses necessary to determine coordination threshold distances are given in the following sections.

2   Coordination distances

2.1   Analyses

The coordination distance, D_c, necessary to ensure that potentially unacceptable interference from aeronautical radionavigation stations into feeder-link earth stations in the MSS does not occur, may be computed as shown in the following paragraphs:

$$D_c = D_{fsl} + D_{oth} + D_{as} \qquad \text{km} \tag{3}$$

where:

   D_{fsl}:   total radio line of sight distance (km)

   D_{oth}: over the horizon distance corresponding to the necessary over the horizon loss (km)

   D_{as}:   distance from aircraft landing surface (applies to ALS and RSMS)

$$D_{fsl} = (2r\,h_1)^{0.5} + (2r\,h_2)^{0.5} \qquad \text{km} \tag{4}$$

where:

   r: radius of the Earth taken as 4/3 geometric to account for atmospheric refraction (8 500 km)

   h_1: ARNS station height (km)

   h_2: feeder-link earth station height (km)

$$L_{oth} = E_{eff}/\text{MHz} + 168.6 - L_{fsl} + G(\varphi) - 10\log T - I/N \qquad \text{dB} \tag{5}$$

where:

L_{oth}: over the horizon loss added to L_{fsl} (dB). (This function is shown below and in Fig. 2 which is derived from the 5% functions for 15 GHz in Recommendation ITU-R P.528; i.e., loss exceeded 95% of the time.)

E_{ef}/MHz: maximum effective e.i.r.p. density of the ARNS station toward the horizon – (see Annex 2 of Recommendation ITU-R S.1340)

L_{fsl}: free space loss computed for D_{fsl} (dB)

$G(\varphi)$: gain of the feeder-link antenna as a function of angle φ above the horizon (dBi)

T: noise temperature of earth station (K)

I/N: acceptable interference/noise of the feeder-link earth station (dB).

The value of D_{oth} for a value of L_{oth} is determined from the following Table 2:

TABLE 2

D_{oth} (km)	L_{oth} (dB)	D_{oth} (km)	L_{oth} (dB)	D_{oth} (km)	L_{oth} (dB)
0	0	175	78	350	104
25	24	200	82	375	107
50	45	225	86	400	110
75	57	250	90	425	113
100	64	275	94	450	116
125	69	300	98	475	118
150	74	325	101	500	120

Values of D_{oth} for values of L_{oth} between those given in Table 2 are interpolated by:

$$D_{oth} = D_{ith} + 25 \left[(L_{oth} - L_{ith}) / (L_{jth} - L_{ith}) \right] \qquad \text{km} \qquad (6)$$

where:

L_{ith}: next lower value of L_{oth} in table, from L_{oth} determined by equation (5)

L_{jth}: next higher value of L_{oth} in table, from L_{oth} determined by equation (5)

2.2 Computed coordination distances

The parameters in the Table 3 are used for determining coordination distances.

If the horizontal plane is in the side lobes of the earth station antenna, then:

$$L_{oth} \text{ (dB)} = 87.2 - 25 \log \varphi \qquad \text{for the ALS} \qquad (7)$$

$$L_{oth} \text{ (dB)} = 75.0 - 25 \log \varphi \qquad \text{for the MBR}$$

The side-lobe envelope gain is taken as $29 - 25 \log \varphi$ in dBi where φ is in degrees.

Using equation (7) for L_{oth} and determining the corresponding distances from equations (6) and (3) results shown in Table 4 for the ALS and MPR. The RSMS distances are within line-of-sight.

TABLE 3

Parameter	ALS	MBR	RSMS
h_1 (km)	0.01	15	1.5
h_2 (km)	0.01	0.01	0.01
D_{fsl} (km)	26	518	25[1]
D_{as} (km)	0	0	40
L_{fsl} (dB)	145	171	NA
10 log T (dB(K))	24	24	24
I/N (dB)	−10	−10	−10
E_{eff}/MHz (dBW)	48.2	62	−13.1
L_{oth} (dB)	69.7	57.4	0
D_{oth} (km)	129	77	0
D_c (km)	155	595	65

[1] This is based on free space propagation for an angle of arrival at the earth station of 3.2°.

TABLE 4

Elevation angle φ (degrees)	Coordination distances (km)		
	ALS	MPR	RSMS
5	155	595	65
10	120	578	54
15	104	569	47
20	96	565	
25	91	562	
30	87	560	

The dominant mode of operation of the MPR is over ocean areas which in most cases will be beyond 600 km of feeder-link earth stations and this would not require coordination. If feeder-link earth stations were located inland the areas of operation over the oceans would be enhanced.

3 Mitigation factors for reducing the separation distance within the coordination threshold distance

The following considerations should be taken into account where it is necessary for a feeder-link earth station operating in the space-to-Earth direction to be located within the coordination threshold distance.

–   Typically, feeder-link earth stations will have antenna beamwidths of less that 1° and operate at elevation angles of more than 5°. Thus considerable earth station antenna discrimination can be achieved with respect to surface based interfering emissions.

–   The surface based aeronautical radionavigation stations may also provide additional antenna discrimination depending on their operations. This is particularly true for the ALS, where the horizontal scan limits do not include the azimuth toward the earth station (see Annex 1).

– Use of an earth mound specifically constructed around the feeder-link earth station antenna(s) to provide additional receiving discrimination for the feeder-link earth station.

– The geographical location of the feeder-link earth station can be considered to take advantage of natural terrain blocking which will increase the propagation path loss.

FIGURE 2

Loss added to free space loss at line-of-sight
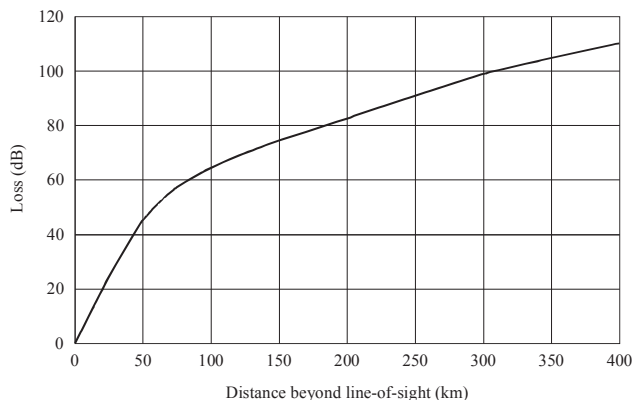
1341-02

4　Summary

– A method for determining the coordination distances needed for the protection of feeder-link earth stations from interference from aeronautical radionavigation stations in the 15.4-15.7 GHz band is presented in this annex.

– This method can also be used in conjunction with interference mitigation techniques to minimize the separation distances during coordination.

– With an elevation angle constraint of 5° so that only the feeder link earth station antenna side lobes are directed toward the horizon, a coordination distance in the order of 150 km is reasonable for the ALS and 60 km for the RSMS as measured from the landing surface.

– MPRs can operate without coordination at distances greater than 600 km from a feeder-link earth station, (e.g., over ocean areas).

RECOMMENDATION ITU-R S.1428-1

Reference FSS earth-station radiation patterns for use in interference assessment involving non-GSO satellites in frequency bands between 10.7 GHz and 30 GHz

(Question ITU-R 42/4)

(2000-2001)

The ITU Radiocommunication Assembly,

considering

a) that for earth station antennas in the fixed-satellite service (FSS), Recommendation ITU-R S.465 prescribes a reference antenna radiation pattern which represents an envelope of the side-lobe peaks;

b) that peak envelope antenna reference patterns are necessary for interference calculations involving a non-mobile receiver and a single non-mobile interference source to ensure that the worst case is covered, and that in the FSS such circumstances predominated in the past;

c) that in circumstances where there are multiple interfering sources or receivers whose positions vary substantially with time, the level of interference received inevitably depends on the troughs as well as the peaks in the antenna side lobe gain pattern of the victim or source of interference, respectively, and that the occurrence of such circumstances is rapidly increasing in the FSS;

d) that for FSS earth stations a suitable reference antenna radiation pattern is needed for use in calculations of interference from moving sources or receivers;

e) that to facilitate its use in computer simulations of interference, the reference antenna pattern should cover all off-axis angles from 0° to ±180° in all planes which include the principal axis;

f) that the reference antenna pattern should be consistent both with antenna theory and with the results of measurements on as wide a range of FSS earth station antennas as practicable;

g) that it might be appropriate to establish different reference antenna patterns for different ranges of D/λ and for different FSS frequency bands;

h) that for the purpose of specifying antenna performance, the peak envelope reference patterns in Recommendation ITU-R S.580 are appropriate;

j) that the use of the reference antenna pattern should lead to interference levels that would be representative of those received by antennas meeting relevant ITU-R antenna pattern Recommendations,

recommends

1   that for interference calculations involving moving interfering sources and/or victim receivers of FSS interference, the following reference earth station radiation antenna pattern should be employed:

for $20 \leq \dfrac{D}{\lambda} \leq 25$:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 \qquad \text{dBi} \qquad \text{for } 0 \quad < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{for } \varphi_m \quad \leq \varphi < \left(95 \frac{\lambda}{D} \right)$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } 95 \frac{\lambda}{D} \leq \varphi < 33.1°$$

$$G(\varphi) = -9 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 33.1° < \varphi \leq 80°$$

$$G(\varphi) = -5 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 80° \quad < \varphi \leq 180°$$

for $25 < \dfrac{D}{\lambda} \leq 100$:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 \qquad \text{dBi} \qquad \text{for } 0 \quad < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{for } \varphi_m \quad \leq \varphi < \left(95 \frac{\lambda}{D} \right)$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } 95 \frac{\lambda}{D} \leq \varphi \leq 33.1°$$

$$G(\varphi) = -9 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 33.1° < \varphi \leq 80°$$

$$G(\varphi) = -4 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 80° \quad < \varphi \leq 120°$$

$$G(\varphi) = -9 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 120° < \varphi \leq 180°$$

where:

  D: antenna

  λ: wavelength expressed in the same unit[*]

  φ: off-axis angle of the antenna (degrees)

$$G_{max} = 20 \log \left(\frac{D}{\lambda} \right) + 7.7 \qquad \text{dBi}$$

$$G_1 = 29 - 25 \log \left(95 \frac{\lambda}{D} \right)$$

$$\varphi_m = \frac{20\,\lambda}{D} \sqrt{G_{max} - G_1} \qquad \text{degrees}$$

---

[*] D is the equivalent diameter for non-symmetric antennas.

for $\dfrac{D}{\lambda} > 100$:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda} \varphi \right)^2 \qquad \text{dBi} \qquad \text{for } 0 \quad < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad\qquad\qquad\qquad\qquad\qquad \text{for } \varphi_m \ \leq \varphi < \varphi_r$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } \varphi_r \ \leq \varphi < 10°$$

$$G(\varphi) = 34 - 30 \log \varphi \qquad \text{dBi} \qquad \text{for } 10° \ \leq \varphi < 34.1°$$

$$G(\varphi) = -12 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 34.1° \leq \varphi < 80°$$

$$G(\varphi) = -7 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 80° \ \leq \varphi < 120°$$

$$G(\varphi) = -12 \qquad \text{dBi} \qquad\qquad\qquad \text{for } 120° \leq \varphi \leq 180°$$

where:

$$G_{max} = 20 \log \left(\dfrac{D}{\lambda} \right) + 8.4 \qquad \text{dBi}$$

$$G_1 = -1 + 15 \log \dfrac{D}{\lambda} \qquad \text{dBi}$$

$$\varphi_m = \dfrac{20\,\lambda}{D} \sqrt{G_{max} - G_1} \qquad \text{degrees}$$

$$\varphi_r = 15.85 \left(\dfrac{D}{\lambda} \right)^{-0.6} \qquad \text{degrees}$$

NOTE 1 – For the purposes of calculation or computer simulation of the total power at the antenna output due to multiple interfering sources at varied polarizations, it should be assumed that the contribution of the cross-polar components at off-axis angles up to 30° and in the spill-over regions up to 120° is negligible. Outside these angular regions, even though a paraboloid antenna exhibits very little polarization discrimination, for the purpose of non-GSO/GSO interference calculations the contribution of cross-polar components can be ignored.

NOTE 2 – This Recommendation is based on studies of a range of paraboloid antennas. Further study is required of the applicability of the recommended reference patterns to planar array antennas.

NOTE 3 – This Recommendation may require revisions in the future when data on measured performance of antennas in the 20/30 GHz range becomes available.

NOTE 4 - Within this Recommendation, the use of the term moving when applied to an FSS earth station denotes a tracking earth station in the FSS and not a mobile earth station.

RECOMMENDATION ITU-R BO.1443-2

Reference BSS earth station antenna patterns for use in interference assessment involving non-GSO satellites in frequency bands covered by RR Appendix 30*

(Question ITU-R 73/6)

(2000-2002-2006)

Scope

This Recommendation intends to provide tri-dimensional reference earth station antenna patterns for the broadcasting-satellite service (BSS) that can be used for the calculation of interference generated by non-GSO FSS satellites into BSS earth station antennas.

The ITU Radiocommunication Assembly,

considering

a)   that for earth station antennas in the BSS the reference antenna radiation patterns for GSO BSS receive antennas in Annex 5 to RR Appendix 30 were used to develop the BSS Plans and prescribe a reference radiation pattern which represents an envelope of the side lobes;

b)   that such reference radiation patterns are necessary for interference calculations involving fixed or transportable BSS receivers and GSO satellites to ensure adequate protection of the BSS Plans;

c)   that in circumstances where there are multiple interfering sources whose positions vary substantially with time, the level of interference received inevitably depends on the troughs as well as the peaks in the gain pattern of the victim BSS earth station antenna;

d)   that for BSS earth stations, suitable reference radiation patterns are needed for use in assessing interference from non-GSO FSS systems;

e)   that to facilitate computer simulations of interference, the reference patterns should cover all off-axis angles from 0° to ±180° in all planes;

f)   that the reference patterns should be consistent with the results of measurements on a wide range of consumer BSS earth station antennas;

g)   that it is appropriate to establish different reference patterns for different ranges of antenna sizes;

h)   that the patterns may exhibit characteristics that may be important when modelling non-GSO interference, for example in the case of small offset-fed antennas,

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*   The basis for the patterns contained in this Recommendation, including the methodology for analysing and plotting the data which measures the goodness of fit of the data sets to the recommended pattern are contained in Report ITU-R BO.2029 – Broadcasting-satellite service earth station antenna pattern measurements and related analyses. This Report along with the raw data sets and the spread sheets used to perform the graphical analysis are contained on a CD-ROM available from ITU.

recommends

1   that for calculations of interference generated by non-GSO FSS satellites into BSS earth station antennas, the reference earth station antenna radiation patterns described in Annex 1 should be employed;

2   that the methodology described in Annex 2 be used to convert the relative azimuth and elevation angle of the non-GSO satellite under investigation into the same coordinate system as employed for the three-dimensional antenna pattern;

3   that the following Notes be considered part of this Recommendation:

NOTE 1 – The cross-polarization radiation pattern may be of importance in non-GSO interference calculations. This issue requires further study.

NOTE 2 – This Recommendation is based on measurements and analysis of paraboloid antennas. If new earth station antennas are developed or are considered for use in the BSS, the reference antenna patterns in this Recommendation should be updated accordingly.

Annex 1

Reference BSS antenna radiation patterns

For $11 \leq D/\lambda \leq 25.5$

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D\varphi}{\lambda} \right)^2 \qquad \text{for} \qquad 0 \leq \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for} \qquad \varphi_m \leq \varphi < 95\lambda/D$$

$$G(\varphi) = 29 - 25 \log(\varphi) \qquad \text{for} \quad 95\lambda/D \leq \varphi < 36.3°$$

$$G(\varphi) = -10 \qquad \text{for} \quad 36.3° \leq \varphi < 50°$$

for $56.25° \leq \theta < 123.75°$

$$G(\varphi) = M_1 \cdot \log(\varphi) - b_1 \qquad \text{for} \quad 50° \leq \varphi < 90°$$

$$G(\varphi) = M_2 \cdot \log(\varphi) - b_2 \qquad \text{for} \quad 90° \leq \varphi < 180°$$

where:

$$M_1 = \frac{2 + 8 \cdot \sin(\theta)}{\log\left(\frac{90}{50} \right)} \qquad \text{and} \qquad b_1 = M_1 \cdot \log(50) + 10$$

where:

$$M_2 = \frac{-9 - 8 \cdot \sin(\theta)}{\log\left(\frac{180}{90} \right)} \qquad \text{and} \qquad b_2 = M_2 \cdot \log(180) + 17$$

for $0° \leq \theta < 56.25°$ and $123.75° \leq \theta < 180°$

$$G(\varphi) = M_3 \cdot \log(\varphi) - b_3 \qquad \text{for} \quad 50° \leq \varphi < 120°$$

$$G(\varphi) = M_4 \cdot \log(\varphi) - b_4 \qquad \text{for} \quad 120° \leq \varphi < 180°$$

where:

$$M_3 = \frac{2 + 8 \cdot \sin(\theta)}{\log\left(\dfrac{120}{50}\right)} \qquad \text{and} \qquad b_3 = M_3 \cdot \log(50) + 10$$

where:

$$M_4 = \frac{-9 - 8 \cdot \sin(\theta)}{\log\left(\dfrac{180}{120}\right)} \qquad \text{and} \qquad b_4 = M_4 \cdot \log(180) + 17$$

for $180° \leq \theta < 360°$

$$G(\varphi) = M_5 \cdot \log(\varphi) - b_5 \qquad \text{for} \quad 50° \leq \varphi < 120°$$

$$G(\varphi) = M_6 \cdot \log(\varphi) - b_6 \qquad \text{for} \quad 120° \leq \varphi < 180°$$

where:

$$M_5 = \frac{2}{\log\left(\dfrac{120}{50}\right)} \qquad \text{and} \qquad b_5 = M_5 \cdot \log(50) + 10$$

where:

$$M_6 = \frac{-9}{\log\left(\dfrac{180}{120}\right)} \qquad \text{and} \qquad b_6 = M_6 \cdot \log(180) + 17$$

where:

D: antenna diameter

λ: wavelength expressed in the same unit as the diameter

G: gain

φ: off-axis angle of the antenna relative to boresight (degrees)

θ: planar angle of the antenna (degrees) (0° azimuth is the horizontal plane).

$$G_{max} = 20 \log\left(\frac{D}{\lambda}\right) + 8.1 \qquad \text{dBi}$$

$$G_1 = 29 - 25 \log\left(95 \frac{\lambda}{D}\right) \qquad \text{dBi}$$

$$\varphi_m = \frac{\lambda}{D} \sqrt{\frac{G_{max} - G_1}{0.0025}} \qquad \text{degrees}$$

For $25.5 < D/\lambda \leq 100$

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} (D\varphi/\lambda)^2 \quad \text{dBi} \qquad \text{for} \qquad 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad\qquad\qquad\qquad\qquad\qquad \text{for} \qquad \varphi_m \leq \varphi < (95\lambda/D)$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad\qquad \text{dBi} \qquad \text{for} \quad (95\lambda/D) \leq \varphi < 33.1°$$

$G(\varphi) = -9$ dBi   for $33.1° < \varphi \le 80°$

$G(\varphi) = -4$ dBi   for $80° < \varphi \le 120°$

$G(\varphi) = -9$ dBi   for $120° < \varphi \le 180°$

where:

$G_{max} = 20 \log (D/\lambda) + 8.1$ dBi

$G_1 = 29 - 25 \log (95\lambda/D)$ dBi

$$\varphi_m = (\lambda/D) \sqrt{\frac{G_{max} - G_1}{0.0025}}$$

For D/λ > 100

$G(\varphi) = G_{max} - 2.5 \times 10^{-3} (D\varphi/\lambda)^2$ dBi   for $0 < \varphi < \varphi_m$

$G(\varphi) = G_1$ for $\varphi_m \le \varphi < \varphi_r$

$G(\varphi) = 29 - 25 \log \varphi$ dBi   for $\varphi_r \le \varphi < 10°$

$G(\varphi) = 34 - 30 \log \varphi$ dBi   for $10° \le \varphi < 34.1°$

$G(\varphi) = -12$ dBi   for $34.1° \le \varphi < 80°$

$G(\varphi) = -7$ dBi   for $80° \le \varphi < 120°$

$G(\varphi) = -12$ dBi   for $120° \le \varphi < 180°$

where:

$G_{max} = 20 \log (D/\lambda) + 8.1$ dBi

$G_1 = -1 + 15 \log (D/\lambda)$ dBi

$$\varphi_m = (\lambda/D) \sqrt{\frac{G_{max} - G_1}{0.0025}}$$

$\varphi_r = 15.85 (D/\lambda)^{-0.6}$ degrees

Annex 2

Geometric conversions for use with the 3-D antenna model

Definition of θ

θ is defined as the planar angle of the non-GSO satellite relative to the zero degree plane of the antenna model (corresponding to the standard bottom-mounted offset feed assembly). As seen by the earth station, the θ = 0 line is to the right, and θ increases in an anticlockwise direction.

Calculation approach

Figure 1 shows a geometric approach to calculate the planar angle θ. All calculations are shown using degrees, though typically these must be converted into radians when computing trigonometric values.

Inputs

      GSO satellite   (az, el)

      Non-GSO satellite   (az, el)

NOTE 1 – What is required is the difference in azimuth, so if that is available the actual azimuths would not be needed.

The following section shows how to calculate these parameters from the vectors of each station.

FIGURE 1
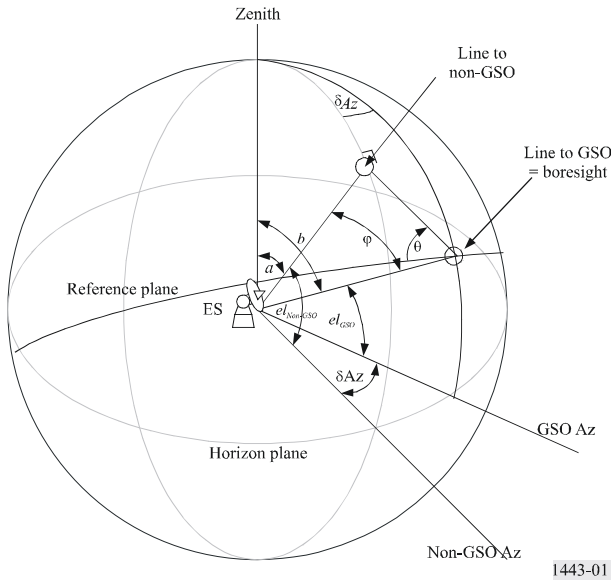
From Fig. 1:

$$a = 90 - el_{non-GSO}$$

$$b = 90 - el_{GSO}$$

$$\delta Az = Az_{non-GSO} - Az_{GSO}$$

δAz should be set to be in the range {−180 to +180}

Then the off-axis angle φ (topocentric separation angle between the satellites) can be calculated by using the spherical geometry formula:

$$\cos(c) = \cos(a)\cos(b) + \sin(a)\sin(b)\cos(C)$$

with $C = \delta Az$ and $c = \varphi$.

The same formula can be used to define an angle B:

$$\cos(B) = \frac{\cos(b) - \cos(c)\cos(a)}{\sin(c)\sin(a)}$$

from which the planar angle θ can be derived:

if ($\delta Az > 0$ and $B < 90$) $\theta = 90 - B$

if ($\delta Az > 0$ and $B > 90$) $\theta = 450 - B$

if ($\delta Az < 0$) $\theta = 90 + B$

In the case that both satellites have the same azimuth and so $\delta Az = 0$, then

$$\varphi = \left| el_{GSO} - el_{non-GSO} \right|$$

if $el_{GSO} > el_{non-GSO}$ $\theta = 270$

else $\theta = 90$

Example data

For the following positions:

Station	Latitude (degrees)	Longitude (degrees)	Height (km)
Earth station	10	20	0
GSO sat	0	30	35 786.055
Non-GSO sat	0	−5	1 469.200

Then for the earth station the following az/els can be calculated (with respect to the earth station horizon and north direction):

Station	Azimuth (degrees)	Elevation (degrees)
GSO sat	134.5615	73.4200
Non-GSO sat	−110.4248	10.0300

Hence the off-axis angles and planar angles are:

Station	φ (off-axis) (degrees)	θ (planar) (degrees)
Non-GSO sat	87.2425	26.69746

Calculation of azimuth and elevation

The following can be used to calculate azimuth and elevation from the vectors involved.

Given:

Position vector of earth station: $\underline{r}_G$

Position vector of GSO satellite: $\underline{r}_S$

Position vector of non-GSO satellite: $\underline{r}_N$

Then create:

     Vector from earth station to GSO $\underline{r}_{GS} = \underline{r}_S - \underline{r}_G$

     Vector from earth station to non-GSO $\underline{r}_{GN} = \underline{r}_N - \underline{r}_G$

     Unit vector of earth station position vector $\hat{\underline{r}}_G$

Then the elevation angles are:

$$el_S = 90 - \angle(\underline{r}_{GS}, \underline{r}_G)$$

$$el_N = 90 - \angle(\underline{r}_{GN}, \underline{r}_G)$$

To calculate the difference in azimuth, convert vectors from earth station to GSO/non-GSO to be in the horizontal plane that is perpendicular to the zenith vector, i.e.

$$\underline{r}'_{GS} = \underline{r}_{GS} - (\hat{\underline{r}}_G \cdot \underline{r}_{GS})\hat{\underline{r}}_G$$

$$\underline{r}'_{GN} = \underline{r}_{GN} - (\hat{\underline{r}}_G \cdot \underline{r}_{GN})\hat{\underline{r}}_G$$

Then:

$$\delta Az = \angle(\underline{r'_{GS}}, \underline{r'_{GN}})$$

The sign of δAz will be the same as the sign of the difference in longitude of the two satellites.

RECOMMENDATION ITU-R M.1583-1*

Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites

(Question ITU-R 236/8)

(2002-2007)

Scope

This Recommendation describes a methodology to be used to calculate the amount of data loss due to interference produced by a non-GSO mobile-satellite or radionavigation-satellite service system at a radio astronomy site. This methodology is based on the calculation of the epfd produced by the considered active system at the radio astronomy site.

The ITU Radiocommunication Assembly,

considering

a)   that, in some cases, the radio astronomy service and space services (space-to-Earth) have been allocated to adjacent or nearby frequency bands;

b)   that the radio astronomy service is based on the reception of emissions at much lower power levels than are generally used in other radio services;

c)   that, due to these low received power levels, the radio astronomy service is generally more susceptible to interference from unwanted emissions than other services;

d)   that due to the characteristics of non-geostationary (non-GSO) satellite systems, and in particular to the time-varying nature of interference, the level of interference from such satellites into radio telescopes cannot be evaluated in the same way as for the case of GSO satellites,

recommends

1   that the determination of unwanted emission levels produced by a non-GSO radionavigation-satellite service (RNSS) or a mobile-satellite service (MSS) systems on radio astronomy sites should be based on the method described in Annex 1;

2   that when performing this determination, the antenna pattern described in Recommendation ITU-R RA.1631 should be used to model radio astronomy antennas;

3   that the percentage of time during which an equivalent power flux-density (epfd) threshold level is exceeded should also be determined in accordance with the method described in Annex 2.

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*   This Recommendation should be brought to the attention of Radiocommunication Study Group 7.

Annex 1

Calculation of unwanted emission levels produced by a non-GSO RNSS or an MSS system at radio astronomy sites

The methodology described here, based on the "equivalent power flux-density" (epfd) concept, is intended for use in calculating the power flux-density (pfd) levels produced by unwanted emissions of a non-GSO satellite system into radio telescopes, taking into account the characteristics of both the satellite system and the radio telescope antenna. The value of the epfd is the aggregate of the contributions from all satellite emissions expressed as the pfd of a single equivalent source on the boresight (peak of main beam) of the radio telescope.

1   Required parameters

Due to the particular characteristics of non-GSO satellite systems, it is clear that the level of the interference from such satellites into a radio telescope cannot be evaluated in the same way as for GSO satellites. A statistical approach is needed which takes into account the dynamic aspect of non-GSO satellites.

The evaluation of interference resulting from the satellites at the radio telescope during the integration time (2 000 s) should be based on statistical calculations and should take into account the parameters of both the satellites and the radio telescope.

Non-GSO satellite system parameters:

–   the number of satellites visible in the sky at the radio astronomy station;

–   the detailed orbital characteristics of the satellites;

–   the pfd radiated by each satellite at the radio telescope within the radio astronomy band considered, which may be estimated using a model of unwanted emissions mask.

Radio telescope parameters:

–   the antenna location;

–   the antenna pattern and antenna gain;

–   the practical range of pointing directions;

–   the boresight pointing direction;

–   the off-axis angles between the boresight of the antenna of the radio astronomy station and the directions of the transmitting satellites;

–   the integration time (2 000 s).

2   Calculation of epfd at radio astronomy sites

The receiving gain of a radio telescope in the direction of a non-GSO satellite (as opposed to GSO) varies with time chiefly because of the movement of the satellite and the fine angular structure of the radio telescope's side-lobe pattern. There will be times when the telescope gain in the direction of a satellite is much higher than 0 dBi, and other times when it is less.

In addition, in the case of multiple satellites of a non-GSO system, all their contributions must be included and properly taken into account.

This may be done using the concept of epfd originally defined to assess possible sharing conditions between GSO and non-GSO systems. In the section below the concept is developed for the case of a radio astronomy station subject to interference from non-GSO satellites.

2.1 Definition of epfd

When an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is that pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

The instantaneous epfd is calculated using the following formula:

$$epfd = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi \, d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}} \right] \tag{1}$$

where:

N_a : number of non-GSO space stations that are visible from the radio telescope

i : index of the non-GSO space station considered

P_i : RF power of the unwanted emission at the input of the antenna (or RF radiated power in the case of an active antenna) of the transmitting space station considered in the non-GSO system (dBW) in the reference bandwidth

θ_i : off-axis angle (degrees) between the boresight of the transmitting space station considered in the non-GSO system and the direction of the radio telescope

$G_t(\theta_i)$: transmit antenna gain (as a ratio) of the space station considered in the non-GSO system in the direction of the radio telescope

d_i : distance (m) between the transmitting station considered in the non-GSO system and the radio telescope

φ_i : off-axis angle (degrees) between the pointing direction of the radio telescope and the direction of the transmitting space station considered in the non-GSO system

$G_r(\varphi_i)$: receive antenna gain (as a ratio) of the radio telescope, in the direction of the transmitting space station considered in the non-GSO system (see Recommendation ITU-R RA.1631)

$G_{r,max}$: maximum gain (as a ratio) of the radio telescope

$epfd$: instantaneous equivalent power flux-density (dB(W/m^2)) in the reference bandwidth at the radio telescope.

The epfd calculation in equation (1) assumes that the pfd due to all interfering sources is directed at the boresight of the receiving antenna, where the antenna gain is maximum. However, radio astronomy protection criteria are based on a 0 dBi contour of the radio astronomy antenna. Using the approach in equation (1), the pfd due to all interfering sources directed at the 0 dBi gain of the receiving antenna, can be determined as follows:

$$epfd_{G_r=0\,dBi} = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi \, d_i^2} \cdot G_r(\varphi_i) \right] \tag{2}$$

The $epfd_{G_r = 0\,\text{dBi}}$ values resulting from equation (2), averaged (in linear form) over a 2 000 s integration time, can be compared with pfd levels (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given this integration time).

NOTE 1 – It is assumed that each transmitter is located in the far field of the radio telescope (that is, at a distance greater than $2D2/\lambda$ where D is the effective diameter of the radio telescope and λ is the observing wavelength). Though this may not always be satisfied, it is considered to be an adequate approximation.

NOTE 2 – For some telescopes, the direction of maximum gain (boresight direction) may not always coincide with the geometrical axis of the radio telescope.

NOTE 3 – In the case of active antennas, P_i should be taken as the radiated RF power rather than the power at the input to the antenna.

NOTE 4 – The antenna gain of the transmitting station, $G_t(\theta_i)$ is taken at the frequency of the radio astronomy band considered. This may differ from the gain at the frequencies of the intended transmissions.

Annex 2

Distribution of epfd levels

This Annex describes a way to derive epfd statistics over the whole sky.

1   Division of the sky into cells of approximately equal solid angle

The first step of this approach is to divide the sky into M rings parallel to the horizon and equally spaced in terms of elevation angle, from 0° to 90°. The width of each ring is 90/M°. The next step is to divide these rings into cells whose azimuth width is chosen to provide an integer number of cells per ring and is approximately equal to:

$$\frac{90/M}{\cos(elevation)} \qquad \text{degrees}$$

Figure 1 provides an example of division based on a step of 3° width in elevation, this divides the sky into 30 rings of 3° of elevation angle. Then, the azimuth width is approximately equal to:

$$\frac{90/30}{\cos(elevation)} \qquad \text{degrees}$$

Elevation is a mean elevation in a given ring.

FIGURE 1

Example of division of the sky in cells of approximately

9 square degrees of solid angle

	87° (3 cells)
	84° (9 cells)
	48° (72 cells)
	45° (90 cells)
	3° (120 cells)

3°

1583-01

This leads to a division of the sky into 2 334 cells of approximately 9 square degrees of solid angle each. Table 1 provides the number of cells for each ring corresponding to this example.

TABLE 1

Example of division of the sky into square cells
of about 9 square degrees solid angle

Lower elevation of the ring (degrees)	Ring solid angle (square degrees)	Cumulative solid angle (square degrees)	Azimuth step (degrees)	Number of cells in the ring	Cell solid angle (square degrees)	Cumulative number of cells	Percentage of solid angle (%)	Cumulative solid angle (%)
0	1 079.51	1 079.51	3	120	9.00	120	5.23	5.23
3	1 076.55	2 156.05	3	120	8.97	240	5.22	10.45
6	1 070.64	3 226.69	3	120	8.92	360	5.19	15.64
9	1 061.79	4 288.49	3	120	8.85	480	5.15	20.79
12	1 050.04	5 338.53	3	120	8.75	600	5.09	25.88
15	1 035.41	6 373.93	3	120	8.63	720	5.02	30.90
18	1 017.94	7 391.87	3	120	8.48	840	4.94	35.84
21	997.68	8 389.55	3	120	8.31	960	4.84	40.67
24	974.68	9 364.23	3	120	8.12	1 080	4.73	45.40
27	949.01	10 313.24	3	120	7.91	1 200	4.60	50.00
30	920.75	11 233.99	4	90	10.23	1 290	4.46	54.46
33	889.95	12 123.94	4	90	9.89	1 380	4.31	58.78

TABLE 1 (*end*)

Lower elevation of the ring (degrees)	Ring solid angle (square degrees)	Cumulative solid angle (square degrees)	Azimuth step (degrees)	Number of cells in the ring	Cell solid angle (square degrees)	Cumulative number of cells	Percentage of solid angle (%)	Cumulative solid angle (%)
36	856.72	12 980.66	4	90	9.52	1 470	4.15	62.93
39	821.14	13 801.81	4	90	9.12	1 560	3.98	66.91
42	783.31	14 585.12	4	90	8.70	1 650	3.80	70.71
45	743.34	15 328.46	4	90	8.26	1 740	3.60	74.31
48	701.32	16 029.79	5	72	9.74	1 812	3.40	77.71
51	657.39	16 687.17	5	72	9.13	1 884	3.19	80.90
54	611.65	17 298.82	5	72	8.50	1 956	2.97	83.87
57	564.23	17 863.06	6	60	9.40	2 016	2.74	86.60
60	515.27	18 378.33	6	60	8.59	2 076	2.50	89.10
63	464.90	18 843.23	6	60	7.75	2 136	2.25	91.35
66	413.25	19 256.48	8	45	9.18	2 181	2.00	93.36
69	360.47	19 616.95	9	40	9.01	2 221	1.75	95.11
72	306.70	19 923.65	10	36	8.52	2 257	1.49	96.59
75	252.09	20 175.74	12	30	8.40	2 287	1.22	97.81
78	196.79	20 372.53	18	20	9.84	2 307	0.95	98.77
81	140.95	20 513.49	24	15	9.40	2 322	0.68	99.45
84	84.73	20 598.21	40	9	9.41	2 331	0.41	99.86
87	28.27	20 626.48	120	3	9.42	2 334	0.14	100.00

2   epfd distribution for a cell

First, a random choice is made for a pointing direction of the radio astronomy service antenna which will lie within a specific cell on the sky as defined in § 1. Then, the starting time of the constellation is randomly chosen. The epfd is then evaluated for each time sample over a 2 000 s integration time. The average epfd corresponding to this trial is then calculated for the chosen pointing direction and starting time of the constellation.

This operation is repeated to obtain a statistical distribution of the epfd in the considered cell. The methodology involves a number of trials, each of which calculates the averaged epfd level over a 2 000 s integration interval. The greater the number of trials, the more accurate this distribution will be. A sufficient number of trials is needed to achieve the required confidence level in the results. In particular, the number of trials multiplied by the 2 000 s integration time should be significantly higher than the period of the constellation. It is also necessary to ensure adequate statistical sampling over the full period of the constellation. Once it is found that no further significant change occurs in the distribution, it can be concluded that a sufficient number of trials has been performed. This check can be done either automatically as an integral part of the simulation, or manually, by stopping the simulation at regular intervals.

3   Output in terms of percentage of data loss

The epfd determination described in § 2 provides a distribution of epfd levels for each cell of the sky which can be compared to the threshold levels used for radio astronomical measurements. When these levels are exceeded, some radio astronomy data will be lost. The percentage of this loss is defined as the sum of these losses in all cells over the number of trials. Figure 2 shows an example of the percentage of data loss per cell over the whole sky for a non-GSO RNSS constellation.

FIGURE 2

Distribution of data loss over the sky

1583-02
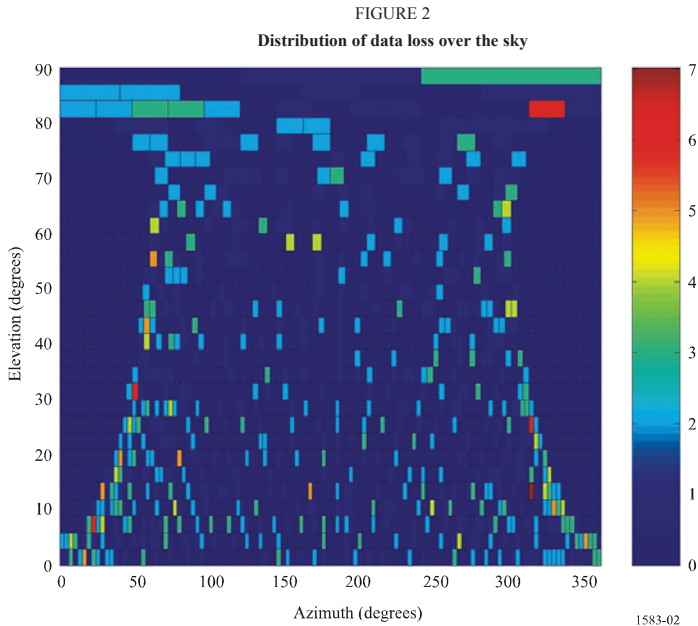
RECOMMENDATION ITU-R S.1586-1

Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites

(Question ITU-R 236/4)

(2002-2007)

Scope

This Recommendation describes a method that could be used to calculate the unwanted emission levels produced by a non-GSO fixed-satellite service system on radio astronomy sites. It also contains a procedure for the calculation of the percentage of time during which a given equivalent power flux-density (epfd) is exceeded when the receiving antenna gain is assumed to be 0 dBi in the direction of the incoming interference, and a given integration time is considered.

The ITU Radiocommunication Assembly,

considering

a)   that, in some cases, the radio astronomy service and space services (space-to-Earth) have been allocated to adjacent or nearby frequency bands;

b)   that the radio astronomy service is based on the reception of emissions at much lower power levels than are generally used in other radio services;

c)   that, due to these low received power levels, the radio astronomy service is generally more susceptible to interference from unwanted emissions than other services;

d)   that several footnotes to the Radio Regulations (RR) (such as RR Nos. 5.149, 5.443B and 5.511A) draw attention to the protection of the radio astronomy service, particularly from space-borne transmitters;

e)   that due to the characteristics of non-geostationary (non-GSO) satellite systems, and in particular to the time-varying nature of interference, the level of interference from such satellites into radio telescopes cannot be evaluated in the same way as for GSO satellites,

recommends

1   that the calculation of unwanted emission levels produced by a non-GSO fixed-satellite service (FSS) system on radio astronomy sites could be conducted by administrations using the method described in Annex 1;

2   that when performing these calculations, the antenna pattern described in Recommendation ITU-R RA.1631 could be used to model radio astronomy antennas;

3   that the percentage of time during which an equivalent power flux-density (epfd) level (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given an integration time) is exceeded could be calculated according to the method described in Annex 2.

Annex 1

Calculation of unwanted emission levels produced by a non-GSO
FSS system at radio astronomy sites

The methodology described here, based on the epfd concept defined in RR Article 22, No. 22.5C, is intended for use in calculating the power flux-density (pfd) levels produced by unwanted emissions of a non-GSO FSS satellite system into radio telescopes, taking into account the characteristics of both the satellite system and the radio telescope antenna. The value of the epfd is the aggregate of the contributions from all satellite emissions expressed as the pfd of a single equivalent source on the boresight (peak of main beam) of the radio telescope.

1   Required parameters

Due to the particular characteristics of non-GSO satellite systems, it is clear that the level of the interference from such satellites into a radio telescope cannot be evaluated in the same way as for GSO satellites. A statistical approach is needed which takes into account the dynamic aspect of non-GSO satellites.

The evaluation of interference resulting from the satellites at the radio telescope during the integration time (2 000 s) should be based on statistical calculations and should take into account the parameters of both the satellites and the radio telescope.

Non-GSO satellite system parameters:
–   the number of satellites visible in the sky at the radio astronomy station;
–   the pfd at the radio telescope within the radio astronomy band considered, estimated using a dBsd or dBc mask;
–   the distances between the satellites and the radio astronomy station;
–   the detailed orbital characteristics of the satellites.

Radio telescope parameters:
–   the antenna location;
–   the antenna pattern and antenna gain;
–   the practical range of pointing directions;
–   the boresight pointing direction;
–   the off-axis angles between the boresight of the antenna of the radio astronomy station and the directions of the transmitting satellites;
–   the integration time (2 000 s).

2   Calculation of epfd levels at radio astronomy sites

The receiving gain of a radio telescope in the direction of a non-GSO satellite (as opposed to a GSO satellite) varies with time chiefly because of the movement of the satellite and the fine angular structure of the radio telescope's side-lobe pattern. There will be times when the telescope gain in the direction of a satellite is much higher than 0 dBi, and other times when it is less. In addition, in the case of multiple satellites of a non-GSO system, all their contributions must be included and properly taken into account.

This may be done using the concept of epfd originally defined to assess possible sharing conditions between GSO and non-GSO systems. In the section below the concept is developed for the case of a radio astronomy station subject to interference from non-GSO satellites. The definition is based upon RR No. 22.5C as adopted at the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000).

2.1 Definition of epfd

When an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is that pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

The instantaneous epfd, expressed in $dB(W/m^2)$, is calculated using the following formula:

$$epfd = 10 \log_{10} \left(\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi \, d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}} \right) \tag{1}$$

where:

N_a: number of non-GSO space stations that are visible from the radio telescope

i: index of the non-GSO space station considered

P_i: RF power of the unwanted emission at the input of the antenna (or RF radiated power in the case of an active antenna) of the transmitting space station considered in the non-GSO system in the reference bandwidth (dBW)

θ_i: off-axis angle between the boresight of the transmitting space station considered in the non-GSO system and the direction of the radio telescope

$G_t(\theta_i)$: transmit antenna gain (as a ratio) of the space station considered in the non-GSO system in the direction of the radio telescope

d_i: distance (m) between the transmitting station considered in the non-GSO system and the radio telescope

φ_i: off-axis angle between the pointing direction of the radio telescope and the direction of the transmitting space station considered in the non-GSO system

$G_r(\varphi_i)$: receive antenna gain (as a ratio) of the radio telescope, in the direction of the transmitting space station considered in the non-GSO system (see Recommendation ITU-R RA.1631)

$G_{r,max}$: maximum gain (as a ratio) of the radio telescope

$epfd$: instantaneous epfd in the reference bandwidth at the radio telescope $(dB(W/m^2))$.

The epfd calculation in equation (1) assumes that the pfd due to all interfering sources is directed at the boresight of the receiving antenna, where the antenna gain is maximum. However, radio astronomy protection criteria are based on a 0 dBi contour of the radio astronomy antenna. The pfd due to all interfering sources directed at the 0 dBi gain of the receiving antenna, can be determined as follows:

–   From equation (1), the instantaneous epfd directed at the 0 dBi gain of the receiving antenna, expressed in (W/m^2), is given by

$$epfd_{G_r = 0\,\text{dBi}} = \left(\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi d_i^2} \cdot G_r(\varphi_i) \right)$$
                                                                                                                (2)

–   The instantaneous $epfd_{G_r = 0\,\text{dBi}}$ values resulting from equation (2), averaged over a 2 000 s integration time, can be compared with pfd levels, also expressed in (W/m^2) (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given this integration time).

NOTE 1 – It is assumed that each transmitter is located in the far field of the radio telescope (that is, at a distance greater than $2D^2/\lambda$, where D is the effective diameter of the radio telescope and λ is the observing wavelength). Though this may not always be satisfied, it is considered to be an adequate approximation.

NOTE 2 – For some telescopes, the direction of maximum gain (boresight direction) may not always coincide with the geometrical axis of the radio telescope.

NOTE 3 – In the case of active antennas, P_i should be taken as the radiated RF power rather than the power at the input to the antenna.

NOTE 4 – The antenna gain of the transmitting station, $G_t(\theta_i)$, is taken at the frequency of the radio astronomy band considered. This may differ from the gain at the frequencies of the intended transmissions.

Annex 2

Distribution of epfd levels

This Annex describes a way to derive epfd statistics over the whole sky.

1   Division of the sky into cells of approximately equal solid angle

The first step of this approach is to divide the sky into M rings parallel to the horizon and equally spaced in terms of elevation angle, from 0° to 90°. The width of each ring is 90°/M. The next step is to divide these rings into cells whose azimuth width is chosen to provide an integer number of cells per ring and is approximately equal to:

$$\frac{90/M}{\cos(\text{elevation})} \qquad \text{degrees}$$

Figure 1 provides an example of division based on a step of 3° width in elevation, this divides the sky into 30 rings of 3° of elevation angle. Then, the azimuth width is approximately equal to:

$$\frac{90/30}{\cos (\text{elevation})} \quad \text{degrees}$$

Elevation is a mean elevation in a given ring.

FIGURE 1

**Example of division of the sky in cells of approximately
9 square degrees of solid angle**

This leads to a division of the sky into 2 334 cells of approximately 9 square degrees of solid angle each. Table 1 provides the number of cells for each ring corresponding to this example.

TABLE 1

Example of division of the sky into square cells of about 9 square degrees solid angle

Lower elevation of the ring (degrees)	Ring solid angle (square degrees)	Cumulative solid angle (square degrees)	Azimuth step (degrees)	Number of cells in the ring	Cell solid angle (square degrees)	Cumulative number of cells	Percentage of solid angle (%)	Cumulative solid angle (%)
0	1 079.51	1 079.51	3	120	9	120	5.23	5.23
3	1 076.55	2 156.05	3	120	8.97	240	5.22	10.45
6	1 070.64	3 226.69	3	120	8.92	360	5.19	15.64
9	1 061.79	4 288.49	3	120	8.85	480	5.15	20.79
12	1 050.04	5 338.53	3	120	8.75	600	5.09	25.88
15	1 035.41	6 373.93	3	120	8.63	720	5.02	30.90
18	1 017.94	7 391.87	3	120	8.48	840	4.94	35.84
21	997.68	8 389.55	3	120	8.31	960	4.84	40.67
24	974.68	9 364.23	3	120	8.12	1 080	4.73	45.40
27	949.01	10 313.24	3	120	7.91	1 200	4.60	50
30	920.75	11 233.99	4	90	10.23	1 290	4.46	54.46
33	889.95	12 123.94	4	90	9.89	1 380	4.31	58.78
36	856.72	12 980.66	4	90	9.52	1 470	4.15	62.93
39	821.14	13 801.81	4	90	9.12	1 560	3.98	66.91
42	783.31	14 585.12	4	90	8.70	1 650	3.80	70.71
45	743.34	15 328.46	4	90	8.26	1 740	3.60	74.31
48	701.32	16 029.79	5	72	9.74	1 812	3.40	77.71
51	657.39	16 687.17	5	72	9.13	1 884	3.19	80.90
54	611.65	17 298.82	5	72	8.50	1 956	2.97	83.87
57	564.23	17 863.06	6	60	9.40	2 016	2.74	86.60
60	515.27	18 378.33	6	60	8.59	2 076	2.50	89.10
63	464.90	18 843.23	6	60	7.75	2 136	2.25	91.35
66	413.25	19 256.48	8	45	9.18	2 181	2.00	93.36
69	360.47	19 616.95	9	40	9.01	2 221	1.75	95.11
72	306.70	19 923.65	10	36	8.52	2 257	1.49	96.59
75	252.09	20 175.74	12	30	8.40	2 287	1.22	97.81
78	196.79	20 372.53	18	20	9.84	2 307	0.95	98.77
81	140.95	20 513.49	24	15	9.40	2 322	0.68	99.45
84	84.73	20 598.21	40	9	9.41	2 331	0.41	99.86
87	28.27	20 626.48	120	3	9.42	2 334	0.14	100

2   epfd distribution for a cell

First, a random choice is made for a pointing direction of the radio astronomy service antenna which will lie within a specific cell on the sky as defined in the paragraph above. Then, the starting time of the constellation is randomly chosen. The epfd is then evaluated for each time sample over a 2 000 s integration time. The average epfd corresponding to this trial is then calculated for the chosen pointing direction and starting time of the constellation.

This operation is repeated to obtain a statistical distribution of the epfd in the considered cell. The methodology involves a number of trials, each of which calculates the averaged epfd level over a 2 000 s integration interval. The greater the number of trials, the more accurate this distribution will be. A sufficient number of trials is needed to achieve the required confidence level in the results. In particular, the number of trials multiplied by the 2 000 s integration time should be significantly higher than the period of the constellation. It is also necessary to ensure adequate statistical sampling over the full period of the constellation. Once it is found that no further significant change occurs in the distribution, it can be concluded that a sufficient number of trials has been performed. This check can be done either automatically as an integral part of the simulation, or manually, by stopping the simulation at regular intervals.

3   epfd distribution in worst-case pointing directions (to be applied only if the pfd levels from satellites are constant for a given elevation angle of radio astronomy service antenna)

The evaluation of the epfd distributions in cells on the sky may be simplified by first evaluating the epfd distribution in pointing directions corresponding to worst-case pointing directions. These worst-case pointing directions may be taken as those pointing directions where the probability of visibility of satellites is the highest. These pointing directions may be determined according to Recommendation ITU-R S.1257 – Analytical method to calculate short-term visibility and interference statistics for non-geostationary satellite orbit satellites as seen from a point on the Earth's surface (equations (28) and (29)). For a given elevation angle and a given constellation of non-GSO satellites, this Recommendation allows the calculation of the worst-case azimuths (there are usually two worst-case azimuths at a given elevation).

For the cells within which these worst-case pointing directions lie, the epfd distribution may be evaluated for a sufficient number of 2 000 s integration times. Then, this epfd distribution may be compared with a pfd threshold level (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given a 2 000 s integration time).

For a cell, the percentage of time during which a pfd threshold level is exceeded can be calculated as the percentage of 2 000 s integration periods in which the average pfd at the radio telescope exceeds this pfd threshold level.

Considering the 2% criterion in *recommends* 2 of Recommendation ITU-R RA.1513, the comparison of the epfd distribution with the pfd threshold level for cells corresponding to these worst-case pointing directions, can provide the following conclusions:

–   If, in all *M* rings, the time-averaged epfd for the worst-case pointing directions is equal to or less than the threshold of detrimental interference for 98% or more of time (see Fig. 2), then the criteria for avoidance of detrimental interference are met over the whole sky.

–   If, in a ring defined for a given elevation angle, the time-averaged epfd for the worst-case pointing directions is equal to or less than the detrimental threshold for 98% or more of time (see Fig. 2), then the criteria for avoidance of detrimental interference are met for the corresponding entire ring.

–   If the interference criteria are not met, then further investigation is needed.

The consideration of these worst-case pointing directions provides information on the location of worst-case cells.

4   Output in terms of epfd distribution

The epfd calculation described in § 2 provides a distribution of epfd levels for each cell of the sky as shown in Fig. 2.

FIGURE 2

Example of a cumulative epfd distribution for a cell
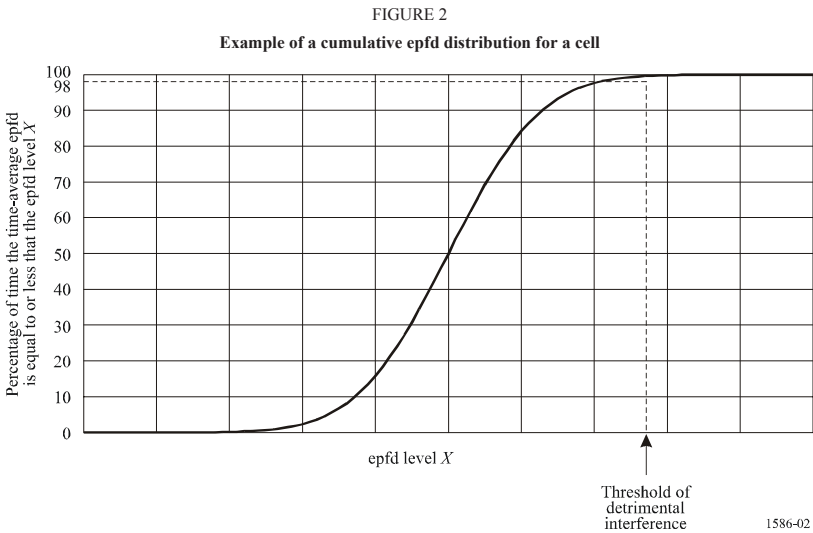
RECOMMENDATION ITU-R F.1613*,**

**Operational and deployment requirements for fixed wireless access
systems in the fixed service in Region 3 to ensure the protection
of systems in the Earth exploration-satellite service
(active) and the space research service (active)
in the band 5 250-5 350 MHz**

(Questions ITU-R 113/9 and 218/7)

(2003)

The ITU Radiocommunication Assembly,

considering

a)   that the frequency band 5 250-5 350 MHz is allocated to the Earth exploration-satellite service (EESS) (active) and space research service (SRS) (active) for spaceborne active sensors and to the radiolocation service on a primary basis;

b)   that the allocations in the frequency band 5 250-5 350 MHz will be reviewed by WRC-03 under agenda item 1.5 with a view to allocating this band to the fixed service in Region 3 on a primary basis;

c)   that some administrations in Region 3 have proposed using the band 5 250-5 350 MHz for licence-based fixed wireless access (FWA) systems in the fixed service;

d)   that these FWA systems operating outdoors may cause unacceptable interference to the EESS/SRS (active) in the above band;

e)   that there is a need to specify operational and deployment requirements for FWA systems in Region 3 in order to protect spaceborne active sensor systems,

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*   This Recommendation was developed jointly by Radiocommunication Study Groups 7 and 9, and any future revision will also be undertaken jointly.

**   This Recommendation should be brought to the attention of Radiocommunication Study Groups 7 and 8.

noting

a)   that the interference from EESS/SRS (active) systems into FWA systems with the characteristics described in Annex 1 is considered to be acceptable,

recognizing

a)   that it is difficult for FWA and other types of wireless access systems (including radio local area networks (RLANs)) to operate simultaneously on a co-coverage, co-frequency basis,

recommends

1   that the aggregate interference from FWA systems (sum of the directional e.i.r.p. towards the satellite) should be smaller than −7.6 dB(W/20 MHz) at the Earth's surface within the footprint of the active sensor of the EESS/SRS satellite (see Notes 1, 2 and 3);

2   that the methodology described in Annex 1 should be used to assess the aggregate interference level from FWA systems;

3   that, based on the FWA system characteristics presented in Table 4 for Region 3, a maximum density of 23 FWA base stations per 220 km^2 should be allowed within a satellite active sensor footprint. Variation of the maximum e.i.r.p., antenna pattern and frequency planning would imply a variation in the maximum allowed density of FWA base stations;

4   that the maximum e.i.r.p. of each FWA station should be no more than 3 dB(W/20 MHz) (see Notes 4 and 5);

5   that administrations should control these systems to ensure that the deployment requirements for FWA systems specified in the above *recommends* are satisfied.

NOTE 1 – This aggregate interference level is derived from the interference threshold of −132.35 dB(W/20 MHz) at the satellite receiver specified for the SAR4 in Table 5.

NOTE 2 – The footprint of the active sensor of the EESS/SRS the satellite referred to here has an area of about 220 km^2.

NOTE 3 – The aggregate interference from FWA systems toward the spaceborne active sensor satellite depends on such parameters as transmit power of the FWA systems, the antenna directivity and the number of the FWA base stations using the same RF channel within the satellite active sensor footprint.

NOTE 4 – If the main beam direction is above 10° in elevation, a 6 dB lower e.i.r.p. limit should apply, i.e. a maximum e.i.r.p. of −3 dB(W/20 MHz).

NOTE 5 – The direction of FWA station antennas should be controlled in order to avoid accidental direct illumination to the satellite due to misalignment of antenna direction, for example, a remote station not pointing towards the base station.

NOTE 6 – Additional guidance should be developed in order to facilitate the application of this Recommendation. This matter requires further study.

Annex 1

Frequency sharing between FWA systems and spaceborne active sensor systems in the EESS (active) and the SRS (active) in the band 5 250-5 350 MHz

1 Introduction

The frequency band 5 250-5 350 MHz is considered to be suitable for FWA systems in the fixed service to provide high-speed Internet or other multimedia service applications. Since the frequency band is allocated in the ITU Radio Regulations to the EESS (active) and the SRS (active) on a worldwide basis, sharing feasibilities between FWA systems and systems in the EESS/SRS (active) needs to be determined.

In this frequency band various types of spaceborne synthetic aperture radar (SAR), spaceborne radar altimeter and spaceborne scatterometer systems in the EESS/SRS (active) are operating.

This Annex deals with sharing consideration between FWA systems and these spaceborne active sensors, using typical system parameters that are currently available or being considered in the developmental stage.

2 Technical characteristics of spaceborne active sensors

Technical characteristics of spaceborne active sensors in the 5 250-5 350 MHz are given in Tables 1 to 3.

TABLE 1

5.3 GHz typical spaceborne SAR characteristics

Parameter	Value		
	SAR2	**SAR3**	**SAR4**
Orbital altitude (km)	600 (circular)	400 (circular)	
Orbital inclination (degrees)	57		
RF centre frequency (MHz)	5 405	5 305	5 300
Peak radiated power (W)	4 800	1 700	
Polarization	Horizontal and vertical (HH, HV, VH, VV)		
Pulse modulation	Linear FM chirp		
Pulse bandwidth (MHz)	310		40
Pulse duration (μs)	31	33	

TABLE 1 (*end*)

Parameter	Value		
	SAR2	**SAR3**	**SAR4**
Pulse repetition rate (pps)	4 492	1 395	
Duty cycle (%)	13.9	5.9	
Range compression ratio	9 610	10 230	1 320
Antenna type (m)	Planar phased array 1.8 × 3.8	Planar phased array 0.7 × 12.0	
Antenna peak gain (dBi)	42.9	42.7/38 (full focus/beamspoiling)	
Antenna median side-lobe gain (dBi)	−5		
Antenna orientation (degrees)	20-38 from nadir	20-55 from nadir	
Antenna beamwidth	1.7 (El), 0.78 (Az)	4.9/18 (El), 0.25 (Az)	
Antenna polarization	Linear horizontal/vertical		
Receiver noise figure (dB)	4.62		
Receiver front end 1 dB compression point referred to receiver input	−62 dBW input		
Receiver input maximum power handling (dBW)	+7		
Operating time	30% of the orbit		
Minimum time for imaging (s)	15		
Service area	Land masses and coastal areas		
Image swath width (km)	20	16/320	
Footprint (km^2)	159.03	76.5	76.5-220
Receiver bandwidth (MHz)	356.5		46.00
Interference threshold (dB)	$I/N = -6$		

TABLE 2

5.3 GHz typical spaceborne altimeter characteristics

Jason mission characteristics	
Lifetime	5 years
Altitude (km)	1 347 ± 15
Inclination (degrees)	66
Poseidon 2 altimeter characteristics	
Signal type	Pulsed chirp linear frequency modulation
C band PRF (Hz)	300
Pulse duration (µs)	105.6
Carrier frequency (GHz)	5.3
Bandwidth (MHz)	320
Emission RF peak power (W)	17
Emission RF mean power (W)	0.54
Antenna gain (dBi)	32.2
3 dB aperture (degrees)	3.4
Side-lobe level/Maximum (dB)	−20
Back-side-lobe level/Maximum (dB)	−40
Beam footprint at −3 dB (km)	77
Interference threshold (dBW)	−118

TABLE 3

5.3 GHz typical spaceborne scatterometer characteristics

Parameter	Value	
System name	Scatterometer 1	Scatterometer 2
Orbital altitude (km)	780	800
Inclination (degrees)	81.5	
Centre frequency (GHz)	5.3	5.255
Pulse width	70 µs (mid) 130 µs (fore/aft)	8 ms (mid) 10.1 ms (fore/aft)
Modulation	Interrupted CW	Linear FM (chirp)
Transmitter bandwidth (kHz)	15	500
PRF (Hz)	115 (mid) 98 (fore/aft)	29.4
Antenna type	Slotted waveguide	

TABLE 3 (*end*)

Parameter	Value			
Antenna gain (dBi)	31 (mid) 32.5 (fore/aft)		28.5 (mid) 29.5 (fore/aft)	
Antenna main beam orientation (degrees)	Incidence angles: 18-47 (mid) 24-57 (fore/aft)		Incidence angles: 25.0-54.5 (mid) 33.7-65.3 (fore/aft)	
Antenna beamwidth (−3 dB) elevation (degrees) Azimuth beamwidth (degrees)	24 (mid) 1.3	26 (fore/aft) 0.8	23.6 (mid) 1.1	23.9 (fore/aft) 0.8
Instrument elevation angle (degrees)	29.3		37.6	
Antenna polarization	Vertical			
Transmitter peak power	4.8 kW		120 W	
Receiver noise figure (dB)	3			
Service area	Oceanic and coastal areas, land masses			
Interference threshold (dB(W/Hz))	−207			

3   Technical features of FWA systems

Technical parameters of FWA systems should be decided to meet both the high-speed Internet service requirements and the sharing criteria with other services.

When FWA systems are to operate in the band 5 250-5 350 MHz, the following points have to be considered:

–   FWA systems are composed of a base station and many remote stations within the service coverage, in other words a cell. It is assumed that all the remote stations communicate to the base station only during the assigned time slot (in case of time division multiple access (TDMA)) or accessible timings (in case of carrier sense multiple access (CSMA)). This means that within a cell only one station is transmitting at any instant in time. Therefore, the deployment density (per km^2) of FWA base stations will affect the interference to a spaceborne active sensor satellite station.

–   The antenna directivity for high elevation angle is important. If the antenna at the FWA stations has enough upward discrimination, the interference power will be sufficiently suppressed.

–   Active ratio of a group of FWA transmitters in a cell may become 100% in the worst case.

–   Licence-based measures will be required to control the deployment density of FWA systems.

Considering the aforementioned features, examples of technical parameters for FWA systems are assumed as shown in Table 4 for the purpose of preliminary studies in this Annex.

The characteristics chosen in this analysis are those which would result in the worst-case interference to a narrow-band SAR receiver. For this type of FWA system, if the antenna boresight is pointed approximately along the horizon for a point-to-multipoint connection, the angle from the boresight becomes the elevation angle. At nadir angles of 20° to 55°, FWA station elevation angles directed towards a spaceborne SAR range from 69° to 30°.

TABLE 4

Technical characteristics of FWA system at 5.3 GHz

	Base station	**Remote station**
Frequency band (MHz)	5 250-5 350	
Operational mode	Point-to-multipoint	
Cell radius (km)	1-2	
Maximum transmit e.i.r.p./power (W)	2/0.2	2/0.063
Antenna gain/ characteristics	10 dBi/ Rec. ITU-R F.1336 Omnidirectional pattern ($k = 0$) (Fig. 1)	15 dBi/ Rec. ITU-R F.1336 Low-cost, low-gain antenna (Fig. 2)
Bandwidth (MHz)	20	
Receiver noise figure (dB)	8	
Interference threshold	$I/N = -6$ dB or -128.8 dB(W/20 MHz)	
Polarization	Vertical or horizontal	
Active ratio (%)	90	10

FIGURE 1

Base station antenna pattern

1613-01

FIGURE 2

Remote station antenna pattern
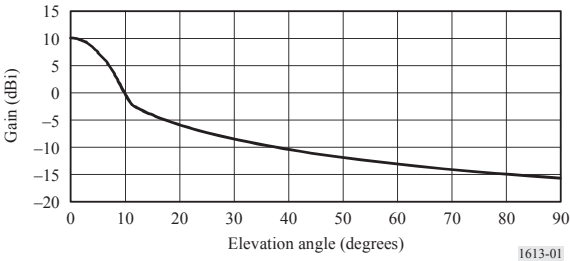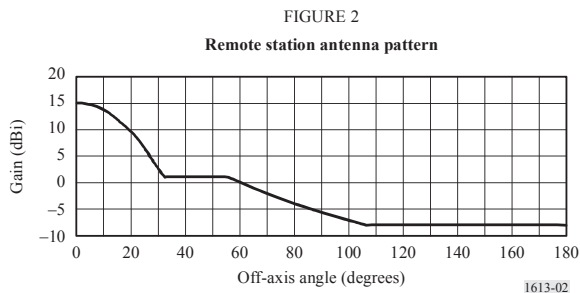
4   **Frequency sharing between spaceborne active sensors and FWA systems**

4.1   **Sharing between SAR and FWA**

4.1.1   **Interference from FWA into SAR**

Table 5 presents a calculation result of interference from an FWA system with parameters in Table 4 to SAR4 in Table 1. Although SAR2, SAR3 and SAR4 provide the equivalent interference threshold per MHz, the analysis hereafter refers to SAR4 with the most stringent requirement in absolute value. In calculating the interference, the side-lobe effect of the FWA antenna and the scattering effect at the surface/building are considered. With regard to the side-lobe interference from remote stations, the average e.i.r.p. towards the satellite from all remote stations surrounding the base station is calculated (see Appendix 1 to Annex 1). Note that the frequency reuse factor of 4 is assumed in Table 5.

The surface scattered contribution or eventual scattering from nearby buildings will be possible sources of interference. This is dependent on the area where these systems are deployed and on which altitude they will be placed (top or side of buildings), etc. It can be envisaged that FWA systems are present in high-density urban areas where by definition scattering from a wide range of objects will occur, so besides surface scattering these other cases will have to be taken into account. One could especially envisage modern office buildings, which are constructed out of metal where the possibility of a high reflectivity into the direction of the sensor cannot be excluded. As the worst-case approach, a scattering coefficient is taken as -18 dB. This assumption may need to be reviewed.

The above analysis is based on the hypothesis of having only FWA transmitters not using sector antennas. The presence of sector antennas would deteriorate the sharing scenario related to scattering.

The result indicates that 23 FWA cells can be operated in the SAR4 footprint within an area of 220 km^2 while the interference to the SAR satellite receiver is smaller than the acceptable level. If the parameters of FWA systems are different from those listed in Table 4, including the case where sector antennas are employed at the base stations, the number of cells allowed within the satellite footprint would be different. Table 5 should be recalculated with the actual parameters.

TABLE 5

Interference from an FWA system to SAR4

Parameter			20° from nadir		55° from nadir	
			Value	dB	Value	dB
Interfering e.i.r.p. due to FWA antenna side lobe	From base station	Transmitted peak power (W)	0.2	−7.00	0.2	−7.00
		Transmit antenna gain (dBi)		−14.20		−8.80
		Active ratio	90%	−0.46	90%	−0.46
		e.i.r.p. (dBW)		−21.66		−16.26
	From remote station	Transmitted peak power (W)	0.063	−12.00	0.063	−12.00
		Average transmit antenna gain (dBi)		−4.96		−2.34
		Active ratio	10%	−10.00	10%	−10.00
		e.i.r.p. (dBW)		−26.96		−24.34
	Total e.i.r.p. due to side lobe (dBW)			−20.54		−15.63
Interfering power due to scattering at the surface	From base station	Transmitted peak power (W)	0.2	−7.00	0.2	−7.00
		Active ratio	90%	−0.46	90%	−0.46
		Transmitted power (dBW)		−7.46		−7.46
	From remote stations	Transmitted peak power (W)	0.063	−12.00	0.063	−12.00
		Active ratio	10%	−10.00	10%	−10.00
		Transmitted power (dBW)		−22.00		−22.00
	Total transmitted power (dBW)			−7.31		−7.31
	Scattering coefficient (dB)			−18.00		−18.00
	Total scattered e.i.r.p. (dBW)			−25.31		−25.31
Total interfering e.i.r.p. from a cell (dBW)				−19.29		−15.19
Interference power received at SAR	Receive antenna gain (dBi)			42.70		42.70
	Polarization loss (dB)			−3.00		−3.00
	Free space loss (dB)		(427 km)	−159.55	(749 km)	−164.43
	Power received (dBW)			−139.14		−139.92
SAR receiver sensitivity	Noise figure (dB)			4.62		4.62
	kT		4.0×10^{-21}	−203.98	4.0×10^{-21}	−203.98
	Receiver bandwidth (MHz)		20.0	73.01	20.0	73.01
	Noise power (dBW)			−126.35		−126.35
	SAR interference threshold ($I/N = -6$ dB) (dBW)			−132.35		−132.35
Allowable number of FWA cells	Margin (dB)			6.79		7.57
	Maximum number of FWA cells using the same RF channel within the SAR footprint		4.78		5.71	
	Maximum number of FWA cells assuming frequency reuse factor of 4		19.1		22.8	

4.1.2   Interference from SAR into FWA

The first step in analysing the interference potential from spaceborne SARs into FWA systems is to determine the signal power from spaceborne SARs side lobes onto the Earth's surface. For this analysis the median side-lobe gain has been used since these side lobes give a substantially larger footprint than the peak gain and will result in a longer duration interference. Table 6 shows the interference levels caused from SAR4 satellite side lobes into FWA. SAR4 was selected to represent the worst case. This Table shows a positive margin in the order of 20 dB and would result in a positive sharing scenario as far as side lobes are concerned.

TABLE 6

Interference from SAR4 side lobes into FWA

Parameter	20° from nadir		55° from nadir	
	Interference into base station	Interference into remote station	Interference into base station	Interference into remote station
Transmitted power (dBW)	32.3		32.3	
Transmit antenna gain (dBi)	−5.0		−5.0	
Free space loss (dB)	−159.5 (427 km)		−164.4 (749 km)	
Receive antenna gain (dBi)	−14.2	−2.2	−8.8	2.3
FWA feeder loss (dB)	−5.0	−10.0	−5.0	−10.0
Power received (dBW)	−151.4	−144.4	−150.9	−144.8
Bandwidth reduction (dB)	−3.0		−3.0	
Power received (dB(W/20 MHz))	−154.4	−147.4	−153.9	−147.8
FWA interference threshold (dB(W/20 MHz))	−128.8		−128.8	
Margin (dB)	25.6	18.6	25.1	19.0

However, the peak antenna gain is 43-47.7 dB higher than the average side-lobe gain of −5 dBi. Therefore, for the duration of the flyover the interference levels at the surface would be above the FWA interference threshold. Although the threshold is exceeded, the frequency and duration of this excess interference are estimated once per 8-10 days and 0.5-1 s per event, respectively.

4.1.3   Summary

It is demonstrated that frequency sharing between the SAR system and an FWA system is feasible in the band 5 250-5 350 MHz under certain operational and deployment requirements for the FWA system. FWA systems may experience short periods of high interference from SAR systems during their flyover periods. This interference is considered to be acceptable, given the assumed small joint probability of SAR interference and fading by the FWA systems. However, further studies may be required on the detailed interference effects on FWA systems.

4.2 Sharing between spaceborne altimeter and FWA

4.2.1 Interference from FWA into spaceborne altimeter

Table 7 shows the interference calculation from FWA into the spaceborne altimeter. The result shows an ample margin of 42.6 dB with respect to a −118 dBW threshold, and thus it can be concluded that FWA systems will not cause unacceptable interference to the spaceborne altimeter operation.

TABLE 7

Interference from FWA into spaceborne altimeter

Parameter			From nadir	
			Value	dB
Interfering e.i.r.p. due to FWA antenna side lobe	From base station	Transmitted peak power (W)	0.2	−7.00
		Transmit antenna gain (dBi)		−15.84
		Active ratio	90%	−0.46
		e.i.r.p. (dBW)		−23.30
	From remote station	Transmitted peak power (W)	0.063	−12.00
		Average transmit antenna gain (dBi)		−5.71
		Active ratio	10%	−10.00
		e.i.r.p. (dBW)		−27.71
	Total e.i.r.p. due to side lobe (dBW)			−21.96
Interfering power due to scattering at the surface	From base station	Transmitted peak power (W)	0.2	−7.00
		Active ratio	90%	−0.46
		Transmitted power (dBW)		−7.46
	From remote stations	Transmitted peak power (W)	0.063	−12.00
		Active ratio	10%	−10.00
		Transmitted power (dBW)		−22.00
	Total transmitted power (dBW)			−7.31
	Scattering coefficient (dB)			−18.00
	Total scattered e.i.r.p. (dBW)			−25.31
Total interfering e.i.r.p. from a cell (dBW)				−20.31
Interference power received at altimeter receiver	Receive antenna gain (dBi)			32.20
	Polarization loss (dB)			−3.00
	Free space loss (dB)		(1 347 km)	−169.53
	Power received (dBW)			−160.64
Altimeter interference threshold (dBW)				−118.00
Margin (dB)				42.64

4.2.2   Interference from spaceborne altimeter into FWA

Table 8 shows interference levels from the spaceborne altimeter main beam into a base station and a remote station. There are sufficient margins in both cases.

TABLE 8

Interference from spaceborne altimeter into FWA

Parameter	To nadir	
	Interference into base station	**Interference into remote station**
Transmitted power (dBW)	12.3	
Transmit antenna gain (dBi)	32.2	
Free space loss (dB)	−169.5 (1 347 km)	
Receive antenna gain (dBi)	−15.8	−5.7
FWA feeder loss (dB)	−5.0	−10.0
Power received (dBW)	−145.8	−140.7
Bandwidth reduction (20 MHz/320 MHz) (dB)	−12.0	
Power received (dB(W/20 MHz))	−157.8	−152.7
FWA interference threshold (dB(W/20 MHz))	−128.8	
Margin (dB)	29.0	23.9

4.2.3   Summary

It has been demonstrated that frequency sharing between spaceborne altimeter system and FWA systems is feasible in the band 5 250-5 350 MHz.

4.3   Sharing between scatterometer and FWA

4.3.1   Interference from FWA into scatterometer

Table 9 shows an interference analysis from FWA into Scatterometer 1. Scatterometer 1 is selected to represent the worst case. Table 9 shows that the interference from FWA does not cause unacceptable interference.

4.3.2   Interference from scatterometer into FWA

Table 10 shows an analysis of interference from the scatterometer into FWA. The negative margins mean that FWA systems may experience short periods of high interference during the flyover of the scatterometer system.

TABLE 9

Interference from FWA into Scatterometer 1

Parameter			18° from nadir (El: 69.7°)		57° from nadir (El: 19.7°)	
			Value	dB	Value	dB
Interfering e.i.r.p. due to FWA antenna side lobe	From base station	Transmitted peak power (W)	0.2	−7.00	0.2	−7.00
		Transmit antenna gain (dBi)		−14.20		−5.94
		Active ratio	90%	−0.46	90%	−0.46
		e.i.r.p. (dBW)		−21.66		−13.40
	From remote station	Transmitted peak power (W)	0.063	−12.00	0.063	−12.00
		Average transmit antenna gain (dBi)		−4.93		0.64
		Active ratio	10%	−10.00	10%	−10.00
		e.i.r.p. (dBW)		−26.96		−21.36
	Total e.i.r.p. due to side lobe (dBW)			−20.54		−12.76
Interfering power due to scattering at the surface	From base station	Transmitted peak power (W)	0.2	−7.00	0.2	−7.00
		Active ratio	90%	−0.46	90%	−0.46
		Transmitted power (dBW)		−7.46		−7.46
	From remote stations	Transmitted peak power (W)	0.063	−12.00	0.063	−12.00
		Active ratio	10%	−10.00	10%	−10.00
		Transmitted power (dBW)		−22.00		−22.00
	Total transmitted power (dBW)			−7.31		−7.31
	Scattering coefficient (dB)			−18.00		−18.00
	Total scattered e.i.r.p. (dBW)			−25.31		−25.31
Total interfering e.i.r.p. from a cell (dBW)				−19.29		−12.53
Interference power received at SAR	Receive antenna gain (dBi)			31.00		32.50
	Polarization loss (dB)			−3.00		−3.00
	Free space loss (dB)		(825 km)	−165.27	(1 745 km)	−171.78
	Power received (dBW)			−156.56		−154.81
	Power received (dB(W/Hz))			−229.57		−227.82
Scatterometer interference threshold (dB(W/Hz))				−207.00		−207.00
Margin (dB)				22.57		20.82

TABLE 10

Interference from Scatterometer 1 into FWA

Parameters	18° from nadir (El: 69.7°)		57° from nadir (El: 19.7°)	
	Interference into a base station	**Interference into a remote station**	**Interference into a base station**	**Interference into a remote stations**
Transmitted power (dBW)	36.8		36.8	
Transmit antenna gain (dBi)	31.0		32.5	
Free space loss (dB)	−165.3 (825 km)		−171.8 (1 745 km)	
Receive antenna gain (dBi)	−14.2	−4.9	−5.9	0.6
FWA feeder loss (dB)	−5.0	−10.0	−5.0	−10.0
Power received (dBW)	−116.7	−112.4	−113.4	−111.9
FWA interference threshold (dBW)	−128.8		−128.8	
Margin (dB)	−12.1	−16.4	−15.4	−16.9

4.3.3   Summary

It has been demonstrated that frequency sharing between scatterometer systems and FWA systems is feasible. FWA systems may experience short periods of high interference from Scatterometer systems during their flyover periods. This interference is considered to be acceptable, given the assumed small joint probability of scatterometer interference and fading by FWA systems. However, further studies may be required on the detailed interference effects on FWA systems.

5   Conclusion

Frequency sharing between EESS/SRS (active) and FWA is possible under the condition that deployment of FWA systems is controlled so that the total interference e.i.r.p. from FWA to the EESS/SRS satellite does not exceed −7.6 dB(W/20 MHz) within the footprint of the active sensor of the satellite. FWA systems may experience short periods of interference from active sensor systems of EESS/SRS satellites during their flyover periods. This interference is considered to be acceptable for this band, given the assumed small joint probability of the active sensor interference and fading by FWA systems.

It is noted that these conclusions apply only to sharing between FWA and EESS/SRS (active), and do not address the possible increased aggregate interference to EESS/SRS (active) from the effects of mobile devices which may also operate in the EESS/SRS (active) footprint. However, studies have indicated that it is difficult for FWA and other types of wireless access systems (including RLANs) to operate simultaneously on a co-coverage, co-frequency basis. This matter is under further study and it is assumed not to impact on the conclusions of this Recommendation.

Appendix 1
to Annex 1

Interference into the spaceborne active sensor caused by
side lobes of FWA remote stations

In an FWA cell, remote stations are scattered around the base station. It is assumed that remote stations surround the base station uniformly in terms of azimuth angles observed from the remote station. Since the main beam of remote stations are directed to the base station, the angle from the main beam of remote station is larger than the elevation angle towards the EESS/SRS satellite due to the azimuth separation as shown in Fig. 3.

FIGURE 3

Off-beam angle: θ towards the EESS/SRS satellite at the remote station
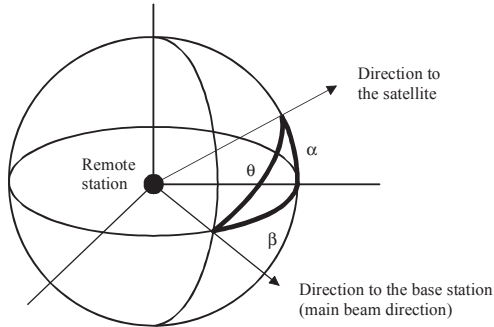
1613-03

The off-beam angle: θ towards the satellite at the remote station is calculated by the following relation, assuming that the elevation of remote station antenna is 0°:

$$\cos\theta = \cos\alpha \cdot \cos\beta$$

where:

      α :   elevation angle towards the satellite

      β :   azimuth separation angle between the satellite and the base station directions.

Assuming β to be uniformly distributed over 0° to 360°, the average gain towards the satellite is calculated as shown in Table 11.

TABLE 11

Average antenna gain of remote stations towards the satellite

Satellite elevation (degrees)	70	30
Average gain (dBi)	−4.96	−2.34

Appendix 2
to Annex 1

List of abbreviations

Az	Azimuth
BW	Bandwidth
CSMA	Carrier sense multiple access
CW	Continuous wave
EESS	Earth exploration-satellite service
El	Elevation
FM	Frequency modulation
FWA	Fixed wireless access
PRF	Pulse repetition frequency
RF	Radio frequency
RLAN	Radio local area network
SAR	Synthetic aperture radar
SRS	Space research service
TDMA	Time division multiple access

RECOMMENDATION ITU-R RA.1631

Reference radio astronomy antenna pattern to be used for compatibility analyses between non-GSO systems and radio astronomy service stations based on the epfd concept

(Question ITU-R 146/7)

(2003)

The ITU Radiocommunication Assembly,

considering

a)   that there is a need to determine the levels of interference which may occur at typical observatory sites, due to various sources of interference;

b)   that, to determine these levels of interference, a reference antenna pattern needs to be defined;

c)   that Recommendation ITU-R SA.509 gives a reference antenna pattern which represents the side-lobe gain levels that are not expected to be exceeded at most off-axis angles in the majority of antennas used in the service;

d)   that the antenna pattern given in Recommendation ITU-R SA.509 is appropriate in some compatibility or sharing analyses;

e)   that, if the peak envelope radiation pattern such as given in Recommendation ITU-R SA.509 is used in the assessment of the aggregate interference consisting of many interference entries, the predicted interference will result in values that are greater than values that would be experienced in practice;

f)   that Recommendation ITU-R S.1586 and Recommendation ITU-R M.1583 provide a methodology based on the epfd concept as defined in No. 22.5C of the Radio Regulations to calculate the level of unwanted emission levels produced by a non-geostationary-satellite system at radio astronomy stations;

g)   that it is necessary to use an antenna radiation pattern representing average side-lobe levels to predict interference to a radio astronomy station from one or more fast moving stations seen under continuously variable angle such as non-GSO systems;

h)   that, a simple mathematical formula is preferable to the radiation pattern representing average side-lobe levels;

j)   that, to derive the epfd resulting from unwanted emission levels produced by a non-geostationary-satellite system at radio astronomy stations, it is necessary to use the typical maximum antenna gain of radio astronomy service (RAS) stations,

recommends

1   that, in the absence of particular information concerning the radiation pattern of the radio astronomy antenna involved, the mathematical model of the average radiation pattern as stated below should be used for compatibility analyses between non-GSO systems and RAS stations for frequencies above 150 MHz:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 \qquad \text{dBi} \qquad \text{for} \qquad 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad\qquad\qquad \text{for} \qquad \varphi_m \leq \varphi < \varphi_r$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad \text{dBi} \qquad\qquad \text{for} \qquad \varphi_r \leq \varphi < 10°$$

$$G(\varphi) = 34 - 30 \log \varphi \qquad \text{dBi} \qquad\qquad \text{for} \qquad 10° \leq \varphi < 34.1°$$

$$G(\varphi) = -12 \qquad \text{dBi} \qquad\qquad\qquad \text{for} \qquad 34.1° \leq \varphi < 80°$$

$$G(\varphi) = -7 \qquad \text{dBi} \qquad\qquad\qquad \text{for} \qquad 80° \leq \varphi < 120°$$

$$G(\varphi) = -12 \qquad \text{dBi} \qquad\qquad\qquad \text{for} \qquad 120° \leq \varphi \leq 180°$$

where:

$$G_{max} = 20 \log \left(\frac{D}{\lambda} \right) + 20 \log \pi \qquad\qquad \text{dBi}$$

$$G_1 = -1 + 15 \log \frac{D}{\lambda} \qquad\qquad \text{dBi}$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{max} - G_1} \qquad\qquad \text{degrees}$$

$$\varphi_r = 15.85 \left(\frac{D}{\lambda} \right)^{-0.6} \qquad\qquad \text{degrees}$$

D: diameter of the telescope (m)

λ: wavelength (m);

2   that the following mathematical model of the radiation pattern may be adopted for a more accurate representation of the main beam radiation pattern for frequencies above 150 MHz:

$$G(\varphi) = G_{max} \left[\frac{J_1(2\pi x)}{\pi x} \right]^2 \qquad\qquad \text{(expressed as a ratio not in dB)}$$

where:

$J_1(x)$:   first order Bessel function

$G_{max} = \left[\dfrac{4\pi A_{eff}}{\lambda^2} \right]$:   maximum gain (expressed as a ratio not in dB)

$A_{eff} = \pi(D/2)^2$:   area of the aperture of the telescope (m^2)

D: diameter of the telescope (m)

λ: wavelength (m)

and where:

$$x = \frac{\pi \cdot D \cdot \varphi}{360 \cdot \lambda}$$ with φ, off-boresight angle (degrees) $(0 \leq \varphi < \varphi_0)$

φ_0 :   first null in this antenna pattern at $69.88/(D/\lambda)$ (degrees) off-boresight

and that the following mathematical model of the radiation pattern may be adopted for a more accurate representation of the radiation pattern of near side lobes up to 1° from the boresight for frequencies above 150 MHz:

$$G(\varphi) = B \left[\frac{\cos(2\pi x - 3\pi/4 + 0.0953)}{\pi x} \right]^2$$ (expressed as a ratio not in dB)

where:

$$x = \frac{\pi \cdot D \cdot \varphi}{360 \cdot \lambda}$$ with φ, off-boresight angle (degrees) $(\varphi_0 \leq \varphi \leq 1°)$

D : diameter of the telescope

λ : wavelength

and:

$$B = 10^{3.2} \, \pi^2 \, ((\pi D/2)/(180 \cdot \lambda))^2$$

This main beam model corresponds to the ideal case of 100% aperture efficiency;

3   that the following typical maximum RAS antenna gain be used in compatibility analysis between non-GSO systems and RAS antenna stations.

RAS allocated band (MHz)	Typical maximum antenna gain
150.05-153	44
322-328.6	51
406.1-410	53
608-614	56
1 400-1 427	63
1 610.6-1 613.8	64
1 660-1 670	65
2 690-2 700	69
4 990-5 000	74

RAS allocated band (GHz)	Typical maximum antenna gain
10.6-10.7	81
14.47-14.5	84
15.35-15.4	84
22.21-22.5	87
23.6-24	88
31.3-31.7	90
42.5-43.5	93

The corresponding antenna diameter may be derived using the following equations (see *recommends* 2):

$$G_{max} = \left[\frac{4\pi A_{eff}}{\lambda^2} \right] \qquad \text{maximum gain (expressed as a ratio)}$$

where:

$A_{eff} = \pi(D/2)^2$: area of the aperture of the telescope (m^2)

$\qquad\qquad\quad$ D : diameter of the telescope (m)

$\qquad\quad$ λ : wavelength (m).

RECOMMENDATION ITU-R RS.1632*

Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service

(Question ITU-R 218/7)

(2003)

The ITU Radiocommunication Assembly,

considering

a)   that the frequency band 5 250-5 350 MHz is allocated to the Earth exploration-satellite service (EESS) (active) and to the radiolocation service on a primary basis;

b)   that some administrations have proposed to use the band 5 250-5 350 MHz for low power high speed wireless local area networks (WLANs), or radio local area networks (RLANs);

c)   that these high speed WLANs are proposed to be deployed in the band as unlicensed devices, making regulatory control of their deployment density non-feasible,

recognizing

a)   that studies are continuing in ITU-R with a view to facilitating sharing of wireless access systems (including RLANs) with EESS (active),

noting

a)   that some administrations have adopted technical limits which permit wireless access systems (including RLANs) to operate with an e.i.r.p. power limit of 1 W, while other administrations have adopted more stringent e.i.r.p. limits,

recommends

1   that sharing between spaceborne active sensors of the EESS with the characteristics as given in Annex 1 and high speed WLANs in the 5 250-5 350 MHz band is feasible with wireless access systems (including RLANs) having constraints such as those given in Annex 2;

2   that the level of protection required for EESS systems as given in Annex 1 may also be achieved using alternative sets of operational and technical limits being studies under *recognizing* a).

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*   Radiocommunication Study Group 7 made editorial amendments to this Recommendation.

Annex 1

Technical characteristics of spaceborne active sensors in the 5 250-5 570 MHz band

Technical characteristics of spaceborne active sensors in the 5.3 GHz frequency range are given in Tables 1 and 2.

TABLE 1

5.3 GHz typical spaceborne imaging radar characteristics

Parameter	Value			
	SAR1	SAR2	SAR3	SAR4
Orbital altitude (km)	426 (circular)	600 (circular)	400 (circular)	400 (circular)
Orbital inclination (degrees)	57	57	57	57
RF centre frequency (MHz)	5 305	5 405	5 405	5 300
Peak radiated power (W)	4.8	4 800	1 700	1 700
Polarization	Horizontal (HH)	Horizontal and vertical (HH, HV, VH, VV)	Horizontal and vertical (HH, HV, VH, VV)	Horizontal and vertical (HH, HV, VH, VV)
Pulse modulation	Linear FM chirp	Linear FM chirp	Linear FM chirp	Linear FM chirp
Pulse bandwidth (MHz)	8.5	310	310	40
Pulse duration (µs)	100	31	33	33
Pulse repetition rate (pps)	650	4 492	1 395	1 395
Duty cycle (%)	6.5	13.9	5.9	5.9
Range compression ratio	850	9 610	10 230	1 320
Antenna type (m)	Planar phased array 0.5×16.0	Planar phased array 1.8×3.8	Planar phased array 0.7×12.0	Planar phased array 0.7×12.0

TABLE 1 (*end*)

Parameter	Value			
	SAR1	**SAR2**	**SAR3**	**SAR4**
Antenna peak gain (dBi)	42.2	42.9	42.7/38 (full focus/beamspoiling)	42.7/38 (full focus/beamspoiling)
Antenna median side lobe gain (dBi)	−5	−5	−5	−5
Antenna orientation (degrees from nadir)	30	20-38	20-55	20-55
Antenna beamwidth (degrees)	8.5 (El), 0.25 (Az)	1.7 (El), 0.78 (Az)	4.9/18.0 (El), 0.25 (Az)	4.9/18.0 (El), 0.25 (Az)
Antenna polarization	Linear horizontal/vertical	Linear horizontal/vertical	Linear horizontal/vertical	Linear horizontal/vertical
Receiver front end 1 dB compression point ref to receiver input (dBW)	−62 input	−62 input	−62 input	−62 input
Allowable density of configuration saturation ref to receiver input	−114/−54 dBW input at 71/11 dB receiver gain	−114/−54 dBW input at 71/11 dB receiver gain	−114/−54 dBW input at 71/11 dB receiver gain	−114/−54 dBW input at 71/11 dB receiver gain
Receiver input max. power handling (dBW)	+7	+7	+7	+7
Operating time (%)	30 the orbit	30 the orbit	30 the orbit	30 the orbit
Minimum time for imaging (s)	9	15	15	15
Service area	Land masses and coastal areas	Land masses and coastal areas	Land masses and coastal areas	Land masses and coastal areas
Image swath width (km)	50	20	16/320	16/320

TABLE 2

5.3 GHz typical spaceborne radar altimeter characteristics

Jason mission characteristics	
Lifetime	5 years
Altitude	1 347 km ± 15 km
Inclination	66°
Poseidon 2 altimeter characteristics	
Signal type	Pulsed chirp. linear FM
C band pulse repetition frequency (PRF)	300 Hz
Pulse duration	105.6 µs
Carrier frequency	5.3 GHz
Bandwidth (BW)	320 MHz
Emission RF peak power	17 W
Emission RF mean power	0.54 W
Antenna gain	32.2 dBi
3 dB aperture	3.4°
Side lobe level/maximum	−20 dB
Backside lobe level/maximum	−40 dB
Beam footprint at −3 dB	77 km
Interference threshold	−118 dBW

TABLE 3

5.3 GHz typical spaceborne scatterometer characteristics

Parameter	Value	
System name	Scatterometer 1	Scatterometer 2
Orbital altitude (km)	780	800
Inclination (degrees)	98.5	98.5
Centre frequency (GHz)	5.3	5.255
Pulse width	70 µs (mid)	8 ms (mid)
	130 µs (fore/aft)	10.1 ms (fore/aft)
Modulation	Interrupted CW	Linear FM (chirp)
Transmitter BW (kHz)	15	500
PRF (Hz)	115 (mid)	29.4
	98 (fore/aft)	
Antenna type	Slotted waveguide	Slotted waveguide

TABLE 3 (*end*)

Parameter	Value	
Antenna gain (dBi)	31 (mid) 32.5 (fore/aft)	28.5 (mid) 29.5 (fore/aft)
Antenna mainbeam orientation (degrees)	Incidence angles: 18-47 (mid) 24-57 (fore/aft)	Incidence angles: 25.0-54.5 (mid) 33.7-65.3 (fore/aft)
Antenna beamwidth (−3 dB), elevation Azimuth beamwidth	24° (mid) 26° (fore/aft) 1.3° 0.8°	23.6° (mid) 23.9° (fore/aft) 1.1° 0.8°
Instrument elevation angle (degrees)	29.3	37.6
Antenna polarization	Vertical	Vertical
Transmitter peak power	4.8 kW	120 W
Receiver noise temperature (dB)	Noise factor: 3	Noise factor: 3
Service area	Oceanic and coastal areas, land masses	Oceanic and coastal areas, land masses

Annex 2

Sharing constraints between spaceborne active sensors and high speed WLANs in the 5 250-5 350 MHz band

1 Introduction

This Annex presents the results of three sharing analyses for the band 5 250-5 350 MHz between the spaceborne active sensors and the high speed WLANs, or RLANs. The first study, given in § 2 of this Annex, uses high performance RLAN (HIPERLAN) type 1 classes B and C and HIPERLAN type 2 characteristics for the RLANs and uses SAR4 characteristics for the SAR. In this study, it is feasible for the indoor only HIPERLAN type 1 class B and HIPERLAN type 2 to share the 5 250-5 350 MHz band with SAR4, but is not feasible for the HIPERLAN type 1 class C to share the band, nor for any HIPERLAN type designed to be operated outdoors with the technical characteristics assumed in the study.

The second study, as given in § 3 of this Annex, uses three RLAN types, RLAN1, RLAN2, and RLAN3, and uses SAR2, SAR3, and SAR4 characteristics for the SARs. In this study, for the single transmitter deployed outdoors, the RLAN1 high speed WLAN transmitter interference was above the acceptable level for SAR4, the RLAN2 high speed WLAN transmitter interference was above the acceptable levels for both SAR3 and SAR4, and the RLAN3 high speed WLAN transmitter interference was above the acceptable level for SAR4. For indoors/outdoors RLAN deployment, it is feasible for the RLAN1, based on an assumption of only 12 active transmitters per km^2 within the

SAR (footprint) and a single frequency channel for the RLAN1, to share with SAR2, SAR3, and SAR4, but it is not feasible for the RLAN2, based on an assumption of 1 200 active transmitters per office space and 14 channels across a 330 MHz band, to share with SAR2, SAR3, and SAR4. For an indoor deployment and considering the interference from the RLAN3 configuration of high speed WLANs to the SARs, the analysis shows that any surface density less than 37-305 transmitters/km^2/channel will yield acceptable interference levels into the SAR, depending on the imaging SAR pixel S/N for an imaging SAR. The anticipated mean density is estimated to 1 200 transmitter/large office area and 250 transmitters/industrial area. The anticipated high density assumes 14 channels, each 23.6 MHz wide, over a 330 MHz band. For interference from the RLAN3 configuration of high speed WLANs to the SARs, the analysis shows that only for a surface density less than 518 to 4 270 transmitters/km^2 over 14 channels, will local area networks (LANs) yield acceptable interference levels into the SAR. For RLAN3 interference into SAR2 and SAR4, this would correspond to about 3 to 12 large office buildings or 15 to 60 industrial areas within the SAR footprint, depending on the SAR pixel S/N.

The third study, as given in § 4 of this Annex, uses the more critical HIPERLAN type 1 characteristics for the RLANs and uses the altimeter characteristics as given in Table 2 for the altimeter. The radar altimeter operation with a 320 MHz bandwidth around 5.3 GHz is compatible with HIPERLANs.

The fourth study, as given in § 5 of this Annex, uses the HIPERLAN type 2 characteristics for the RLANs and uses the scatterometer characteristics as given in Table 3 for the scatterometer. The scatterometer operation around 5.3 GHz is compatible with HIPERLANs operated indoors.

2   Study of HIPERLANs types 1 and 2 and SARs

2.1   Technical characteristics of the two systems

The technical characteristics of the WLANs used for the sharing analysis are those of the HIPERLAN type 1 and type 2, for which the European Telecommunications Standards Institute (ETSI) in Europe has published the relevant specifications: EN 300 652 for type 1 and TS 101 683 for type 2. For other study parameters (building attenuation, operational activity duty cycle, HIPERLAN density, etc.) the values used are those agreed by ETSI ERM for these studies in Europe.

HIPERLAN type 1:

It provides high speed RLAN communications that are compatible with wired LANs based on Ethernet and Token-ring Standards ISO 8802.3 and ISO 8802.5.

HIPERLAN/1 parameters:

e.i.r.p. (high bit rate (HBR), in 23.5 MHz, low bit rate (LBR), in 1.4 MHz):

                              class A: 10 dBm maximum e.i.r.p.

                              class B: 20 dBm maximum e.i.r.p.

                              class C: 30 dBm maximum e.i.r.p.

Channel spacing: 30 MHz

Antenna directivity: omnidirectional

Minimum useful receiver sensitivity: −70 dBm

Receiver noise power (23.5 MHz):   −90 dBm

C/I for BER 10^{-3} at HBR: 20 dB

Effective range (class C):   50 m.

Only classes B (100 mW maximum e.i.r.p.) and C (1 W maximum e.i.r.p.) are considered for this study.

HIPERLAN type 2:

It provides high speed RLAN communications that are compatible with wired LANs based on ATM and IP standards.

HIPERLAN/2 parameters:

e.i.r.p.:   0.2 W (in the 5 250-5 350 MHz band)

Channel bandwidth: 16 MHz

Channel spacing: 20 MHz

Antenna directivity: omnidirectional

Minimum useful receiver sensitivity: −68 dBm (at 54 Mbit/s) to −85 dBm
                                     (at 6 Mbit/s)

Receiver noise power (16 MHz):   −93 dBm

C/I: 8-15 dB

Effective range: 30-80 m.

In European countries, in the band 5 250-5 350 MHz, the e.i.r.p. is limited to 200 mW and the use of HIPERLANs is only allowed when the following mandatory features are realized:

−   transmitter power control (TPC) to ensure a mitigation factor of at least 3 dB;

−   dynamic frequency selection (DFS) associated with the channel selection mechanism required to provide a uniform spread of the loading of the HIPERLANs across a minimum of 330 MHz.

Currently HIPERLAN/1 does not support these two features.

The DFS does not only provide a uniform load spread, but it allows also each HIPERLAN system to detect interference from other systems and therefore is able to avoid co-channel operation with other systems, notably radar systems. The system senses which channel is free for use and automatically switches to it. This allows large numbers of HIPERLAN systems to operate in the same office environment.

It is to be noted that the numbers given in the deployment scenarios are based on the assumption of the availability of a total of 330 MHz band for WLANs. Assuming that this bandwidth will be available in two sub-bands (5 150-5 350 MHz and 130 MHz above 5 470 MHz) and given the channel spacing and the need to create a guardband at the boundaries of the two sub-bands, the assumed number of channels used in the study is 8 for type 1 and 14 for type 2.

Other HIPERLAN parameters used for this study are those agreed by ETSI:

–   average building attenuation towards EESS instruments: 17 dB;

–   active/passive ratio: 5%;

–   percentage of outdoor usage: 15%;

–   deployment scenarios: 1 200 systems for large office buildings, 250 systems for industrial sites.

For the spaceborne active sensors are taken from the SAR characteristics in Annex 1 of this Recommendation. The SAR4 type is taken as example for the analysis of the interference from HIPERLAN into SAR, but similar results can be obtained for the other types. SAR types 2-4 have been used for the analysis of the interference from SAR into HIPERLAN.

2.2   Sharing analysis (from WLAN into SAR)

The sharing analysis is given in Table 4 for the three cases considered: HIPERLAN type 1 (class B and class C) and type 2.

Given the expected HIPERLAN density (1 200 systems per large office building and 250 for industrial sites) the outdoor only or mixed indoor-outdoor cases do not represent a feasible sharing scenario for any of the three cases considered.

For the indoor use only, sharing is not feasible for the high power type 1 class C, while the type 1 class B and type 2 cases require further considerations.

In fact the 440 systems limit indicated in Table 4 for type 2 indoor only is per channel. Considering the DFS mechanism described above, one can make the hypothesis that the HIPERLAN type 2 systems can be spread across the 14 channels available, giving a theoretical upper limit of 6 160 systems within the 76.5 km^2 of the SAR footprint. Type 1 class B gives an upper limit of 5 208 systems.

TABLE 4

Permissible active HIPERLAN capacity in channels shared with SAR4

HIPERLAN type	Type 1/Class B		Type 1/Class C		Type 2	
Parameter	Value	dB	Value	dB	Value	dB
Max transmitted power (W)	0.1	−10	1	0	0.2	−7
TPC effect on average	Not available		Not available			−3
Distance (km) and free space loss	425.7	−159.5	425.7	−159.5	425.7	−159.5
Additional transmit path loss (dB): – Outdoor only – Indoor only – Mixed (15% outdoor)		0 −17 −7.8		0 −17 −7.8		0 −17 −7.8
Antenna gain, transmitter (dB)		0		0		0

TABLE 4 (*end*)

HIPERLAN type	Type 1/Class B		Type 1/Class C		Type 2	
Parameter	Value	dB	Value	dB	Value	dB
Antenna gain, receiver (dB)		42.7		42.7		42.7
Polarization loss (dB)		−3		−3		−3
SAR interference threshold ($I/N = -6$ dB), (dB(W/Hz))		−205.4		−205.4		−205.4
Power received (dB(W/channel)) (channel: 23.5 MHz type 1/16 MHz type 2): – Outdoor only – Indoor only – Mixed (15% outdoor)		−129.8 −146.8 −137.6		−119.8 −136.8 −127.6		−129.8 −146.8 −137.6
Power received (dB(W/Hz)): – Outdoor only – Indoor only – Mixed (15% outdoor)		−203.5 −220.5 −211.3		−193.5 −210.5 −201.3		−201.8 −218.8 −209.6
Margin dB/(Hz^{-1}): – Outdoor only – Indoor only – Mixed (15% outdoor)		−1.9 15.1 5.9		−11.9 5.1 −4.1		−3.6 13.4 4.2
SAR antenna footprint (km^2)	76.5	18.8	76.5	18.8	76.5	18.8
Permissible active HIPERLAN density (/km^2/ch): – Outdoor only – Indoor only – Mixed (15% outdoor)	0.0085 0.43 0.051	−20.7 −3.7 −12.9	0.00085 0.043 0.0051	−30.7 −13.7 −22.9	0.0058 0.29 0.034	−22.4 −5.4 −14.6
Active/passive ratio	5%	13	5%	13	5%	13
Permissible total (active + passive) HIPERLAN density (/km^2/ch): – Outdoor only – Indoor only – Mixed (15% outdoor)	0.17 8.51 1.02	−7.7 9.3 0.1	0.017 0.851 0.102	−17.7 −0.7 −9.9	0.11 5.75 0.69	−9.4 7.6 −1.6
Maximum number of active + passive HIPERLAN per channel within the SAR footprint (76.5 km^2): – Outdoor only – Indoor only – Mixed (15% outdoor)	13 651 78		1 65 8		8 440 53	

These values correspond to roughly five large office buildings in the 76.5 km^2 of the SAR footprint and, although far from being a worst case, can be considered a reasonable assumption for urban and suburban areas.

It can therefore be concluded that, although marginally, the two services can share the band when systems with the HIPERLAN type 2 or type 1 class B systems are deployed indoor.

The DFS mechanism will provide a uniform spread of the load across the available channels. If the channel selection is not based on a random choice, this hypothesis is likely to be incorrect and the conclusion needs to be revised.

2.3   Sharing analysis (from SARs into high speed WLANs)

The first step in analysing the interference potential from spaceborne SARs into high speed WLANs is to determine the signal power from a spaceborne SAR's side lobes onto the Earth's surface. For this analysis the median side lobe gain has been used since these side lobes give a substantially larger footprint than the peak gain and will result in a longer during interference. Next, the threshold of the high speed WLAN receiver is determined. Then, the interference margin can be calculated by comparing the SAR interference level with the LAN interference threshold. Table 5 shows the interference margin for the side lobes of SAR2-4 into wireless high speed local area networks with an outdoor deployment in the 5 250-5 350 MHz band. This Table shows a positive margin and would result in a positive sharing scenario.

TABLE 5

SAR side lobes to high speed WLANs

Parameter	SAR2		SAR3		SAR4	
	Value	dB	Value	dB	Value	dB
Transmitted power (W)	4 800.00	36.81	1 700.00	32.30	1 700.00	32.30
Antenna gain, transmitter (dB)	−5.00	−5.00	−5.00	−5.00	−5.00	−5.00
Antenna gain, receiver (dB)	0.00	0.00	0.00	0.00	0.00	0.00
Wavelength (m)	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96
$(4\pi)^{-2}$	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98
Distance (km)	638.51	−116.10	425.67	−112.58	425.67	−112.58
Bandwidth reduction (dB)	−12.87	−12.87	−12.87	−12.87	−3.98	−3.98
Power received (dBW)		−144.11		−145.09		−136.20
HIPERLANs interference threshold		−115.00		−115.00		−115.00
Margin (dB)		29.11		30.09		21.20

However, for SAR2-4, the peak antenna gains are 43-47.7 dB higher than the average side lobe levels of −5 dBi. Therefore for the duration of the flyover, which in the main beam of the SAR would be about 0.5-1.0 s, the SAR interference levels at the surface would be above the WLAN interference threshold worst case (HIPERLAN type 2: −115 dBW). This can be observed in Table 5 when looking at the margin which would become negative.

A more proper way to determine the maximum allowable interference level would be to take the *C/I* into account, which has to be greater than 15 dB. In case the RLAN transmitters are within 50 m of each other (worst-case scenario), this can raise the allowable interference level by 10 dB

(−105 dBW instead of −115 dBW). For SAR4 this analysis gives a worst case margin of −16.5 dB for outdoor equipment. Using indoor deployment of RLANs in this analysis (17 dB attenuation) would result in a marginally positive sharing scenario. The repeat period for the SAR is 8-10 days, although the SAR is not necessarily active for every repeat pass. Therefore, a given area on the Earth would be illuminated by a single SAR main beam no more often than 0.5-1.0 s every 8-10 days.

2.4 Conclusions

For the interference from WLANs to SAR, the analysis brings three main conclusions in the band 5 250-5 350 MHz:

–   WLANs used only indoor are compatible with the operation of SARs, while outdoor operation of WLANs does not give compatibility with the operation of SARs.

–   Indoor WLANs limited to a mean e.i.r.p.[1] of 200 mW (or 100 mW if TPC is not used) and mean e.i.r.p. density limit of 10 mW in any 1 MHz band are compatible with the operation of SARs.

–   In addition to the above, two features are needed in the WLAN systems to achieve compatibility with the operation of SARs:

    –   transmitter power control to ensure a mitigation factor of at least 3 dB; without the TPC feature, the mean e.i.r.p. should not exceed 100 mW in any 20 MHz channel;

    –   DFS associated with the channel selection mechanism required to provide a uniform spread of the loading of the WLAN channels across a minimum of 330 MHz.

The analysis of the interference from SARs into WLANs brings positive results considering indoor deployment.

3 Study of RLANs and SARs

3.1 Technical characteristics of typical high speed WLANs

The technical characteristics for typical high speed WLANs at 5.3 GHz are given herein for three configurations. These high speed WLANs are sometimes referred to as radio LANs or RLANs. The characteristics chosen in this analysis for the configurations are those which would result in the worst-case interference to a SAR receiver. The information on the first configuration, RLAN1, of high speed WLANs was taken from the FCC Report and Order FCC 97-7, 9 January 1997, and on the HIPERLANs from Document 7C/54, 18 September 1996. These characteristics are summarized in Table 6. The information on the second configuration RLAN2 of high speed WLANs was taken from the Space Frequency Coordination Group (SFCG)-18/45, 8-17 September 1998. The second

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[1]   The mean e.i.r.p. refers to the e.i.r.p. averaged over the transmission burst at the highest power control setting.

configuration, RLAN2, has a noticeable increase in high speed WLANs transmitter power, increase in the indoor/outdoor use ratio and resulting lower mean building attenuation, increase in the active/passive ratio, and increase in the anticipated deployment density. The information on the third configuration, RLAN3, of high speed WLANs was taken from the Space Frequency Coordination Group (SFCG)-19/39, 8-15 September 1999 and Document 7C/110 "Sharing constraints between spaceborne active sensors (SARs) and wireless high speed local area networks in the 5 250-5 350 MHz band", 17 February 1999. The third configuration, RLAN3, is restricted to indoor use only, with a medium anticipated deployment density.

TABLE 6

Technical characteristics of high speed WLANs at 5.3 GHz

Parameter	Value		
	RLAN1	**RLAN2**	**RLAN3**
Peak radiated power (W)	0.25	1.00	0.20
Deployment (%)	99 indoors/ 1 outdoors	85 indoors/ 15 outdoors	100 indoors/ 0 outdoors
Mean attenuation (dB)	17.0	7.8	17.0
Polarization	Random	Random	Random
Bandwidth (MHz)	23.6	23.6/channel (14 channels)	23.6/channel (14 channels)
Interference duty cycle into SAR (%)	100	100	100
Operational activity (active/passive ratio (%))	1	5	5
Mean density (transmitters/km^2)	12	1 200/office area (89 000/km^2/channel)	1 200/office area, 250/industrial area
Interference threshold (dBW)	−120	−120 (to be developed)	−100

3.2   Interference from high speed WLANs into SARs

The first step in analysing the interference potential from high speed WLANs into spaceborne SARs receivers is to determine the signal power from a single high speed WLAN transmitter at the spaceborne SAR. Then, the single interferer margin can be calculated by comparing the interference level with the SAR interference threshold. Knowing the SAR footprint, the allowable density of active high speed WLANs transmitters can then be calculated, using a conservative activity ratio for the fraction of transmitters operating at any one time.

3.2.1 Interference from a single RLAN transmitter located outdoors

Table 7 shows the interference from a single RLAN high speed WLAN transmitter in the 5 250-5 350 MHz band for SAR2-4. SAR1 was not used because this SAR1 system was designed to operate in the 5 150-5 250 MHz band. An omni antenna is assumed for RLAN1, RLAN2, and RLAN3. For SAR4, Table 7 shows negative margin for the RLAN1, RLAN2, and RLAN3 high speed WLAN transmitters. For SAR3, Table 7 shows a positive margin for the RLAN1 and RLAN3 transmitters, and negative margin for RLAN2. For SAR2, and interference from RLAN1, RLAN2, and RLAN3, there are positive margins for all three RLAN transmitters interference.

TABLE 7

Interference from a single outdoor RLAN transmitter to SARs

Parameter	SAR2		SAR3		SAR4	
	Value	dB	Value	dB	Value	dB
Transmitted power (W)						
RLAN1	0.25	−6.02	0.25	−6.02	0.25	−6.02
RLAN2	1.00	0.00	1.00	0.00	1.00	0.00
RLAN3	0.20	−6.99	0.20	−6.99	0.20	−6.99
Building attenuation (dB)		0.00		0.00		0.00
Antenna gain, transmit (dB)		0.00		0.00		0.00
Antenna gain, receiver (dB)		43.33		44.52		44.52
Polarization loss (dB)		−3.00		−3.00		−3.00
Wavelength (m)	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96
$(4\pi)^{-2}$	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98
Distance (km)	638.51	−116.10	425.67	−112.58	425.67	−112.58
Power received (dBW)						
RLAN1		−128.74		−124.03		−124.03
RLAN2		−122.72		−118.00		−118.00
RLAN3		−129.71		−124.99		−124.99
Noise figure (dB)		4.62		4.62		4.62
$k\,T$	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98
Receiver bandwidth (MHz)	356.50	85.52	356.50	85.52	46.00	76.63
Noise power (dBW)		−113.84		−113.84		−122.73
SAR interference threshold ($I/N = -6$ dB)		−119.84		−119.84		−128.73
Margin (dB)						
RLAN1		8.90		4.19		−4.71
RLAN2		2.88		−1.83		−10.73
RLAN3		9.87		5.16		−3.74

3.2.2   Interference from an indoor deployment of RLAN transmitters

Table 8 shows the allowable configuration RLAN1 high speed WLANs density in the 5 250-5 350 MHz band for SAR2-4. For SAR4, Table 8 shows the allowable density of RLAN1 high speed WLANs to be about 118 transmitters/km^2, below which the interference level to the 40 MHz SAR4 is acceptable. Using information on the anticipated HIPERLANs deployment density from Document 7C/54, 18 September 1996, the HIPERLANs mean density over Europe was estimated at that time to be 12 transmitters/km^2. It was expected that the density in metropolitan and densely inhabited areas would be higher than the mean. Table 9 shows the allowable density of configuration RLAN2 high speed WLANs in the 5 250-5 350 MHz band for SAR2-4. For SAR4, Table 9 shows the allowable RLAN2 high speed WLANs density to be about 0.2 transmitters/km^2, or equivalently 1 transmitter/5 km^2, below which the interference level to the 40 MHz SAR4 is acceptable. This low allowable density is to be compared with the anticipated deployment density from Document SFCG-18/45, 8-17 September 1998, of 1 200 transmitters/office area; there is also the indoor RLAN2 capacity of 89×10^3/km^2/channel, for separation distances of 0.5 m. The anticipated high density uses 14 channels, each 23.6 MHz wide, over 330 MHz band. Table 10 shows the allowable density of configuration RLAN3 high speed WLANs in the 5 250-5 350 MHz band for SAR2-4. For SAR4, Table 10 shows the allowable RLAN3 high speed WLANs density to be about 37 transmitters/km^2/channel, below which the interference level to the 40 MHz SAR4 is acceptable. The anticipated high density uses 14 channels, each 23.6 MHz wide, over 330 MHz band. For 14 channels, the allowable density is then 518 transmitters/km^2. This low allowable density is to be compared with the anticipated deployment density from Document 7C/110, of 1 200 transmitters/large office area and 250 transmitters/industrial sites. Thus, for SAR4, the allowable density would be that for less than one large office area and about two industrial areas, which seems to be unrealistic. For SAR2 and SAR4, the allowable density over 14 channels would be 4 270 and 3 990 transmitters, respectively. This would correspond to about three large office buildings or 15 industrial areas which may be a slightly more reasonable assumption for urban and suburban areas.

For imaging SARs with S/N 8 dB or higher, the I/N can be 0 dB and still not degrade the pixel power standard deviation more than 10%. This increases the allowable transmitter density by a factor of 4. For RLAN3 interference into SAR2 and SAR4, this would correspond to about 12 large office buildings or 60 industrial areas within the SAR footprint. However, for interferometric SARs, the I/N must be less than −6 dB, independent of the S/N.

TABLE 8

Interference from RLAN1 high speed WLANS to SARs

Parameter	SAR2		SAR3		SAR4	
	Value	dB	Value	dB	Value	dB
Transmitted power (W)	0.25	−6.02	0.25	−6.02	0.25	−6.02
Building attenuation (dB)		−17.00	17.00	−17.00	17.00	−17.00
Antenna gain, transmitter (dB)		0.00	0.00	0.00	0.00	0.00
Antenna gain, receiver (dB)		43.33	44.52	44.52	44.52	44.52
Polarization loss (dB)		−3.00	3.00	−3.00	3.00	−3.00
Wavelength (m)	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96
$(4\pi)^{-2}$	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98
Distance (km)	638.51	−116.10	425.67	−112.58	425.67	−112.58
Power received (dBW)		−145.74		−141.03		−141.03
Noise figure (dB)		4.62	4.62	4.62	4.62	4.62
$k\,T$	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98
Receiver bandwidth (MHz)	356.50	85.52	356.50	85.52	46.00	76.63
Noise power (dBW)		−113.84		−113.84		−122.73
SAR interference threshold ($I/N = -6$ dB)		−119.84		−119.84		−128.73
Margin (dB)		25.90		21.19		12.29
SAR footprint (km^2)	159.03	22.01	57.55	17.60	57.55	17.60
Mean surface power of HIPERLANs (dB(W/km^2))		3.88		3.59		−5.31
Active transmitter/km^2	9.78		9.14		1.18	
Active transmitter/km^2 at 1% activity ratio	978.40		913.56		117.88	

TABLE 9

Interference from RLAN2 high speed WLANS to SARs

Parameter	SAR2		SAR3		SAR4	
	Value	dB	Value	dB	Value	dB
Transmitted power (W)	1.00	0.00	1.00	0.00	1.00	0.00
Building attenuation (dB)		−7.80	7.80	−7.80	7.80	−7.80
Antenna gain, transmitter (dB)		0.00	0.00	0.00	0.00	0.00
Antenna gain, receiver (dB)		43.33	44.52	44.52	44.52	44.52
Polarization loss (dB)		−3.00	3.00	−3.00	3.00	−3.00
Wavelength (m)	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96	5.65×10^{-2}	−24.96
$(4\pi)^{-2}$	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98	6.33×10^{-3}	−21.98
Distance (km)	638.51	−116.10	425.67	−112.58	425.67	−112.58
Power received (dBW)		−130.52		−125.80		−125.80
Noise figure (dB)		4.62	4.62	4.62	4.62	4.62
$k\,T$	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98	4.00×10^{-21}	−203.98
Receiver bandwidth (MHz)	356.50	85.52	356.50	85.52	46.00	76.63
Noise power (dBW)		−113.84		−113.84		−122.73
SAR interference threshold ($I/N = −6$ dB)		−119.84		−119.84		−128.73
Margin (dB)		10.68		5.97		−2.93
SAR footprint (km²)	159.03	22.01	57.55	17.60	57.55	17.60
Mean surface power of HIPERLANs (dB(W/km²))		−11.34		−11.63		−20.53
Active transmitter/km²	0.07		0.07		0.01	
Active transmitter/km² at 5% activity ratio	1.47		1.37		0.18	

As far as a self-limiting density such that the surrounding high speed WLANs interfere unacceptably among themselves, for RLAN3, the high speed WLANs are assumed to occupy 14 channels, each 23.6 MHz wide, over a 330 MHz band, and the transmitters can be as close as 0.5 m, giving a possible density of 89×10^{3}/km²/channel over small areas corresponding to the large office area. The LAN receiver no longer requires the interference to be lower than −100 dBW, but that the C/I be greater than 20 dB. This allows the transmitters to operate within 0.5 m of each other without mutual self-interference.

TABLE 10

Interference from RLAN3 high speed WLANs to SARs

Parameter	SAR2		SAR3		SAR4	
	Value	dB	Value	dB	Value	dB
Transmitted power (W)	0.20	–6.99	0.20	–6.99	0.20	–6.99
Building attenuation (dB)		–17.00		–17.00		–17.00
Antenna gain, transmitter (dB)		0.00		0.00		0.00
Antenna gain, receiver (dB)		43.33		44.52		44.52
Polarization loss (dB)		–3.00		–3.00		–3.00
Wavelength (m)	5.65×10^{-2}	–24.96	5.65×10^{-2}	–24.96	5.65×10^{-2}	–24.96
$(4\pi)^{-2}$	6.33×10^{-3}	–21.98	6.33×10^{-3}	–21.98	6.33×10^{-3}	–21.98
Distance (km)	638.51	–116.10	425.67	–112.58	425.67	–112.58
Power received (dBW)		–146.71		–141.99		–141.99
Noise figure (dB)		4.62		4.62		4.62
$k\,T$	4.00×10^{-21}	–203.98	4.00×10^{-21}	–203.98	4.00×10^{-21}	–203.98
Receiver bandwidth (MHz)	356.50	85.52	356.50	85.52	46.00	76.63
Noise power (dBW)		–113.84		–113.84		–122.73
SAR interference threshold ($I/N = -6$ dB)		–119.84		–119.84		–128.73
Margin (dB)		26.87		22.16		13.26
SAR footprint (km^2)	159.03	22.01	57.55	17.60	57.55	17.60
Mean surface power of HIPERLANs (dB(W/km^2))		4.85		4.56		–4.34
Active transmitter/km^2/channel	15.29		14.27		1.84	
Active transmitter/km^2/channel at 5% activity ratio	305.75		285.49		36.84	

3.3 Interference from SARs into high speed WLANs

The first step in analysing the interference potential from spaceborne SARs into high speed WLANs is to determine the signal power from a spaceborne SAR onto the Earth's surface. Next, the threshold of the high speed WLAN receiver is determined. Then, the interference margin can be calculated by comparing the SAR interference level with the LAN interference threshold. For SAR1-4, the peak antenna gains are 40-50 dB higher than the average side lobe levels of –5 dBi. Therefore for the duration of the flyover, which in the main beam of the SAR would be about

0.5-1.0 s, the SAR interference levels at the surface would be well above the RLAN1 interference thresholds. However, for RLAN2, the level of –120 dBW is no longer the maximum allowable interference level, but rather that C/I be greater than 20 dB, which in the case of transmitters within 0.5 m of each other, can raise the allowable interference level by 50-80 dB.

The situation for RLAN3 is similar to that for RLAN2. For these typical SAR2-4, the peak antenna gains are 14-38 dB higher than the average side lobe levels of –5 dBi. Therefore for the duration of the flyover, which in the main beam of the SAR would be about 0.5-1.0 s, the SAR interference levels at the surface would be well above the RLAN3 interference thresholds. However, for RLAN3, the level of –120 dBW is no longer the maximum allowable interference level, but rather that C/I be greater than 20 dB, which in the case of transmitters within 0.5 m of each other, can raise the allowable interference level by 50-80 dB. The repeat period for the SAR is 8-10 days, although the SAR is not necessarily active for every repeat pass. Therefore, a given area on the Earth would be illuminated by the SAR beam no more often than 0.5-1.0 s every 8-10 days.

3.4   Conclusion

The potential interference between one configuration RLAN3 of high speed WLANs and spaceborne synthetic aperture radars in the band 5 250-5 350 MHz was analysed in this Recommendation for 1) a single RLAN1-3 transmitter deployed outdoors and 2) a density of RLAN3 indoors deployment. For the single transmitter deployed outdoors, the RLAN1 high speed WLAN transmitter interference was above the acceptable level for SAR4, the RLAN2 high speed WLAN transmitter interference was above the acceptable levels for both SAR3 and SAR4, and the RLAN3 high speed WLAN transmitter interference was above the acceptable level for SAR4.

For interference from the RLAN1 configuration of high speed WLANs to the SARs, the analysis shows that any surface density less than 32-128 transmitters/km^2 will yield acceptable interference levels into the SAR, depending on the imaging SAR pixel S/N. The anticipated mean density over Europe was in the past estimated to be only 12 transmitters/km^2. At a density of 0.32 active transmitters/km^2 (density of 32 active transmitters/km^2 with a 1% activity ratio) a typical high speed WLAN (0.25 W transmitter power) deployed outdoors will experience self-interference levels of –120 dBW, a level which the RLAN1 high speed WLANs hold as their interference threshold. For interference from the RLAN2 configuration of high speed WLANs to the SARs, the analysis shows that only for a surface density less than 0.2-1.5 transmitters/km^2 will LANs yield acceptable interference levels into the SAR, depending on the imaging SAR pixel S/N. The current anticipated mean density is 1 200 transmitters/office area, up to about 89×10^3/km^2/channel. The anticipated high density assumes 14 channels, each 23.6 MHz wide, over a 330 MHz band. For an indoor deployment and considering the interference from the RLAN3 configuration of high speed WLANs to the SARs, the analysis shows that any surface density less than 37-305 transmitters/km^2/channel will yield acceptable interference levels into the SAR, depending on the imaging SAR pixel S/N for an imaging SAR. The anticipated mean density is estimated to 1 200 transmitter/large office area and 250 transmitters/industrial area. The anticipated high density assumes 14 channels, each 23.6 MHz wide, over a 330 MHz band. For interference from the RLAN3 configuration of high

speed WLANs to the SARs, the analysis shows that only for a surface density less than 518 to 4 270 transmitters/km^2 over 14 channels, will LANs yield acceptable interference levels into the SAR. For RLAN3 interference into SAR2 and SAR4, this would correspond to about 3 to 12 large office buildings or 15 to 60 industrial areas within the SAR footprint, depending on the SAR pixel *S/N*.

For interference from the spaceborne SARs into RLAN1 high speed WLANs in the 5 250-5 350 MHz band, the SAR interference levels at the surface for side lobes are 14-38 dB lower than the LAN interference threshold. For SARs peak antenna interference over the duration of the flyover, which in the main beam of the SAR would be about 0.5-1.0 s, the SAR interference levels at the surface would be well above the RLAN1 interference thresholds by 10-30 dB. However, for RLAN2 and RLAN3, the levels of −120 dBW and −100 dBW, respectively, are no longer the maximum allowable interference levels, but rather that *C/I* be greater than 20 dB, which in the case of transmitters within 0.5 m of each other, can raise the allowable interference level by 50-80 dB, so that the SAR even in the mainbeam may be below the LANs interference threshold. Since the repeat period for the SAR is 8-10 days, and the SAR is not necessarily active for every repeat pass, a given area on the Earth would be illuminated by the SAR beam no more often than 0.5-1.0 s every 8-10 days.

4 Study of RLANs and altimeters

4.1 Interference from RLANs into altimeters

For this analysis, we consider one RLAN of the HIPERLAN type in the altimeter main lobe.

The altimeter has an extended bandwidth of 320 MHz, while the HIPERLANs have a channel bandwidth ranging from 16 MHz (type 2) to 23.5 MHz (type 1) included within the altimeter bandwidth. The maximum HIPERLAN transmitted e.i.r.p. ($P_h G_h$) is 30 dBm (type 1) or 23 dBm (type 2). The altimeter antenna gain, G_0, is 32.2 dB, G_a is the off-axis antenna gain towards the HIPERLAN, with additional 1 dB input loss L. The altimeter is nadir pointing, antenna size is 1.2 m. R is the range of the altimeter from the HIPERLAN.

The power received by the altimeter from one HIPERLAN in the boresight of the SAR (i.e. $G_a = G_0$) is:

$$P_r = \frac{P_h G_h G_a \lambda^2}{(4\pi)^2 R^2 L} \qquad (1)$$

Taking the more critical HIPERLAN type 1 parameters (given in § 2.2), we obtain a value for P_r of −108.3 dBm.

The altimeter interference threshold is −88 dBm; we can thus deduce that the altimeter can withstand the operation of a number of HIPERLANs simultaneously, since we have a 20.3 dB margin. Furthermore, the altimeter is built to provide measurements mainly over oceans and is not able to provide accurate data when a significant amount of land is in view of its antenna beam. From this analysis, it is clear that the altimeter will not suffer from the operation of HIPERLANs.

For completeness, the number of HIPERLANs in the −3 dB footprint that can be tolerated by the altimeter operating over land can be calculated. The methodology is described in § 4.1.1 of this Recommendation.

We obtain a range from 586 (outdoor use) to 4 664 (indoor use) HIPERLANs installed as a limit not to interfere into the altimeter. Extra margins remain in the fact that:

–   No polarization loss or additional propagation losses have been taken into account (about 3 dB).

–   Mitigation techniques such as transmitter power control are not considered (which is expected to provide at least 3 dB margin).

–   The gain of the altimeter in the direction of HIPERLAN devices was overestimated in the simulation.

In addition it is expected that typically only HIPERLAN type 2 systems will be deployed in the frequency range used by the altimeters, improving therefore the situation thanks to the lower maximum e.i.r.p. (200 mW).

We can thus conclude that the altimeter will not suffer from interference from HIPERLANs when used over oceans. However, if it were to be operated over land the situation is marginal dependant on the final choice of parameters for the HIPERLAN. The expected margin may allow sharing even when altimeters are operating close to the land. Indoor-only and type 2-only HIPERLAN operation would strongly improve the sharing environment.

4.1.1   Estimation of the number of RLANs in the –3 dB footprint of an altimeter

For this analysis, we consider one HIPERLAN type 1 in the altimeter main lobe.

The altimeter has an extended bandwidth of 320 MHz, while the HIPERLANs have a 23.5 MHz bandwidth included within the altimeter bandwidth. The maximum HIPERLAN transmitted e.i.r.p. ($P_h G_h$) is 30 dBm. The altimeter antenna gain, G_0 is 32.2 dB, G_a is the off-axis antenna gain towards the HIPERLAN, with additional 1 dB input loss L. The altimeter is nadir pointing, antenna size is 1.2 m. R is the range of the altimeter from the HIPERLAN.

The power received by the altimeter from one HIPERLAN in the boresight of the SAR (i.e. $G_a = G_0$) is:

$$P_r = \frac{P_h G_h G_a \lambda^2}{(4\pi)^2 R^2 L} \tag{2}$$

From this we obtain a value for P_r of −108.3 dBm.

The altimeter interference threshold is −88 dBm; we can thus deduce that the altimeter can withstand the operation of a number of HIPERLANs simultaneously, since we have a 20.3 dB margin. Furthermore, the altimeter is built to provide measurements mainly over oceans and is not able to provide accurate data when a significant amount of land is in view of its antenna beam. From this analysis, it is clear that the altimeter will not suffer from the operation of HIPERLANs.

For completeness, the number of HIPERLANs in the −3 dB footprint that can be tolerated by the altimeter operating over land can be calculated; the computation is not straightforward since with a small change in the angle φ from altimeter boresight, the distance to ground, the gain and the surface element intercepted at ground level will vary.

Assuming a certain density of HIPERLAN devices, i.e. D, then the total number of HIPERLAN devices seen by a satellite (assuming the devices are evenly distributed over the Earth's surface) is given by $N = D \times A$, where A is the −3 dB footprint of the altimeter. Since the devices are not equidistant to the satellite, the visible Earth's surface is divided into concentric surface strips (as in Fig. 1), so that one can assume that all of the HIPERLAN devices within the i-th surface strip are at the same distance, d_i, to the satellite, and are seen with the same nadir angle, φ_i, and the same elevation angle, ε_i. The number of HIPERLAN devices within the i-th strip is given by:

$$N_i = A_i \times (N/A) = A_i \times D \tag{3}$$

where:

$$A_i = 2\pi\, R_e^2 \times [\cos(\theta_{i-1}) - \cos(\theta_i)] \qquad \text{for } \theta_i > \theta_{i-1} \tag{4}$$

FIGURE 1

Geometry for aggregating the interference

1632-01
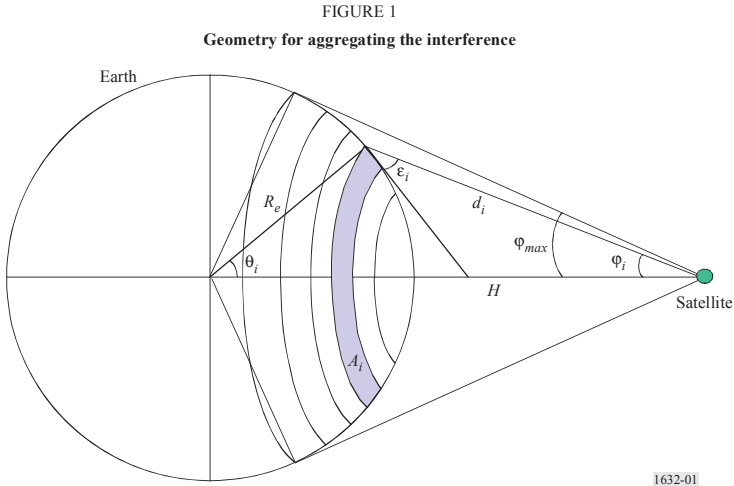
The aggregate HIPERLAN interference power, I, at the altimeter is therefore given by summation of the i-th component I_i as below:

$$I(\text{W}) = \sum_i I_i = \sum_i N_i \cdot \frac{\text{le}\,(e.i.r.p./10)}{(4\,\pi\,d_i\,f_0\,/\,c)^2} \cdot G(\varphi_i) \tag{5}$$

where:

$e.i.r.p.$: effective isotropic radiated power (dBW)

d_i: distance between the satellite and interferer on the Earth

f_0: RF centre frequency

$G(\varphi_i)$: satellite altimeter antenna receive gain which depends on the nadir angle φ_i, i.e. the angle between the sub-satellite point and the considered strip.

For this, a numerical computation has been done: a constant HIPERLAN power density at ground level per square metre has been assumed, and an antenna gain of the altimeter varying as $G_a = G_0 (\sin(\varphi)/\varphi)^2$, φ being the angle between the vertical and the direction satellite to HIPERLAN, which is a worst case since the altimeter lobe will be much lower than this.

The integral of the received power at the altimeter level in the –3 dB footprint was then computed: the mean power acceptable by the altimeter is –60 dBm/m^2, or 0 dBm/km^2 ($D \times e.i.r.p.$).

Since the altimeters are nadir pointing an additional pathloss of 20 dB (due to roof and ceiling attenuation) is included when calculating the interference from indoor HIPERLANs. When considering the case of HIPERLANs which are restricted to indoor operation, it is assumed that at any given time 1% of the HIPERLAN devices will be operating outdoors – leading to an overall additional attenuation factor of 17 dB. For HIPERLANs which are permitted to operate outside, it is assumed that 15% of devices are outdoors at a given time – giving an additional attenuation factor of 8 dB. For both cases it is assumed that 5% of HIPERLANs will be transmitting at once.

TABLE 11

Calculation of number of terminals in –3 dB footprint

	Indoor	**Outdoor**
Power density ($D \times e.i.r.p.$) (dBm/km^2)	0	0
e.i.r.p. (dBm)	30	30
Percentage of HIPERLAN operating outdoor (%)	1	15
Additional margin (dB)	17	8
Active terminals/km^2	0.05	0.063
Active terminals (%)	5	5
Number of terminals/km^2	1.002	0.126
Number of terminals in the –3 dB footprint	4 664	586

We then obtain a range from 586 (outdoor use) to 4 664 (indoor use) HIPERLANs installed in the −3 dB footprint as a limit not to interfere into the altimeter.

4.2 Interference from altimeters into RLANs

In this case we consider a bandwidth reduction factor B_h/B_a, since the altimeter bandwidth B_a is much larger than the HIPERLANs bandwidth B_h. B_a has a value of 320 MHz and B_h is 23.5 MHz (type 1, worst case) or 16 MHz (type 2), hence a reduction factor of 11.34 dB is obtained for type 1 and of 13 dB for type 2. The HIPERLAN antenna gain G_h towards the vertical direction is 0 dB.

The power received by one HIPERLAN from the altimeter is:

$$P_r = \frac{P_a G_a G_h \lambda^2 B_h}{(4\pi)^2 R^2 L B_a}$$

(6)

The power transmitted by the altimeter into the HIPERLAN will then be, at the worst case (e.g. main beam of the altimeter, closest distance 1 347 km, outdoor HIPERLAN type 1), −103.64 dBm.

This case (altimeter main beam into HIPERLAN side lobes at the vertical) has to be considered as a worst case, since altimeter lobes decrease very quickly with boresight angle (they are at a −20 dB level 4° from nadir, and −40 dB 15° from nadir).

The calculation above produces a margin of 10 dB for the most critical case (type 1); it is therefore concluded that the altimeter will not interfere into HIPERLANs. The situation improves further in case of indoor HIPERLAN type 2 operation. Furthermore the altimeter is a pulsed radar; the low duty cycle, polarization and additional propagation losses, which provide additional margins, have not been taken into account.

4.3 Conclusion

It is concluded that radar altimeter operation with a 320 MHz bandwidth around 5.3 GHz is compatible with RLANs. Better margins are achieved with RLAN systems with characteristics similar to HIPERLAN type 2. These RLANs are expected to be the type typically deployed in the altimeter band. It is likely that sharing between RLANs and altimeters will also be feasible in the band above 5 460 MHz.

5   Study of RLANs and scatterometers

Nowadays, scatterometers are more often used for land applications and in the near future and with increasing resolution of these instruments even more applications of scatterometer systems above land are foreseen. This interference analysis therefore does not only restrict itself to the coastal areas, but can be seen on a global basis.

5.1   Interference from RLANs into scatterometers

In scatterometer systems, an estimate of the echo return signal power is made by first measuring the "signal + noise" power (i.e. the echo return plus the system noise contribution), and then subtracting the "noise-only" power (an estimate of the system noise alone, or "noise floor"). To optimize system performance, the "signal + noise" and the "noise-only" measurements are made over different bandwidths and/or different times. This strategy relies on the fact that the nominal system noise is inherently white during the measurement sequence (stationary, and with a flat spectral power distribution).

From the above situation, two different interference scenarios can be envisaged. One where the interference is a constantly present in the measurement sequence, i.e. white CW noise, and one where the interference is present in only one of both measurements, due to satellite motion (displacement of the footprint of one of the fan-beam antennas) or discontinuities in the signal of the interferer. This can also be dependent on the measurement techniques used in the scatterometer systems under consideration.

A wind speed of 3 m/s has been identified as the minimum performance criterion for scatterometers. For this wind speed, the amount of back-scattered signal is the smallest and thus is most sensitive to noise or interference. The estimated error that results from this second interference scenario can be described using a parametric value α that has a typical value for fan-beam antennas ($\alpha = 0.7$ dB) and is given as (Recommendation ITU-R RS.1166).

$$\alpha(\text{dB}) = 10 \log\{[N + (I_{s+n}/B_{s+n})] / [N + (I_n/B_n)]\} \qquad (7)$$

where:

N: nominal noise floor power density (approximately -201 dB(W/Hz) at the scatterometer receiver input for fan-beam antennas)

B_{s+n}:   "signal + noise" measurement bandwidth

B_n: "noise-only" measurement bandwidth

I_{s+n}:   average power from interfering source in B_{s+n} during the "signal + noise" measurement period

I_n: average power from interfering source in B_s during the "noise-only" measurement period.

Figure 2 is a plot of equation (1) for a scatterometer with a receiver noise floor of $N = -201$ dB(W/Hz). It shows α as a function of the power spectral density of the interfering signal I_{s+n}/B_{s+n}. Due to the narrow beamwidth of the fan-beam, changes of several dB in received interference levels should be expected as the scatterometer side lobes move through a transmitter beam. Engineering judgement has led to a value of 6 dB as the assumed maximum expected change in $10 \log [(I_{s+n}/B_{s+n})/(I_n/B_n)]$ during the measurement period. From Fig. 2, it is therefore concluded that the maximum interference power spectral density that any of the fan-beam antennas of the scatterometer can sustain without degraded measurement accuracy is -207 dB(W/Hz).

FIGURE 2
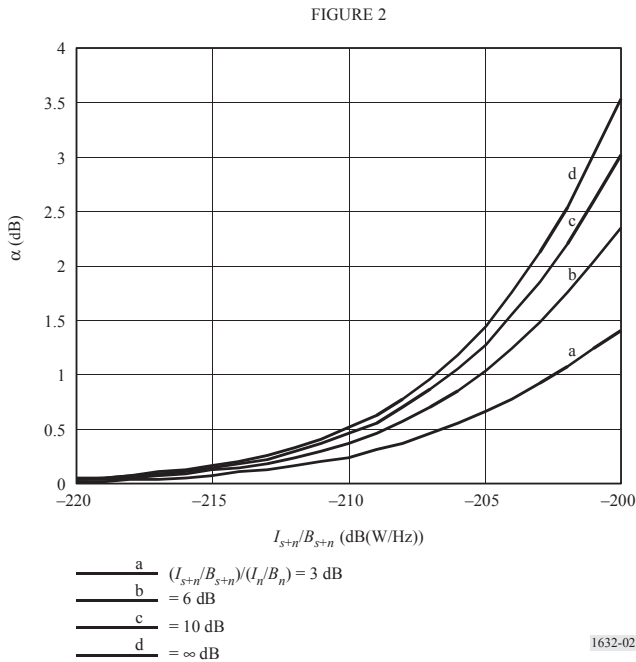
For CW white-noise like interference, the maximum acceptable interference spectral power density would be approximately -195 dB(W/Hz) at the input of the receiver.

The RLAN used in this sharing analysis is the HIPERLAN type 2 standard (parameters given in § 2.2). The most stringent acceptable interference level into the receiver of the scatterometer is −207 dB(W/Hz). For Scatterometer 1, an antenna gain of 31 dBi at 650 km across track distance has been used, which corresponds to a free-space loss of 167.3 dB.

The power received by the scatterometer from one HIPERLAN can be written as:

$$(P_r)\text{dB} = (P_h)\text{dB} - LFS + (G_s)\text{dB} - 3 \tag{8}$$

From this we obtain a value for P_r of −149.3 dB over a 16 MHz bandwidth, which corresponds to −221.3 dB(W/Hz). This gives a 14.3 dB margin. From this can be concluded that the interference from one HIPERLAN/2 into the receiver of a scatterometer does not cause harmful interference. Furthermore, as shown in Table 12, scatterometers are compatible with high density RLAN deployments, in particular when RLANs are deployed indoor.

TABLE 12

Permissible active HIPERLAN/2 capacity shared with Scatterometer 1

Sort of deployment	Outdoor only	Indoor only	Mixed (15% outdoor)
Transmitted power (dBW)	−10	−10	−10
Free space loss (dB)	−167.3	−167.3	−167.3
Antenna gain, receiver (dBi)	31	31	31
Polarization loss (dB)	−3	−3	−3
Additional path loss (dB)	0	−17	−7.8
Power received (dB(W/channel))	−149.3	−166.3	−157.1
Power received (dB(W/Hz))	−221.3	−238.3	−229.1
Scatterometer interference threshold	−207	−207	−207
Margin (dB/Hz)	14.3	31.3	22.1
Active/passive ratio (5%)	13	13	13
Permissible total of active + passive RLANs/km^2 (dB)	27.3	44.3	35.1

5.2   Interference from scatterometers into RLANs

In this case we consider interference from Scatterometer 1 into HIPERLAN type 2. Since this type of RLAN has dynamic frequency selection and the fact that the bandwidth of the scatterometer is relatively small, the scenario given here will only consider one of the side lobes of the scatterometer into one HIPERLAN. The peak power for this scatterometer system is 4.8 kW and again a side lobe value of 26 dBi has been used for this analysis.

The power received by one HIPERLAN from Scatterometer 1 is approximately –106.5 dB which is above the interference threshold of the HIPERLAN or the so-called minimum useful receiver sensitivity of –115 dB. Additional input or polarization losses have not been taken into account in this analysis, but these values will not change the result dramatically (in the order of a few dB). When the scatterometer flies over, the time a RLAN system is in view of one of the scatterometer's antenna side lobes typically is several seconds. Since this type of scatterometer uses several fanbeam antennas, the total interference time when the satellite passes over could even be around 20 s. As mentioned before, these HIPERLAN type 2 systems use dynamic frequency selection, which permits them to switch to another channel before actually transmitting data. This is therefore considered a useful tool to mitigate the interference problem.

A more proper way to determine the maximum allowable interference level would be to take the C/I into account, which has to be greater than 15 dB. In case the transmitters are within 50 m of each other (worst-case scenario), this can raise the allowable interference level by 10 dB (–105 dBW instead of –115 dBW). For Scatterometer 1 this analysis gives a positive margin of 1.5 dB for outdoor equipment. Using indoor deployment of RLANs in this analysis would give a better margin (18.5 dB).

TABLE 13

Scatterometer 1 to high speed WLANs

Parameter	Value	dB
Transmitted power (W)	4 800.00	36.81
Transmit path loss (dB)	0.00	0.00
Antenna gain, transmitter (dB)	26.00	26.00
Antenna gain, receiver (dB)	0.00	0.00
Wavelength (m)	5.65×10^{-2}	–24.96
$(4\pi)^{-2}$	6.33×10^{-3}	–21.98
Distance (km)	1 314.03	–122.37
Bandwidth reduction (dB)	0.00	0.00
Power received (dBW)		–106.50
HIPERLANs interference threshold		–115.00
Margin (dB) (outdoor)		–8.50
Building attenuation (dB)		17
Margin (dB) (indoor)		8.50

5.3 Conclusion

It is concluded that scatterometer operation around 5.3 GHz is compatible with RLANs in the same band. It is foreseen that in the operation of scatterometers, they do not get substantial interference from RLANs. For the interference from scatterometers into RLANs the study indicates that sharing is feasible for the indoor use of RLANs. It is noted that some RLANs with the characteristics of the HIPERLAN type 2 standard are planned to be equipped with DFS, i.e. dynamic frequency selection. These systems will have a lower chance of getting interference from scatterometer systems when operated outdoor.

6   Global conclusions about compatibility

From the sharing analysis contained in this Recommendation for typical spaceborne active sensors operating in the band 5 250-5 350 MHz and high speed WLANs proposed to be deployed in the same band, it could be globally concluded that the two services are compatible given certain RLAN characteristics:

–   Indoor deployment (giving an attenuation of 17 dB with respect to outdoor systems).

–   Mean e.i.r.p.[2] limit of 200 mW (or 100 mW if TPC is not used) and mean e.i.r.p. density limit of 10 mW in any 1 MHz band.

–   TPC function to ensure a mitigation factor of at least 3 dB.

–   Randomized channel selection function such as DFS function associated with the channel selection mechanism required to provide a uniform spread of the loading of the WLAN channels across the whole bandwidth available in the 5 GHz range (the assumptions made in the study for a total of 330 MHz give a density of 440 transmitters over a 20 MHz channel in the SAR footprint).

———————

[2]   The mean e.i.r.p. refers to the e.i.r.p. averaged over the transmission burst at the highest power control setting.

RECOMMENDATION ITU-R M.1638

Characteristics of and protection criteria for sharing studies for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz

(2003)

Summary

This Recommendation describes the technical and operational characteristics of, and protection criteria for, radars operating in the frequency band 5 250-5 850 MHz. These characteristics are intended for use when assessing the compatibility of these systems with other services.

The ITU Radiocommunication Assembly,

considering

a)   that antenna, signal propagation, target detection, and large necessary bandwidth characteristics of radar to achieve their functions are optimum in certain frequency bands;

b)   that the technical characteristics of radiolocation, radionavigation and meteorological radars are determined by the mission of the system and vary widely even within a band;

c)   that the radionavigation service is a safety service as specified by No. 4.10 of the Radio Regulations (RR) and requires special measures to ensure its freedom from harmful interference;

d)   that considerable radiolocation and radionavigation spectrum allocations (amounting to about 1 GHz) have been removed or downgraded since WARC-79;

e)   that some ITU-R technical groups are considering the potential for the introduction of new types of systems (e.g. fixed wireless access and high density fixed and mobile systems) or services in bands between 420 MHz and 34 GHz used by radionavigation, radiolocation and meteorological radars;

f)   that representative technical and operational characteristics of radiolocation, radio-navigation and meteorological radars are required to determine the feasibility of introducing new types of systems into frequency bands in which the latter are operated;

g)   that procedures and methodologies to analyse compatibility between radars and systems in other services are provided in Recommendation ITU-R M.1461;

h)   that radiolocation, radionavigation and meteorological radars operate in the bands between 5 250-5 850 MHz;

j)   that ground-based radars used for meteorological purposes are authorized to operate in the band 5 600-5 650 MHz on a basis of equality with stations in the aeronautical radionavigation service (ARNS) (see RR No. 5.452),

recommends

1   that the technical and operational characteristics of the radiolocation, radionavigation and meteorological radars described in Annex 1 be considered representative of those operating in the frequency bands between 5 250 and 5 850 MHz (see Note 1);

2   that Recommendation ITU-R M.1461 be used as a guideline in analysing compatibility between radiolocation, radionavigation and meteorological radars with systems in other services; that the criterion of interfering signal power to radar receiver noise power level I/N, of −6 dB be used as the required protection trigger level for the radiodetermination sharing studies with other services. This protection criterion represents the net protection level if multiple interferers are present.

NOTE 1 – Recommendation ITU-R M.1313 should be used with regard to the characteristics of maritime radionavigation radars in the frequency band 5 470-5 650 MHz.

Annex 1

Characteristics of radiolocation, aeronautical radionavigation and meteorological radars

1   Introduction

The bands between 5 250 and 5 850 MHz are allocated to the ARNS and radiolocation service on a primary basis as shown in Table 1. Ground-based radars used for meteorological purposes are authorized to operate in 5 600-5 650 MHz on a basis of equality with stations in the maritime radionavigation service (see RR No. 5.452).

TABLE 1

Band (MHz)	Allocation
5 250-5 255	Radiolocation
5 255-5 350	Radiolocation
5 350-5 460	Aeronautical radionavigation
5 460-5 470	Radiolocation
5 470-5 650	Maritime radionavigation[1]
5 650-5 725	Radiolocation
5 725-5 850	Radiolocation

[1]   In accordance with RR No. 5.452, between 5 600 and 5 650 MHz, ground-based radars for meteorological purposes are authorized to operate on a basis of equality with stations in the maritime radionavigation service.

The radiolocation radars perform a variety of functions, such as:

–   tracking space launch vehicles and aeronautical vehicles undergoing developmental and operational testing;

–   sea and air surveillance;

–   environmental measurements (e.g. study of ocean water cycles and weather phenomena such as hurricanes);

–   Earth imaging; and

–   national defence and multinational peacekeeping.

The aeronautical radionavigation radars are used primarily for airborne weather avoidance and windshear detection, and perform a safety service (see RR No. 4.10).

The meteorological radars are used for detection of severe weather elements such as tornadoes, hurricanes and violent thunderstorms. These weather radars also provide the quantitative area precipitation measurements so important in hydrologic forecasting of potential flooding. This information is used to provide warnings to the public and it therefore provides a safety-of-life service.

Recommendation ITU-R M.1313 contains the characteristics of maritime radionavigation radars in the frequency band 5 470-5 650 MHz.

2   Technical characteristics

The bands between 5 250 and 5 850 MHz are used by many different types of radars on land-based fixed, shipborne, airborne, and transportable platforms. Tables 2 and 3 contain technical characteristics of representative systems deployed in these bands. This information is generally sufficient for general calculations to assess the compatibility between these radars and other systems.

However, these Tables do not contain characteristics of frequency-hopping radars which are operating in this frequency range. Frequency hopping is one of the most common Electronic-Counter-Counter-Measures (ECCM). Radar systems that are designed to operate in hostile electronic attack environments use frequency hopping as one of its ECCM techniques. This type of radar typically divides its allocated frequency band into channels. The radar then randomly selects a channel from all available channels for transmission. This random occupation of a channel can occur on a per beam position basis where many pulses on the same channel are transmitted, or on a per pulse basis. This important aspect of radar systems should be considered and the potential impact of frequency hopping radars should be taken into account in sharing studies.

TABLE 2

Characteristics of aeronautical radionavigation and meteorological radar systems

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I	Radar J
Function	Meteorological	Meteorological	Meteorological	Aeronautical radionavigation	Meteorological	Meteorological	Meteorological	Meteorological	Meteorological	Meteorological
Platform type (airborne, shipborne, ground)	Ground/ship	Airborne	Ground	Airborne	Ground	Ground	Ground	Ground	Ground	Ground
Tuning range (MHz)	5 300-5 700	5 370	5 600-5 650	5 440	5 600-5 650	5 300-5 700	5 600-5 650	5 600-5 650	5 600-5 650	5 250-5 725
Modulation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Conventional	With Doppler capability	With Doppler capability
Tx power into antenna	250 kW peak 125 W avg.	70 kW peak	250 kW peak 1 500 W avg.	200 W peak	250 kW peak	250 kW peak	250 kW peak	250 kW peak 150 W avg.	250 kW peak 150 W avg.	2.25 kW peak
Pulse width (μs)	2.0	6.0	0.05-18	1-20	1.1	0.8-2.0	3.0	0.8-5	0.8-5	0.1
Pulse rise/fall time (μs)	0.2	0.6	0.005	0.1	0.11	0.08	0.3	0.2-2	0.2-2	0.005
Pulse repetition rate (pps)	50, 250 and 1 200	200	0-4 000	180-1 440	2 000	250-1 180	259	250-1 200	50-1 200	100 000
Output device	Coaxial magnetron	Coaxial magnetron	Klystron	Magnetron	Klystron	Tunable magnetron	Coaxial magnetron	Coaxial magnetron or Klystron	Coaxial magnetron	Coaxial magnetron
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Conical	Fan	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Solid metal parabolic	Parabolic	Parabolic	Slotted array	Parabolic	Parabolic	Solid parabolic	Solid parabolic	Solid parabolic	Solid parabolic
Antenna polarization	Vertical	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal and/or vertical	Horizontal or vertical	Horizontal or vertical
Antenna main beam gain (dBi)	39	37.5	44	34	50	40	40	40-50	40-50	35-45

TABLE 2 (*end*)

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I	Radar J
Antenna elevation beamwidth (degrees)	4.8	4.1	0.95	3.5	< 0.55	< 1.0	1.65	0.5-2	0.5-2	2.4-12
Antenna azimuthal beamwidth (degrees)	0.65	1.1	0.95	3.5	< 0.55	< 1.0	1.65	0.5-2	0.5-2	1.5-12
Antenna horizontal scan rate (degrees/s)	0.65	24	0-36 (0-6 rpm)	20	21-24	30-48	30-48	6-18 (1-3 rpm)	6-18 (1-3 rpm)	1.2
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (degrees)	360	180 Sector	360	Continuous	Continuous 360 Sector	360	360	360	360	360
Antenna vertical scan rate (degrees/s)	N/A	N/A	N/A	45	15	15	15	1-10	1-14	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A	N/A	N/A	Sector	Stepwise, 0.5-60	Stepwise, -2 to +60	-1 to +60	-1 to +90	-5 to +90	N/A
Antenna side-lobe (SL) levels (1st SLs and remote SLs) (dB)	-26	-20	-35	-31	-27	-25	-25	-25 to -35	-25 to -35	-20
Antenna height (m)	30	Aircraft altitude	10	Aircraft altitude	30	30	30	6-30	6-30	10
Receiver IF 3 dB bandwidth (MHz)	0.5	0.6	20	1.0	0.91	0.6	0.25 to 0.5	0.7 to 4	0.1 to 3.0	10
Receiver noise figure (dB)	7	6	4	5	2.3	3	3	3.5-8	1.5-8	3
Minimum discernable signal (dBm)	-110	-106	-97	-109	-109	-109 to -112	-114	-113 to -120	-113 to -120	-113 to -118

TABLE 3

Characteristics of radiolocation systems

Characteristics	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q	Radar R	Radar S
Function	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search	Research and Earth imaging	Search
Platform type (airborne, shipborne, ground)	Ground	Ground	Ground	Ground	Ground	Ship	Ship	Airborne	Airborne
Tuning range (MHz)	5 300	5 350-5 850	5 350-5 850	5 400-5 900	5 400-5 900	5 300	5 450-5 825	5 300	5 250-5 725
Modulation	N/A	None	None	Pulse/chirp pulse	Chirp pulse	Linear FM	None	Non-linear/ linear FM	CW pulse
Tx power into antenna	250 kW	2.8 MW	1.2 MW	1.0 MW	165 kW	360 kW	285 kW	1 or 16 kW	100-400 W
Pulse width (µs)	1.0	0.25, 1.0, 5.0	0.25, 0.5, 1.0	0.25-1 (plain) 3.1-50 (chirp)	100	20.0	0.1/0.25/1.0	7 or 8	1.0
Pulse rise/fall time (µs)	0.1/0.2	0.02-0.5	0.02-0.05	0.02-0.1	0.5	0.5	0.03/0.05/0.1	0.5	0.05
Pulse repetition rate (pps)	3 000	160, 640	160, 640	20-1 280	320	500	2 400/1 200/ 750	1 000-4 000	200-1 500
Chirp bandwidth (MHz)	N/A	N/A	N/A	4.0	8.33	1.5	N/A	62, 124	N/A
RF emission bandwidth –3 dB (MHz)	4.0	0.5-5	0.9-3.6	0.9-3.6	8.33	1.5	5.0/4.0/1.2	62, 124	4.0
RF emission bandwidth –20 dB (MHz)	10.0		6.4-18	6.4-18	9.9	1.8	16.5/12.5/7.0	65, 130	10.0
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil	Pencil	Pencil	Pencil	Cosecant-squared	Fan	Fan	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic reflector	Parabolic	Parabolic	Phased array	Phased array	Parabolic	Travelling wave feed horn array	Two dual polarized horns on single pedestal	Slotted array

TABLE 3 (*end*)

Characteristics	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q	Radar R	Radar S
Antenna polarization	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Horizontal	Horizontal	Horizontal and vertical	Circular
Antenna main beam gain (dBi)	38.3	54	47	45.9	42	28.0	30.0	26	30-40
Antenna elevation beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	24.8	28.0	28.0	2-4
Antenna azimuthal beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	2.6	1.6	3.0	2-4
Antenna horizontal scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	36, 72	90	N/A	20
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	Continuous 360	30-270 Sector	Fixed to left or right of flight path	Continuous
Antenna vertical scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A	N/A	N/A	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A	Fixed	Fixed in elevation (-20 to -70)	N/A
Antenna side-lobe (SL) levels (1st SLs and remote SLs) (dB)	-20	-20	-20	-22	-22	-20	-25	-22	-25
Antenna height (m)	20	20	8-20	20	20	40	40	To 8 000	9 000
Receiver IF 3 dB bandwidth (MHz)	1	4.8, 2.4, 0.25	4, 2, 1	2-8	8	1.5	1.2, 10	90, 147	1
Receiver noise figure (dB)	6	5	5	11	5	5	10	4.9	3.5
Minimum discernable signal (dBm)	-105	-107	-100	-107, -117	-100	-107	-94 (short/medium pulse) -102 (wide pulse)	-90, -87	-110

3   Operational characteristics

3.1   Meteorological radars

Both airborne and ground-based meteorological radars operate within the frequency range 5 250-5 850 MHz, and the technical characteristics are given in Table 1.

The ground-based weather radar systems are used for detection of severe weather and flight planning activities and are often located near airports worldwide. Therefore, these radars are also in operation continuously 24 h/day.

Meteorological radars provide quantitative area precipitation measurements and in most cases belong to networks which coordinate such measurements over national or regional areas. Those which use Doppler radar technology also observe precipitation velocity, which indicates the presence and motion of severe weather elements such as tornadoes, hurricanes and violent thunderstorms as well as windshear and turbulence. Quantitative measurements from both kinds of radar are used in real time as a critical and unique data source for hydrological, meteorological and environmental forecasting. Through numerical data assimilation, modelling and forecasting of weather, flooding and pollution, particularly on the occasion of damaging events, the data are used to increase the accuracy and timeliness of forecasts and warnings. The data may be used directly, for example to assess lightning risk. Many applications can be critical to safety and protection of the general public (both life and property) and the safety and security of military operations.

The airborne meteorological radars are used for both hurricane research and reconnaissance. The aircraft penetrate the eyewall repeatedly at altitudes up to 20 000 ft (6 096 m) and as low as 1 500 ft (457 m). The aircraft collect research-mission data critical for computer models that predict hurricane intensity and landfall. Other aircraft penetrate hurricanes at higher, less turbulent altitudes (30 000-45 000 ft, or 9 144-13 716 m) to determine the position of the hurricane eye.

3.2   Aeronautical radionavigation radars

Radars operating in the ARNS in the frequency band 5 350-5 460 MHz are primarily airborne systems used for flight safety. Both weather detection and avoidance radars, which operate continuously during flight, as well as windshear detection radars, which operate automatically whenever the aircraft descends below 2 400 ft (732 m), are in use. Both radars have similar characteristics and are principally forward-looking radars which scan a volume around the aircraft's flight path. These systems are automatically scanned over a given azimuth and elevation range, and are typically manually (mechanically) adjustable in elevation by the pilot (who may desire various elevation "cuts" for navigational decision-making).

3.3   Radiolocation radars

There are numerous radar types, accomplishing various missions, operating within the radiolocation service throughout the range 5 250-5 850 MHz. Table 3 gives the technical characteristics for several representative types of radars that use these frequencies that can be used to assess the compatibility between radiolocation radars and systems of other services. The operational use of these radars is briefly discussed in the following text.

Test range instrumentation radars are used to provide highly accurate position data on space launch vehicles and aeronautical vehicles undergoing developmental and operational testing. These radars are typified by high transmitter powers and large aperture parabolic reflector antennas with very narrow pencil beams. The radars have autotracking antennas which either skin track or beacon track the object of interest. (Note that radar beacons have not been presented in the Tables; they normally are tuneable over 5 400-5 900 MHz, have transmitter powers in the range 50-200 W peak, and serve to rebroadcast the received radar signal.) Periods of operation can last from minutes up to 4-5 h, depending upon the test program. Operations are conducted at scheduled times 24 h/day, 7 days/week.

Shipboard sea and air surveillance radars are used for ship protection and operate continuously while the ship is underway as well as entering and leaving port areas. These surveillance radars usually employ moderately high transmitter powers and antennas which scan electronically in elevation and mechanically a full 360° in azimuth. Operations can be such that multiple ships are operating these radars simultaneously in a given geographical area.

Other special-purpose radars are also operated in the band 5 250-5 850 MHz. Radar Q (Table 3) is an airborne synthetic aperture radar which is used in land-mapping and imaging, environmental and land-use studies, and other related research activities. It is operated continuously at various altitudes and with varying look-down angles for periods of time up to hours in duration which depends upon the specific measurement campaign being performed.

4   Protection criteria

The desensitizing effect on radars operated in this band from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can simply be added to the power spectral density of the radar receiver thermal noise, to within a reasonable approximation. If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply $I_0 + N_0$. An increase of about 1 dB for the meteorological and radiolocation radars would constitute significant degradation. Such an increase corresponds to an $(I + N)/N$ ratio of 1.26, or an I/N ratio of about −6 dB. For the radionavigation service and meteorological radars, considering the safety-of-life function, an increase of about 0.5 dB would constitute significant degradation. Such an increase corresponds to an $(I + N)/N$ ratio of about −10 dB. However, further study is required to validate this value. These protection criteria represent the aggregate effects of multiple interferers, when present; the tolerable I/N ratio for an individual interferer depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario.

The aggregation factor can be very substantial in the case of certain communication systems, in which a great number of stations can be deployed.

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation can be inflicted by such desensitization. Assessing it will be an objective for analyses of interactions between specific radar types. In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low-duty cycle pulsed interference are contained in Recommendation ITU-R M.1372 – Efficient use of the radio spectrum by radar stations in the radiodetermination service.

5   Interference mitigation techniques

In general, mutual compatibility between radiolocation, aeronautical radionavigation and meteorological radars is fostered by the scanning of the antenna beams, which limits main beam couplings. Additional mitigation is afforded by differences between the waveforms of the two types of radars and the associated rejection of undesired pulses via receiver filtering and signal processing techniques such as limiting, sensitivity time control and signal integration. Additionally, interference can be mitigated by separation in carrier frequency or discrimination in time through the use of asynchronous pulse rejection/suppression techniques. In radar-to-radar interactions, separation in frequency is not always necessary for compatible operation because high degrees of isolation in power coupling and in time either occur naturally or can be achieved by good design. Additional details of interference mitigation techniques employed by radar systems are contained in Recommendation ITU-R M.1372.

RECOMMENDATION ITU-R M.1642-2

**Methodology for assessing the maximum aggregate equivalent power
flux-density at an aeronautical radionavigation service station
from all radionavigation-satellite service systems
operating in the 1 164-1 215 MHz band**

(2003-2005-2007)

Scope

This Recommendation gives a methodology and the reference antenna characteristics for assessing the maximum aggregate equivalent power flux-density (epfd) level produced at the input of a station of the aeronautical radionavigation service (ARNS) by all radionavigation-satellite service (RNSS) systems operating in any portion of the 1 164-1 215 MHz band.

The ITU Radiocommunication Assembly,

considering

a)   that in accordance with the Radio Regulations (RR), the band 960-1 215 MHz is allocated on a primary basis to the aeronautical radionavigation service (ARNS) in all the ITU Regions;

b)   that analyses show that RNSS signals in the 1 164-1 215 MHz band can be designed not to cause interference to the DME/TACAN ARNS receivers operating in this band;

c)   that a protection criterion for the ARNS has been developed and is expressed in terms of equivalent power flux-density (epfd), which is set out in Recommendation ITU-R M.1639,

recognizing

a)   that WRC-2000 introduced a co-primary allocation for the RNSS in the frequency band 1 164-1 215 MHz, subject to conditions that require the RNSS to protect the ARNS from harmful interference;

b)   that WRC-03 determined that protection of the ARNS from RNSS can be achieved if the value of the epfd produced by all the space stations of all RNSS (space-to-Earth) systems in the band 1 164-1 215 MHz does not exceed the level of -121.5 dB(W/m^2) in any 1 MHz band, and adopted Resolution 609 (WRC-03) in order to ensure that this level is not exceeded;

c)   that the ARNS is a safety service in accordance with RR No. 1.59 and special measures need to be taken by Administrations to protect these services in accordance with provision RR No. 4.10,

recommends

1   that the methodology in Annex 1 and the reference ARNS characteristics in Annex 2 should be used to calculate the maximum aggregate epfd produced by emissions from all RNSS systems at any aeronautical radionavigation station.

Annex 1

Methodology for assessing the maximum aggregate epfd
at an ARNS station from all RNSS systems
operating in the 1 164-1 215 MHz band

Summary of the method

With the method described in this Annex it is possible to calculate the maximum aggregate epfd level of all RNSS systems in the band 1 164-1 215 MHz.

This method allows different systems to be combined easily, so that the effect of changes such as including or excluding one or various systems or the effect of changing the characteristics of specific systems can be examined during a consultation meeting.

The method accommodates both non-GSO systems, with constellations of satellites in any orbits of any inclination, and GSO systems.

The method is based on a two-step process:

Step 1: Calculation of the epfd of each individual RNSS system. This step may be performed by each operator independently prior to the consultation meeting, provided that results are submitted in a compatible format (see § 1.3, for non-GSO systems, and § 1.4, for GSO systems).

Step 2: Combination of the maximum epfd of the individual systems, by superposition of the maps, if necessary at different frequencies, to obtain the maximum aggregate epfd (see § 2) in the band 1 164-1 215 MHz.

Description of the method

1   Method for calculating the maximum epfd from satellites of one RNSS system

1.1   Definition of epfd

The definition of equivalent power flux-density (epfd) is based upon RR No. 22.5C.1 as adopted at WRC-2000.

When an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is that pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

The instantaneous epfd is calculated using the following formula:

$$epfd = 10 \log_{10}\left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,\,max}}\right]$$

where:

N_a :   number of space stations that are visible from the receiver

i :   index of the space station considered

P_i: RF power (in the reference bandwidth) at the input of the antenna (or RF radiated power in the case of an active antenna) of the transmitting space station (dB(W/MHz))

θ_i: off-axis angle (degrees) between the boresight of the transmitting space station and the direction of the receiver

$G_t(\theta_i)$:   transmit antenna gain (as a ratio) of the space station in the direction of the receiver

d_i: distance (m) between the transmitting station and the receiver

φ_i: off-axis angle (degrees) between the pointing direction of the receiver and the direction of the transmitting space station

$G_r(\varphi_i)$:   receive antenna gain (as a ratio) of the receiver, in the direction of the transmitting space station (see Annex 2)

$G_{r,\,max}$:   maximum gain (as a ratio) of the receiver

$epfd$:   instantaneous equivalent power flux-density (dB(W/(m^2 · MHz))) at the receiver.

NOTE 1 – It is assumed that each transmitter is located in the far field of the receiver (that is, at a distance greater than $2D^2/\lambda$, where D is the effective diameter of the receiver antenna and λ is the observing wavelength in the same unit). In the case under consideration this will always be satisfied.

1.2 General consideration

In the first step of the method, the maximum epfd for each constellation of RNSS satellites is calculated at each latitude and longitude over the whole surface of the Earth for each 1 MHz of spectrum occupied by the system.

As the victim ARNS receiver may be mounted on an aircraft flying at an altitude up to 40 000 ft (12 192 m) (see § 2 of Annex 2), the calculation should include all satellites with elevation angles from 90° down to −3.54°.

Calculation of the epfd distribution of each system is only necessary at a single reference frequency, preferably the frequency at which signal power is maximum. The RNSS signal spectral shape should be supplied to a consultation meeting, so that results of the calculation can then be multiplied by the appropriate spectral shaping factors to obtain the results at any other frequency.

1.3 Method for calculating the maximum epfd for a non-GSO RNSS system

The simulation methodology given in Appendix 1 to Annex 1, which is based entirely on Recommendation ITU-R S.1325, may be used to accomplish this.

The methodology, given in Appendix 2 to Annex 1, is based entirely on an analytical technique. The method could be used for obtaining prompt estimates but it does not yield an exact upper bound result.

1.4 Method for calculating the maximum epfd for a GSO RNSS system

The maximum epfd for each GSO satellite is required to be calculated at each latitude and longitude over the whole surface of the Earth for each 1 MHz of spectrum occupied by the system.

In this case the epfd will not be dependent on time, so a single table of results can be calculated directly.

2   Method for calculating the maximum aggregate epfd from all RNSS systems

2.1   Data required for each system

Each non-GSO RNSS system not having a geosynchronous period will, having followed the methodology of § 1.3, provide a consultation meeting with a list of maximum epfd versus latitude (applicable at all longitudes) and a signal spectral shape.

Each non-GSO RNSS system having a geosynchronous period will, having followed the methodology of § 1.3, provide a consultation meeting with a list of maximum epfd versus latitude and longitude, and a signal spectral shape.

Each GSO RNSS system will, having followed the methodology of § 1.4, provide a consultation meeting with a table of maximum epfd versus latitude and longitude and a signal spectral shape.

2.2   Combination of epfds of systems with similar signal characteristics

The determination of aggregate epfd of RNSS systems with the same frequency of signal spectral maximum may be achieved using three steps:

Step 1a: point-by-point summation of maximum epfd's in the 1 MHz of the band where the signal has maximum power at each latitude of all the non-GSO (not having a geosynchronous period) lists to obtain the list of non-GSO (not having a geosynchronous period) aggregate epfd versus latitude;

Step 1b: point-by-point summation of maximum epfds in the 1 MHz of the band where the signal has maximum power at each latitude and longitude of all the non-GSO (having a geosynchronous period) lists to obtain the list of non-GSO (having a geosynchronous period) aggregate epfd versus latitude and longitude;

Step 2: point-by-point summation of maximum epfd's in the 1 MHz of the band where the signal has maximum power at each point of latitude and longitude of all the GSO tables to obtain the table of GSO aggregate epfd versus latitude and longitude;

Step 3: point-by-point summation of the list of non-GSO (not having a geosynchronous period) aggregate epfd versus latitude, and the list of non-GSO (having a geosynchronous period) aggregate epfd versus latitude and longitude to each longitude column of the table of GSO aggregate epfd versus latitude and longitude to obtain the overall the table of aggregate epfd versus latitude and longitude.

Examination of the highest epfd in this table will reveal whether the protection criterion in Recommendation ITU-R M.1639 in any 1 MHz of the band is respected.

2.3   Combination of epfd's of systems with different signal characteristics

It should be noted that the maximum aggregate epfd will be frequency dependent. If the spectra of all the RNSS systems under consideration have their maxima at the same frequency, a single analysis will suffice. However, if different systems have different maxima, either because they use different centre frequencies with overlapping spectra or because they use different modulation techniques, then analysis of the maximum aggregate epfd will require frequency to be taken into account.

The determination of maximum aggregate epfd of RNSS systems with different centre frequencies will require, as a minimum, the above three steps to be performed at each frequency for which any one system has its signal spectral maximum, and may also require analysis at intermediate frequencies.

For each frequency, each list or table will be factored by the appropriate spectral shaping factor before summation with other lists and tables.

Examination of the highest epfd in all of the resultant tables will reveal whether protection criterion in Recommendation ITU-R M.1639 in any 1 MHz of the band is respected.

2.4   Check of results

Following determination of the maximum aggregate epfd, a single simultaneous simulation of all RNSS systems at the ARNS station location where the absolute maximum aggregate epfd was determined may be considered to confirm results obtained using Appendix 1 or 2 to Annex 1.

Appendix 1
to Annex 1

A simulation methodology for determining the maximum epfd
for a non-GSO RNSS system

1   Method and simulation approach description

The framework for this methodology based on Recommendation ITU-R S.1325 is to model all the satellites of one RNSS system at a specific reference frequency (typically the 1 MHz portion of the 1 164-1 215 MHz band with the maximum RNSS signal spectral density). A simulation of the constellation is sampled over a period of time at a relatively fine rate. At each sample the epfd is computed for all latitude and longitude points. The maximum sample should be recorded for each latitude and longitude point. Other samples may be discarded. The result is a table, which can be shown as a map, as illustrated in Figs. 5 and 6. Following this, the maximum epfd, for each latitude should be determined, which will eliminate approximations due to limited simulation time.

2   Simulation assumptions

2.1   Orbit model

The orbit models to simulate the space stations in their orbits are for circular and elliptical orbits only accounting for precession of the line of nodes in the equatorial plane due to asphericity of the Earth.

The orbit model represents satellite motion in a geocentric inertial coordinate frame shown in Fig. 1. The origin of this inertial frame is at the centre of the Earth. The x-axis points to the first point in the constellation Aries (i.e. vernal equinox), the z-axis is the mean rotation axis of the Earth, and the y-axis is determined as the cross product of the unit vectors in the z and x direction, i.e. $\bar{y} = \bar{z} \times \bar{x}$.

The orbital models are based on Newton's equation of motion for a satellite orbiting a perfectly spherical Earth in a circle and in an ellipse. For the non-GSO system using circular orbit, the characteristics of this motion that make it easy to model is that the satellite orbital radius and velocity are constant.

2.1.1 Earth-related constants

For the Earth, the general constants are:

R_e : Earth radius (6 378.137 km)

O : Earth centre

μ : Earth attraction constant (3.986005×10^5 km^3/s^2)

J_2 : second harmonic Earth potential constant ($1 082.63 \times 10^{-6}$)

T_e : Earth rotation period (23 h 56′ 4.0989″ = 86 164.0989 s)

Ω_e : Earth rotation angular velocity $= 2\pi/T_e \cong 7.2921151467 \times 10^{-5}$ rad/s

t : elapsed time since the simulated epoch (s).

2.1.2 Non-GSO satellite system space station related constants

For the non-GSO satellite system space stations using circular orbits (see Fig. 1), the constants are as follows:

N : number of space stations of the non-GSO system

i : index for each of the non-GSO satellites ($0 \le i < N$)

h_{sat} : satellite altitude above the Earth (km)

r : radius of the satellite orbit (km) $= h_{sat} + R_e$

I : inclination angle of the orbital plane above the Equator (rad)

RAAN : right ascension of the ascending node

$\Omega_{i,0}$: RAAN of the i-th non-GSO satellite at the time t (rad)

$u_{i,0}$: argument of latitude of the i-th non-GSO satellite at the time t (rad)

T : satellite orbit period (s) $= 2\pi (r^3/\mu)^{1/2}$

n : mean motion of a satellite (rad/s) $= 2\pi/T$

$u_{i,t}$: argument of latitude of the i-th satellite at the time t (rad) $= u_{i,0} + n_t$

Ω_r : nodal regression of the ascending node (rad/s)

$$= -\frac{3}{2} J_2 \cos(I) R_e^2 \frac{\sqrt{r\mu}}{r^4}$$

$\Omega_{i,t}$: RAAN of the i-th satellite at the time t (rad) $= \Omega_{i,0} + \Omega_r t$

$\overrightarrow{ON_i}$: coordinate vector (inertial coordinate system) of a non-GSO satellite in the Earth-centred fixed coordinate frame:

$$\overrightarrow{ON_i} = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = r \begin{bmatrix} \cos(u_{i,t}) \cdot \cos(\Omega_{i,t}) - \cos(I) \cdot \sin(u_{i,t}) \cdot \sin(\Omega_{i,t}) \\ \cos(u_{i,t}) \cdot \sin(\Omega_{i,t}) + \cos(I) \cdot \sin(u_{i,t}) \cdot \cos(\Omega_{i,t}) \\ \sin(u_{i,t}) \cdot \sin(I) \end{bmatrix}$$

FIGURE 1

Circular orbit geometry

γ : semi-major axis
u: argument of satellite latitude
I: inclination angle
Ω: RAAN
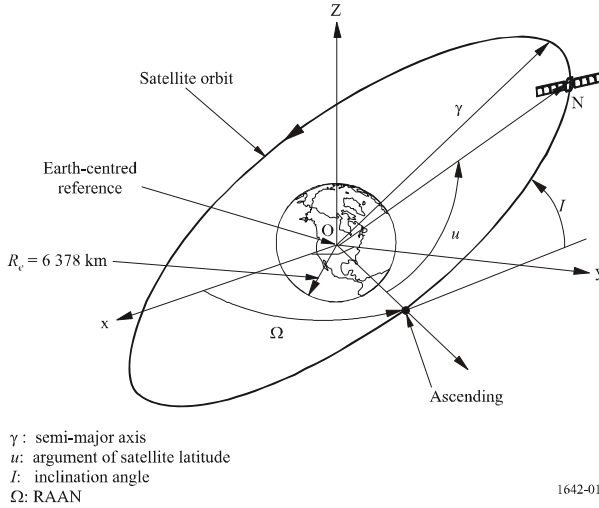
1642-01

For the non-GSO satellite system space stations using elliptical orbits (see Figs. 2 and 3), the constants are as follows:

N: number of space stations of the non-GSO system

i: index for each of the non-GSO satellites ($0 \le i < N$)

a_i: semi-major axis of the i-th satellite (km)

e_i: eccentricity of the i-th satellite

$M_{i,0}$: mean anomaly of the i-th non-GSO satellite at the initial time (rad)

T_i: satellite orbit period of the i-th satellite (s) $= 2\pi(a_i^3/\mu)^{1/2}$

n_i: mean motion of the i-th satellite (rad/s) $= 2\pi/T_i$

$v_{i,t}$: true anomaly of the i-th satellite at time $t = 2 \cdot \tan^{-1}\left[\sqrt{\dfrac{1+e_i}{1-e_i}} \tan\dfrac{E_{i,t}}{2}\right]$

$E_{i,t}$: eccentric anomaly of the i-th satellite at time $t = 2 \cdot \tan^{-1}\left[\sqrt{\dfrac{1-e_i}{1+e_i}} \tan\left(\dfrac{v_{i,t}}{2}\right)\right]$

$M_{i,t}$: mean anomaly of the i-th satellite at time $t = M_{i,0} + n_i \cdot t = E_{i,t} - e_i \cdot \sin E_{i,t}$ [*]

---

[*] Once $M_{i,t}$ is given, $E_{i,t}$ is determined by iteration. Usually, for short time-steps, the last value of $E_{i,t}$ can be used as an initial estimate.

I_i :   inclination angle of the orbital plane above the Equator of the i-th satellite (rad)

RAAN: right ascension of the ascending node

$\Omega_{i,0}$:   RAAN of each of the i-th non-GSO satellites at the initial time (rad)

$\omega_{i,0}$:   argument of perigee of each of the i-th non-GSO satellites at the initial time (rad)

$u_{i,t}$:   argument of latitude of the i-th satellite at the time t (rad) $= \omega_{i,0} + v_{i,t}$

Ω_{ri} :   nodal regression of the ascending node of the i-th satellite (rad/s)

$$= -\frac{3}{2} J_2 \cos(I_i) R_e^2 \frac{\sqrt{a_i \mu}}{a_i^{\,4}(1-e_i^{\,2})^2}$$

$\Omega_{i,t}$:   RAAN of the i-th satellite at the time t (rad) $= \Omega_{i,0} + \Omega_{ri} t$

$\overrightarrow{ON}_{i,t}$:   coordinate vector (inertial coordinate system) of the i-th non-GSO satellite in the Earth-centred fixed coordinate frame at the time t:

$$\overrightarrow{ON}_{i,t} = rot3(-\Omega_{i,t}) \cdot rot1(-I_i) \cdot rot3(-\omega_{i,0}) \cdot \vec{r}_{i,t}$$

$rot1(\alpha)$: rotation about the x-axis

$$rot1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix}$$

$rot3(\alpha)$: rotation about the z-axis

$$rot3(\alpha) = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\vec{r}_{i,t} : \ \vec{r}_{i,t} = r_{i,t} \begin{bmatrix} \cos v_{i,t} \\ \sin v_{i,t} \\ 0 \end{bmatrix} = \frac{a(1-e^2)}{1+e_i \cdot \cos v_{i,t}} \cdot \begin{bmatrix} \cos v_{i,t} \\ \sin v_{i,t} \\ 0 \end{bmatrix}$$

FIGURE 2

Elliptical orbit geometry in focal plane

Auxiliary circle

Satellite orbit

a

$\vec{r}$

v

E

The Earth

Apogee

$r_a = a (1 + e)$

$r_p = a (1 - e)$

Perigee

a

a: semi-major axis
e: eccentricity
r_a: radius of apogee
r_p: radius of apogee
v: true anomaly
E: eccentric anomaly
$\vec{r}$: satellite position vector
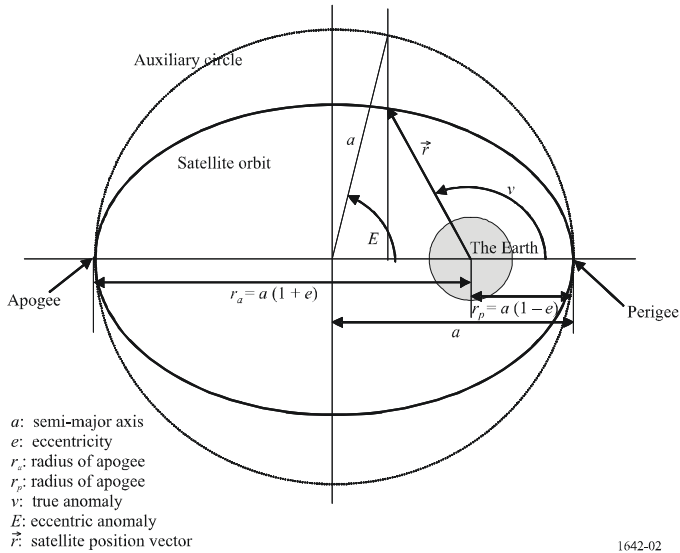
1642-02

FIGURE 3

Elliptical orbit geometry in ECI coordination

Satellite orbit

Z

Earth-centred
reference

ω

I

O

Y

X

Ω

$\vec{n}$

$\vec{ON}$

Ascending node

$\vec{e}$

v

Perigee

$\vec{ON}$: satellite position vector
$\vec{n}$: node vector
$\vec{e}$: eccentricity vector
Ω: right ascension of the node
I: inclination
ω: argument of perigee
v: true anomaly
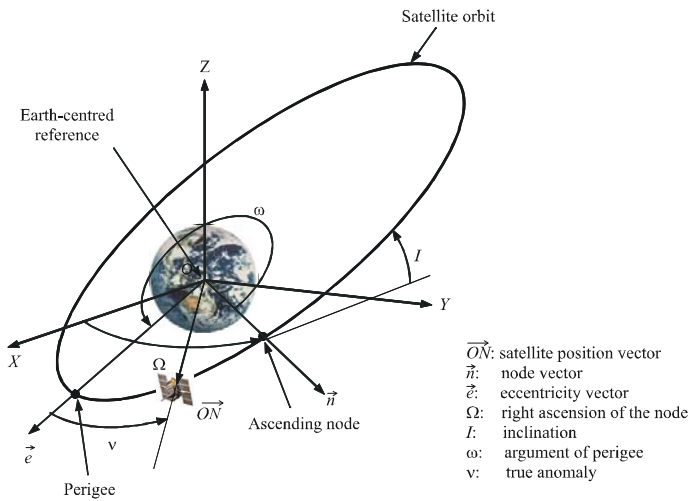
1642-03

The non-GSO perturbation can be considered in calculating the non-GSO constellation related constants, as the position of the satellites may vary when taking perturbation into account.

2.1.3   ARNS station related constants

Lat: latitude of ARNS station (rad)

Lon: longitude of ARNS station (rad)

h_{ARNS}:   altitude of ARNS station (km)

$\overrightarrow{OM}$:   ARNS station coordinates in the Earth-centred, inertial coordinate system

$$\overrightarrow{OM} = \begin{cases} X = (R_e + h_{ARNS}) \cos(\text{Lat}) \cos(\text{Lon} + \Omega_e\, t) \\ Y = (R_e + h_{ARNS}) \cos(\text{Lat}) \sin(\text{Lon} + \Omega_e\, t) \\ Z = (R_e + h_{ARNS}) \sin(\text{Lat}) \end{cases}$$

2.2   Antenna parameters

2.2.1   ARNS station antenna parameters

The antenna pattern for the ARNS station is an input parameter to the simulation (see Annex 2).

2.2.2   Non-GSO space station antenna parameters

In order to perform interference analysis, non-GSO satellite antennas should be modelled using either of the following patterns, subject to availability:

–   measured antenna patterns;

–   proposed reference antenna patterns;

–   an analytical function which models the radiation pattern of the non-GSO satellite antenna.

2.3   Calculation of the simulation time

2.3.1   Simulation time increment

For obtaining accurate results the simulation time increment, t_{inc}, should be as short as possible, but on the other hand the total simulation time should be reasonable. To attain the accuracy required it is necessary to ensure a sufficient number of epfd measurements (N_{hits}) when non-GSO RNSS spacecraft falls into the ARNS antenna pattern of maximum gain visible to a space station. $N_{hits} = 5$ is thought to be sufficient.

The maximum gain visible to a space station occurs at –3.54° to +3° elevation angle (Annex 2) for an aircraft at 40 000 ft (12 192 m). It is important to have 5 N_{hits} within this range, implying that simulation increments of 1° of constellation movement is sufficient.

FIGURE 4

Simulation time increment consideration
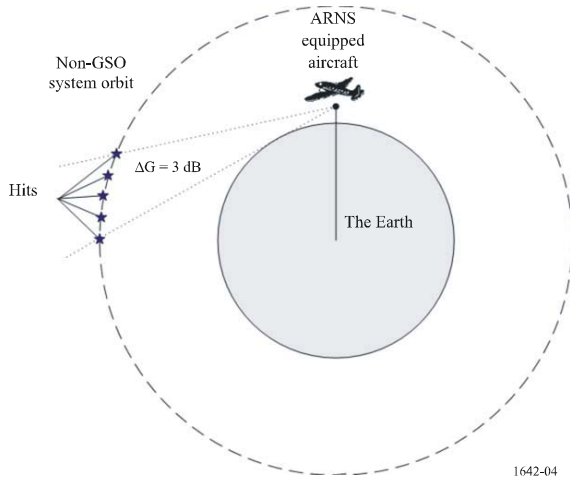
2.3.2 Total simulation time

A satellite of a non-GSO constellation on any orbit traces out a path on the Earth's surface. After a time, which is specific to the system, the satellite or another satellite of the constellation returns to the same or practically to the same point. The time between these two cases is the repeat period of the constellation. The repeat periods of different constellations are from a few days to several months. Typical results of the epfd calculation of a RNSS system over one constellation repeat period is illustrated in Fig. 5.

The exact longitude precession rate of the satellites in a non-GSO constellation will be affected by drifts due to longitudinal station keeping errors. This effect can be modelled and integrated in the simulations.

For the non-GSO system not having a geosynchronous period, the aforementioned effect of this will result in the maximum epfd at any longitude becoming, in fact, the maximum epfd at all longitudes. (In other words, if the simulation were to be extended to cover all possible states of the constellation, the "high spots" of maximum epfd on the map in Fig. 5 would spread horizontally to become uniform horizontal stripes.) It is therefore considered more correct to take, for each latitude, the maximum epfd at any longitude and use it for all longitudes. This converts the table of maximum epfd versus latitude and longitude into a simple list of maximum epfd versus latitude.

If this is done, then the simulation time could be reduced to a single orbital period for the non-GSO system not having a geosynchronous period. The "map" produced by such a limited simulation would show only a few "high spots" but, at each latitude, the value of the "high spots", representing the maximum epfd at any longitude, would be the same.

As a by-product, the amount of information which must be presented to the consultation meeting would be considerably reduced.

FIGURE 5

Example of maximum epfd global distribution

1642-05
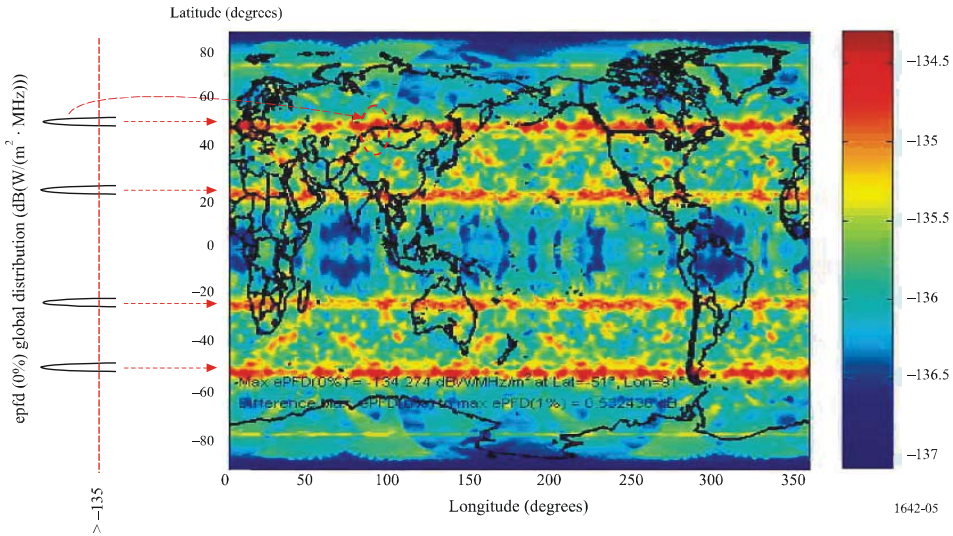
On the other hand, non-GSO systems having a geosynchronous period produce ground tracks that are confined to a limited longitude range on the Earth's surface. This will result in the "high spots" of maximum epfd appearing only within a limited area of the Earth's surface. (In other words, the "high spots" of maximum epfd on the Earth's surface would not spread horizontally.) Therefore, the aggregate epfd, caused by the non-GSO systems having a geosynchronous period, shall be computed for the latitude and longitude points within the visible range from the non-GSO.

For this case of a non-GSO system having a geosynchronous period, the computation could be accomplished considering a single orbital period. Typical results of the epfd calculation for a non-GSO system having a geosynchronous period are shown in Fig. 6.

FIGURE 6

Example of maximum epfd global distribution for a non-GSO system
having a geosynchronous period

1642-06
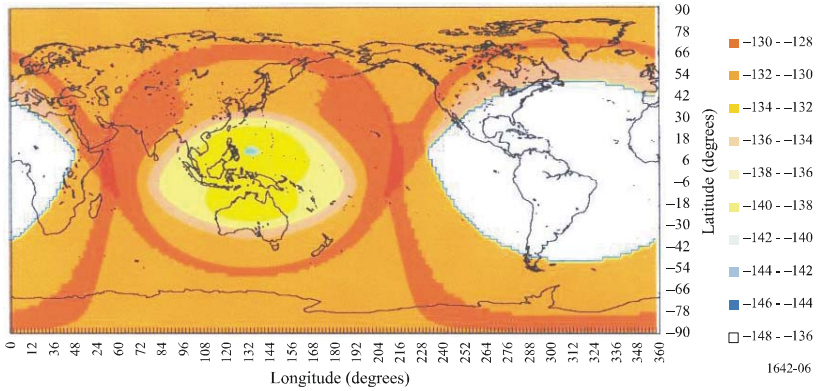
Appendix 2
to Annex 1

Analytical methodology for assessing the maximum epfd of a single
RNSS system operating in the band 1 164-1 215 MHz

1   Introduction

The intent of this methodology is to show how the maximum epfd of a single RNSS system can be evaluated.

The definition of epfd is given in § 1.1 of Annex 1.

2   Description of the methodology

If one assumes that the non-GSO RNSS-system constellations consist of a number of orbital planes, then it is most likely that, in any one particular plane, a maximum of one satellite per plane will be within the −3.54° to +3° elevation angle of the ARNS antenna pattern (see Annex 2). In addition, for non-GSO systems, it is likely that, when a satellite is within the ARNS antenna pattern of maximum gain visible to a space station, other satellites in the plane will have a relatively insignificant epfd contribution. Hence, the number of satellites with a significant contribution to an RNSS system's aggregate epfd is likely to be less than or equal to the number of the system's using these assumptions, one can formulate the non-GSO RNSS constellation maximum epfd ($epfd_{max}$) as:

$$epfd_{max} = 10 \log N_p + epfd_{i,\,max} \qquad \text{dB(W/(m}^2 \cdot \text{MHz))}$$

where:

N_p :   the maximum number of satellites in the main beam of the ARNS receiving antenna (typically, the number of orbital planes in the constellation)

$epfd_{i,max}$: maximum single-satellite epfd contribution (dB(W/(m² · MHz))).

3 Non-GSO examples

For a single-satellite maximum epfd contribution of –136.9 dB(W/(m² · MHz)) within a non-GSO RNSS constellation of six planes using the equation in § 2 the $epfd_{max}$ is:

$$epfd_{max} = (-136.9) + 10 \log 6 = -129.12 \qquad \text{dB(W/(m}^2 \cdot \text{MHz))}$$

A similar calculation, with a single-satellite maximum epfd contribution of –130.24 dB(W/(m² · MHz)), within a non-GSO RNSS constellation of three planes, using the equation in § 2 gives a maximum epfd of –125.47 dB(W/(m² · MHz)).

These values are in very good agreement with the simulation method in Appendix 1 to Annex 1, with only 1.2 dB difference.

Annex 2

ARNS reference station characteristics to be used in epfd calculation

1 ARNS antenna characteristics

Table 1 provides the antenna gain for elevation values between –90° and 90°. For elevation values between two values of Table 1 a linear interpolation should be used. The $G_{r,max}$ value is 3.4 dBi as specified in Recommendation ITU-R M.1639, including 2 dB of circular-to-linear polarization mismatch. It is assumed that the elevation and gain pattern is the same for all azimuth angles.

TABLE 1

Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)
–90	–17.22	22	–10.72	57	–15.28
–80	–14.04	23	–10.81	58	–15.49
–70	–10.51	24	–10.90	59	–15.67
–60	–8.84	25	–10.98	60	–15.82
–50	–5.40	26	–11.06	61	–16.29
–40	–3.13	27	–11.14	62	–16.74
–30	–0.57	28	–11.22	63	–17.19
–20	–1.08	29	–11.29	64	–17.63
–10	0.00	30	–11.36	65	–18.06
–5	–1.21	31	–11.45	66	–18.48
–3	–1.71	32	–11.53	67	–18.89
–2	–1.95	33	–11.60	68	–19.29
–1	–2.19	34	–11.66	69	–19.69

TABLE 1 (*end*)

Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,max}$ (dB)
0	−2.43	35	−11.71	70	−20.08
1	−2.85	36	−11.75	71	−20.55
2	−3.26	37	−11.78	72	−20.99
3	−3.66	38	−11.79	73	−21.41
4	−4.18	39	−11.80	74	−21.80
5	−4.69	40	−11.79	75	−22.15
6	−5.20	41	−12.01	76	−22.48
7	−5.71	42	−12.21	77	−22.78
8	−6.21	43	−12.39	78	−23.06
9	−6.72	44	−12.55	79	−23.30
10	−7.22	45	−12.70	80	−23.53
11	−7.58	46	−12.83	81	−23.44
12	−7.94	47	−12.95	82	−23.35
13	−8.29	48	−13.05	83	−23.24
14	−8.63	49	−13.14	84	−23.13
15	−8.97	50	−13.21	85	−23.01
16	−9.29	51	−13.56	86	−22.88
17	−9.61	52	−13.90	87	−22.73
18	−9.93	53	−14.22	88	−22.57
19	−10.23	54	−14.51	89	−22.40
20	−10.52	55	−14.79	90	−22.21
21	−10.62	56	−15.05		

2   ARNS station location

The ARNS station altitude should be taken at worst case (12 192 m)[1], which gives maximum visibility of potentially interfering satellites from the ARNS receiving antenna.

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[1]   Equivalent to 40 000 ft.

RECOMMENDATION ITU-R M.1643*

Technical and operational requirements for aircraft earth stations of aeronautical mobile-satellite service including those using fixed-satellite service network transponders in the band 14-14.5 GHz (Earth-to-space)

(2003)

Summary

This Recommendation provides the technical and operational requirements for aircraft earth stations (AES) of aeronautical mobile-satellite service (AMSS), including those using FSS network transponders operating in the band 14-14.5 GHz (Earth-to-space), that should be used by administrations as a technical guideline for establishing conformance requirements for AES and facilitating their licensing, for worldwide use.

The ITU Radiocommunication Assembly,

considering

a)   that various technically and operationally different aeronautical mobile-satellite service (AMSS) networks have been designed to commence operation in the near future;

b)   that these planned AMSS networks may provide access to a variety of broadband communication applications (Internet, email, internal corporate networks) to and from aircraft on a global basis;

c)   that the aircraft earth station (AES) will operate on national and international airlines around the world;

d)   that circulation of AES is usually a subject of a number of national and international rules and regulations including satisfactory conformance to a mutually agreed technical standard and operational requirements;

e)   that there is a need for identifying the technical and operational requirements for the conformance testing of AES;

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*   NOTE – The Arab Group represented at RA-03 reserves its position on this Recommendation and is not ready to accept any repercussions with respect to WRC-03 Agenda item 1.11.

f)   that the identification of technical and operational requirements for AES would provide a common technical basis for facilitating conformance testing of AES by various national and international authorities and the development of mutual recognition arrangements for conformance of AES;

g)   that the technical and operational requirements need to achieve an acceptable balance between radio equipment complexity and the need for effective use of the radio-frequency spectrum,

considering also

a)   that in the frequency band 14-14.5 GHz there are allocations to the FSS (Earth-to-space), radionavigation, fixed and mobile (except aeronautical mobile) services on a primary basis; that secondary services allocated in the band 14-14.5 GHz or in parts of the band include mobile-satellite (except aeronautical mobile-satellite) service (Earth-to-space), space research service (SRS), radio astronomy service (RAS), and radionavigation-satellite service;

b)   that there is a requirement to fully protect all primary services and pre-existing systems of secondary services in the band 14-14.5 GHz;

c)   that results of the studies conducted in accordance with Resolution 216 (Rev.WRC-2000) showed the feasibility of using the band 14-14.5 GHz by AMSS (Earth-to-space) on a secondary basis under certain conditions and arrangements[1];

d)   that the identification by ITU-R of technical and operational requirements for AES operating in the band 14-14.5 GHz could assist administrations to prevent harmful and/or unacceptable interference to other services;

e)   that technical and operational characteristics should be continuously and accurately measurable and controllable,

recommends

1   that the technical and operational requirements[1] for aircraft earth stations of AMSS networks operating in the band 14-14.5 GHz given in Annexes 1 and 2 be used by administrations as a guideline for:

–   establishing conformance requirements for AES;

–   facilitating AES operations.

---

[1] The characteristics of the typical aircraft earth stations need to fulfil the requirements described in this Recommendation and, further, need to be within the envelope of those initially published in the International Frequency Information Circular (BR IFIC) relating to the corresponding FSS network. In the case that the characteristics are outside of the envelope of those in the initial publication, the required coordination of such an aircraft earth station needs to be effected in accordance with the current provisions of the Radio Regulations (RR) and a modified Rule of Procedure as contained in § 2 of the Rules of Procedure relating to RR No. 11.32, as appropriate.

Annex 1

Technical and operational requirements for AES of AMSS networks in the band 14-14.5 GHz (Earth-to-space)

Part A

Essential requirements related to the protection of FSS networks

1 AMSS networks should be coordinated and operated in such a manner that the aggregate off-axis e.i.r.p. levels produced by all co-frequency AES within AMSS networks are no greater than the interference levels that have been published and coordinated for the specific and/or typical earth station(s) pertaining to FSS networks where FSS transponders are used.

2 The design, coordination and operation of an AES should, at least, account for the following factors which could vary the aggregate off-axis e.i.r.p. levels generated by the AES:

2.1 mispointing of AES antennas. Where applicable, this includes, at least, effects caused by bias and latency of their pointing systems, tracking error of closed loop tracking systems, misalignment between transmit and receive apertures for systems that use separate apertures, and misalignment between transmit and receive feeds for systems that use combined apertures;

2.2 variations in the antenna pattern of AES. Where applicable, this includes, at least, effects caused by manufacturing tolerances, ageing of the antenna and environmental effects. AMSS networks using certain types of AES antennas, such as phased arrays, should account for variation in antenna pattern with scan angles (elevation and azimuth). Networks using phased arrays should also account for element phase error, amplitude error and failure rate;

2.3 variations in the transmit e.i.r.p. from AES. Where applicable, this includes, at least, effects caused by measurement error, control error and latency for closed loop power control systems. Network control and monitoring centres (NCMCs) that calculate the e.i.r.p. of AES based on the received signal need to take into account error sources and latency in this calculation. NCMCs that calculate the e.i.r.p. of AES based on input power must account for measurement error and reporting latency.

3 AES that use closed loop tracking of the satellite signal need to employ an algorithm that is resistant to capturing and tracking adjacent satellite signals. AES must immediately inhibit transmission when they detect that unintended satellite tracking has happened or is about to happen.

4 AES should be subject to the monitoring and control by an NCMC or equivalent facility. AES must be able to receive at least "enable transmission" and "disable transmission" commands from the NCMC. AES must automatically cease transmissions immediately on receiving any

"parameter change" command, which may cause harmful interference during the change, until it receives an "enable transmission" command from its NCMC. In addition, it should be possible for the NCMC to monitor the operation of an AES to determine if it is malfunctioning.

5   AES need also to be self-monitoring and, should a fault which can cause harmful interference to FSS networks be detected, the AES must automatically mute its transmissions.

Part B

Essential requirements related to the protection of the fixed service

In the 14-14.5 GHz frequency band as used by fixed service networks, within line-of-sight of the territory of an administration where fixed service networks are operating in this band, the maximum pfd produced at the surface of the Earth by emissions from a single AES, of an AMSS network should not exceed:

$$-132 + 0.5 \cdot \theta \qquad \text{dB(W/(m}^2 \cdot \text{MHz))} \qquad \text{for} \qquad \theta \ \leq \ 40°$$

$$-112 \qquad \text{dB(W/(m}^2 \cdot \text{MHz))} \qquad \text{for} \ 40 \ < \ \theta \ \leq \ 90°$$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

NOTE 1 – The aforementioned limits relate to the pfd and angles of arrival that would be obtained under free-space propagation conditions.

NOTE 2 – An e.i.r.p. mask can be derived from the aforementioned pfd mask by applying the method given in Annex 2 of this Recommendation. Simplification of the resulting e.i.r.p. mask could also be considered.

Part C

Essential requirements related to sharing with the RAS

In order to protect the radio astronomy in the band 14.47-14.5 GHz, AMSS earth stations should comply with both following measures:

AMSS channels in the 14.47-14.5 GHz band

–   AMSS stations do not transmit in the 14.47-14.5 GHz band within line-of-sight of radio astronomy stations operating within this band;

         or,

–   if an AMSS operator intends to operate co-frequency within the visibility of the radio astronomy station, a specific agreement with the radio astronomy station will be needed to ensure that AMSS AES will meet the requirements of Recommendations ITU-R RA.769 and ITU-R RA.1513 within the 14.47-14.5 GHz band during observations. Where practicable, this may include advance information to AMSS operators regarding observation schedules.

AMSS channels in the 14-14.47 GHz band

         All AES transmitters on channels in the 14-14.47 GHz band within line-of-sight of radio astronomy stations during radio astronomy observations have emissions in the band 14.47-14.5 GHz such that they meet the levels and percentage of data loss given in

Recommendations ITU-R RA.769 and ITU-R RA.1513. Results from studies show that the following AES pfd levels (dB(W/(m$^2 \cdot$ 150 kHz))) in the band 14.47-14.5 GHz are sufficient, with some margin, to meet the radio astronomy pfd levels in Recommendation ITU-R RA.769 and the percentage of data loss given in Recommendation ITU-R RA.1513, i.e.:

$-190 + 0.5 \cdot \theta$ dB(W/(m$^2 \cdot$ 150 kHz))   for $\theta \leq 10°$

-185 dB(W/(m$^2 \cdot$ 150 kHz))   for $10° < \theta \leq 90°$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

Such AES pfd levels in the band 14.47-14.5 GHz may be achieved by the AMSS operators through a combination of reduced AES signal power, sharp filtering, maintaining adequate frequency separation, or better AES antenna performance.

Part D

Essential requirements related to sharing with the space research service

Coordination agreements should be developed between AMSS and space research systems based on controlling the emissions levels of the AES in the frequency band used by the SRS systems, and, in severe cases, may require cessation of AES emissions on frequencies used by the SRS system when operating in the vicinity of the space research earth station. Specifics of the agreements will vary based on the characteristics of the individual SRS sites and the AMSS networks.

Annex 2

Derivation of a lower hemisphere e.i.r.p. mask from a pfd mask

In testing AMSS equipment to determine if it meets a given pfd mask, such as the one in Annex 1, Part B, it may be useful to determine an equivalent e.i.r.p. mask that can be used for testing purposes.

The pfd mask, pfd(θ) where θ is the angle of arrival (elevation angle) at the Earth's surface, can be used to mathematically determine an e.i.r.p. mask, e.i.r.p.(γ, H) where γ is the angle below the local horizontal plane and H is the altitude of the aircraft. This conversion proceeds in two steps. First, γ is converted to an equivalent angle of arrival, θ. Then the length of the propagation path for angle of arrival θ is determined and used to calculate the spreading loss for the path and the resulting e.i.r.p.

Step 1: Calculation of an angle of arrival in degrees, θ, from γ and H:

$$\theta = \arccos((R_e + H) \cos(\gamma)/R_e)$$

where:

θ : angle of arrival

R_e : earth radius (6 378 km)

H : altitude of the aircraft (km)

γ : angle below horizontal.

NOTE 1 – If the argument of the arccos function is greater than 1, the propagation path in the direction of the angle γ does not intersect the Earth. In this case, which occurs for values of γ of about 3.5° or less, a value for θ does not exist and so there is no defined value for the pfd mask.

Step 2: Calculation of the e.i.r.p. value from the defined pfd(θ):

$$d = (R_e^2 + (R_e + H)^2 - 2\,R_e(R_e + H)\cos(\gamma - \theta))^{1/2}$$

$$\text{e.i.r.p.}(\gamma, H) = \text{pfd}(\theta) + 10\,\log_{10}(4\,\pi\,d^2) + 60$$

where:

d : distance between the AES and the considered point on the Earth's surface (km)

pfd(θ) : (dB(W/(m$^2 \cdot$ MHz)))

e.i.r.p. : (dB(W/MHz)).

The graph in Fig. 1 shows this function for various aircraft altitudes based on the pfd mask provided in Annex 1, Part B of this Recommendation.

FIGURE 1

e.i.r.p. mask derived from pfd mask

1643-01
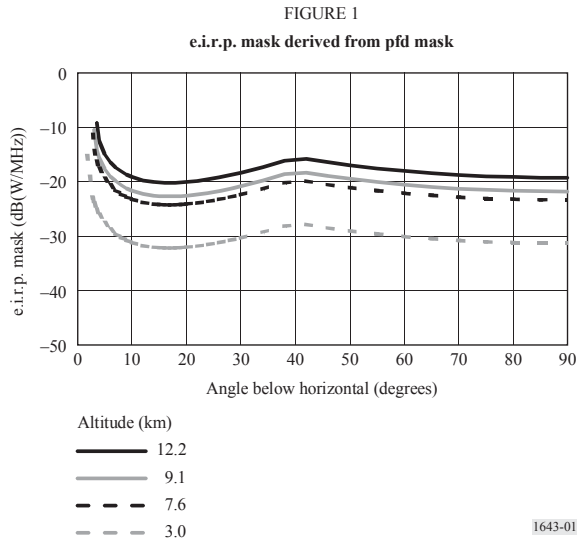
RECOMMENDATION ITU-R M.1652-1

Dynamic frequency selection* in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band

(Questions ITU-R 212/5)

(2003-2011)

Scope

This Recommendation provides requirements of dynamic frequency selection (DFS) as a mitigation technique to be implemented in wireless access systems (WAS) including radio local area networks (RLANs) for the purpose of facilitating sharing with the radiodetermination service in the 5 GHz band. Annex 1 specifies the detection, operational and response requirements. Other Annexes address the methodologies and provide information which can be used by administrations when conducting sharing studies between radars and WAS including RLANs.

The ITU Radiocommunication Assembly,

considering

a)   that harmonized frequencies in the bands 5 150-5 350 MHz and 5 470-5 725 MHz for the mobile service would facilitate the introduction of wireless access systems (WAS) including radio local area networks (RLANs);

b)   that there is a need to protect the radars in the radiodetermination service operating in the bands 5 250-5 350 and 5 470-5 725 MHz;

c)   that in many administrations, the ground-based meteorological radars are extensively deployed and support critical weather services;

d)   that procedures and methodologies to analyse compatibility between radars and systems in other services are provided in Recommendation ITU-R M.1461;

e)   that representative technical and operational characteristics of radiolocation, radionavigation and meteorological radars are provided in Recommendation ITU-R M.1638, including maritime radionavigation radars in, *inter alia*, the band 5 470-5 650 MHz;

f)   that WAS including RLANs as described in Recommendation ITU-R M.1450 are capable of operating both indoor and outdoor;

g)   Report ITU-R M.2034 which addresses the impact of certain detection requirements of the DFS on the performance of WAS,

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*   Dynamic frequency selection is a general term used in this Recommendation to describe mitigation techniques that allow, amongst others, detection and avoidance of co-channel interference with respect to radar systems.

recognizing

a)   that the band 5 250-5 350 MHz is allocated to the radiolocation service on a primary basis; that the band 5 250-5 350 MHz is also allocated to the Earth exploration-satellite service (EESS) (active) on a primary basis;

b)   that the band 5 470-5 650 MHz is allocated to the maritime radionavigation service on a primary basis;

c)   that the band 5 350-5 650 MHz is allocated to the radiolocation service on a secondary basis;

d)   that ground-based radars used for meteorological purposes are authorized to operate in the band 5 600-5 650 MHz on a basis of equality with stations in the maritime radionavigation service;

e)   that the band 5 650-5 725 MHz is allocated to the radiolocation service on a primary basis;

f)   that administrations may take account of detailed information on actual radar deployment when developing guidance for the use of DFS in WAS in consultation with potentially affected administrations,

noting

a)   that the high RF power level and the receiver sensitivity of radars in the radiodetermination service in conjunction with the expected high density of WAS including RLANs would, in general, not enable compatible operation of WAS including RLANs and radars on a co-channel basis in the absence of mitigation techniques;

b)   that WAS including RLANs could be deployed in these bands as licence-exempt devices, consequently making control of their deployment density more difficult;

c)   that there are various standards for RLAN specifications;

d)   that administrations may consider procedures to confirm the ability of interference avoidance mechanisms to function correctly in the presence of the radar systems deployed in this band,

recommends

1   that, in order to facilitate sharing with radars, mitigation techniques as described in Annex 1 be implemented by WAS, including RLANs in the bands used by radars at 5 GHz;

2   that the mitigation techniques comply with the detection, operational and response requirements as given in § 2 of Annex 1;

3   that the methodologies given in Annexes 4, 5, 6 and 7 can be used by administrations when conducting sharing studies between radars and WAS including RLANs.

NOTE 1 – Further information on the results of studies on the requirements stated in *recommends* 2 is given in Report ITU-R M.2115, which provides information on the procedures in place in various administrations and/or regional groups to test compliance with DFS requirements.

Annex 1

The use of DFS in WAS including RLANs for the purpose of protecting the radiodetermination service in the 5 GHz band

1 Introduction

1.1 DFS

In relation to studies on the feasibility of sharing between the mobile service for WAS[1] and the radiodetermination service in the frequency bands 5 250-5 350 and 5 470-5 725 MHz, link budget calculations have shown that interference mitigation techniques are required to enable sharing of WAS with other services such as radar systems. This Annex describes the interference mitigation technique(s) DFS[2] as specified in the 5 GHz RLAN standards, with performance calculations based on typical implementations.

WAS and radars operating in the 5 GHz band will interfere when operating at the same frequencies and within range of each other.

DFS has then been envisaged to:

– ensure a spread of the loading across the available spectrum of the WAS under the field of view of a satellite to reduce the aggregate emission levels at the satellites of the FSS (feeder links) and EESS (active) from WAS;

– avoid co-channel operation with other systems, notably radar systems.

Extension of the use of DFS as described herein allows WAS to avoid interfering with the radiodetermination service. The general principle applied is that WAS should detect interference and identify radar interferers and shall not use those frequencies used by the radar.

1.2 Objective of the use of DFS with respect to radars

The objective of using DFS in WAS is to provide adequate protection to radars in the 5 GHz band. This is achieved by avoiding the use of, or vacating, a channel identified as being occupied by radar equipment based on detection of radar signals.

For the purpose of this Annex, a discussion of radiodetermination systems in the 5 GHz range utilized in determining DFS characteristics can be found in Annex 3.

The implementation of radar detection mechanisms and procedures used by WAS are outside the scope of this Annex. The main reasons for this are that:

– WAS design affects implementation;

– practical experience may lead to innovative and more efficient means than can be formulated today;

– different manufacturers may make different implementation choices to achieve the lowest cost for a given level of performance; therefore only performance criteria rather than specifications for a particular mechanism should be given in regulatory documents.

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[1] Throughout this Recommendation the term "WAS" denotes "wireless access systems including RLANs".

[2] The DFS feature was specified in the 5 GHz RLAN standards initially in order to mitigate interference among uncoordinated RLAN clusters, and to provide optimized spectral efficiency for high-capacity, high bit-rate data transmission.

2   DFS performance requirements

The DFS performance requirement is stated in terms of response to detection of an interference signal.

5 GHz WAS should meet the following detection and response requirements.

Procedures for compliance verification should be incorporated in relevant industry standards for RLANs.

2.1   Detection requirements

The DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold of –62 dBm for devices with a maximum e.i.r.p. of < 200 mW and –64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W[3] averaged over 1 μs.

This is defined as the received signal strength (RSS) (dBm), normalized to the output of a 0 dBi receive antenna, that is required to be detected within the WAS channel bandwidth.

2.2   Operational requirements

The WAS should be able to perform channel availability check: A check during which the WAS listens on a particular radio channel for 60 s to identify whether there is a radar operating on that radio channel.

The WAS should be able to perform in-service monitoring: Monitoring of the operating channel to check that a co-channel radar has not moved or started operation within range of the WAS. During in-service monitoring the radar detection function continuously searches for radar signals in-between normal WAS transmissions. This requires the use of quiet spaces between successive WAS transmissions (see Annex 4).

If the WAS has not previously been in operation or has not continuously monitored the channel with in-service monitoring, it should not start transmission in any channel before completion of a channel availability check.

2.3   Response requirements

A channel that has been flagged as containing a radar signal, either by a channel availability check or in-service monitoring, is subject to a 30 min period (non-occupancy period) where it cannot be used by the WAS device in order to protect scanning radars. The non-occupancy period should start at the time when the radar signal is detected.

Additionally, in the band 5 600-5 650 MHz, if a channel has been flagged as containing a radar, a 10 min continuous monitoring of the flagged channel is required prior to use of that channel. Otherwise, other appropriate methods such as channel exclusion would be required.

Channel move time is defined as the period of 10 s needed by a WAS to cease all transmissions on the operating channel upon detection of an interfering signal above the DFS detection threshold. Transmissions during this period will consist of normal traffic for typically less than 100 ms and a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel.

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[3]   In practice, it may not be necessary for each device to implement full DFS functionality, provided that such devices are only able to transmit under the control of a device that ensures that all DFS requirements are fulfilled.

The aggregate time of the intermittent management and control signals are typically less than 20 ms.

2.4 Summary of the requirements

Table 1 provides a summary of the requirements described above. An example of the operating procedures is given in Annex 2.

TABLE 1

Parameter	Value
DFS detection threshold	–62 dBm for devices with a maximum e.i.r.p. of < 200 mW and –64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W averaged over 1 μs
Channel availability check time	60 s
Non-occupancy period	30 min
Channel move time	≤ 10 s

Annex 2

Radar detection and example of associated DFS procedures

An example of how a DFS mechanism could be described is given in this Annex.

1 Definitions

The following definitions are given for use within this Annex:

Available channel: A radio channel on which a channel availability check has not identified the presence of a radar.

Received radar signal: A signal as characterized below:

− an RSS equal to or greater than the DFS detection threshold level of T_{DFS} (dBm) within the WAS channel bandwidth;

− pulse repetition rates in the range 200-4 000 pulses/s;

− nominal pulse widths in the range 1-20 μs.

Operating channel: Once a WAS starts to operate on an available channel then that channel becomes the operating channel.

2   Procedures

2.1   Finding an initial available channel

Before a WAS transmits, and if no available channel has yet been identified, it shall undertake a channel availability check on a radio channel before it is used for transmission. Consequently, when a network is installed and first powered on, channel availability check(s) should be undertaken, so as to identify at least one available channel. Having identified an available channel, the WAS can start operation on that channel; the checking of other radio channels to identify other available channels is optional.

2.2   Starting operation

Once a WAS starts to operate on an available channel then that channel becomes the operating channel.

2.3   Monitoring the operating channel

In-service monitoring is performed by the WAS to re-check the operating channel for co-channel radar signals that may have come within range of the WAS or started operation on the operating channel.

3   Implementation aspects

3.1   Radar signal detection

Radar signals may occur at any time and they may occur in the presence of co-channel WAS signals.

While finding an initial available channel, the WAS will not be operational and this will assure rapid and reliable detection of any radar signal with the possible exception of very slowly rotating radars. However, these will be detected by the in-service monitoring.

During in-service monitoring the radar detection function continuously searches for radar signal patterns – during or in between normal WAS transmissions. For weakly received radar signals, this may increase the time needed for radar signal detection. This is reflected in the requirements contained in Annex 1.

3.1.1   Detection of frequency hopping radars

Frequency hopping radars operate over a large frequency range, with a rapid change of the operating frequency.

The time required by a WAS for reliable detection varies with the pulse characteristics of the radar. In the case of frequency hopping radars, the time for which the radar occupies the WAS channel (dwell time) also influences the detection probability.

The results will be one of the following:

–   if the dwell time is long enough, DFS detects the radar signal (see Annex 4) and WAS transmissions will cease on the current channel;

–   if the dwell time is very short, the probability of detection of the radar by a WAS on the operating channel may be affected, depending on the number of pulses during the dwell time.

3.1.2 Threshold and antenna gain

The detection threshold is defined in terms of dBm normalized to the output of a 0 dBi receive antenna. If the WAS uses higher antenna gains, the T_{DFS} level should be increased, by adding the antenna gain.

3.1.3 Spurious emissions

Further study is required to determine the impact on the interaction between WAS and radars spurious emissions.

3.2 Channel move time

Upon detection of a signal above the detection threshold, the DFS procedures require the broadcasting of commands to cease all operational transmission and to effect a move to (one of) the available channels identified by the channel availability check. This broadcast will be repeated a number of times to assure reception by all member devices. Part of the WAS population may be in so-called "Sleep Mode" in which the devices re-awaken at intervals of typically hundreds of milliseconds but extremes of up to 60 s are possible. Disregarding the latter, the broadcast has to be repeated a number of times during the channel move time to ensure that, for all practical purposes, all of the WAS devices will have left the channel.

Annex 3

Use of characteristics of radiolocation, maritime radionavigation and meteorological radars

The technical characteristics of some meteorological, radiolocation and maritime radionavigation radars operating in the bands between 5 250-5 350 MHz and 5 470-5 725 MHz can be found in Recommendation ITU-R M.1638. This information is used for the determination of the technical requirements of the DFS mechanism to be implemented in the WAS, which is identified as necessary to enable the introduction of WAS in the mobile service in these frequency bands used by radars. Specifically radars A through S provided in Recommendation ITU-R M.1638 are considered in development of DFS characteristics.

Table 1 of Recommendation ITU-R M.1638 shows the allocations within the 5 GHz range to the radiodetermination service.

Annex 4

Parameters and methodology to calculate the probability of detection of radiodetermination systems by WAS including RLAN devices using DFS in the 5 GHz band during in-service monitoring

The following methodology considers the probability that a WAS device operating in the 5 GHz band using DFS will successfully detect during in-service monitoring a 5 GHz radar operating in the radiodetermination service.

Step 1: Determine the amount of time that an individual device will be in the main beam of the radar antenna (i.e., 3 dB beamwidth/antenna scan rate). Table 2 identifies the radar parameters to be used as a baseline in the study. Analysis time is the period during which the WAS is exposed to the main beam of the radar in one sweep based on the radar antenna pattern and scanned rate.

TABLE 2

Radar	C	K	P	S
3 dB beamwidth (degrees)	0.95	2.5	2.6	2
Scan rate (degrees/s)	36	Not applicable	72	20
Analysis time (ms)	26	100	36	100

Step 2: Radars C, K, P and S represent the more stringent cases and can be utilized to define sharing with all the radars shown in the radar characteristics document. Radar K does not utilize a 360º scan type of function.

Step 3: Based on a distribution of WAS devices using data rate and packet length distributions as shown in Table 3, create a waveform to represent WAS transmit time, and listening periods in length $(x) \cdot 9 + 50$ ms, where x is a random integer between 2 and 32 (i.e., 31 discrete possible durations, uniformly distributed).

TABLE 3

Weighting of RLAN transmit time

Packet size (bytes)	Weight	Data rate (Mbit/s)	Weight
64	0.6	6	0.1
538	0.2	12	0.1
1 500	0.2	18	0.1
		24	0.3
		36	0.3
		54	0.1

The WAS transmit waveform for each instance of a WAS packet transmission is created by randomly choosing a packet transmission, using weights shown in Table 3 for the packet size and transmission data rate, then calculating the transmission time as "Packet size"/(Data rate · 8). Each packet is followed by a quiet period that is required by the WAS network to facilitate sharing of the access medium (i.e., the WAS channel) by the multiple devices using the network. This quiet period is available for in-service monitoring. The quiet period is chosen as defined above. Another random chosen packet is then created in the same manner as the first, with another quiet period following. This is repeated until the waveform has the same duration as that of a WAS device in the main beam of the antenna, as calculated in Step 1.

Step 4: Create a waveform based on the pulse repetition rate (PRR) and pulse width of the radar being analysed. The values to be used for the baseline are shown in Table 4. The waveform should be of the same duration as calculated in Step 1.

TABLE 4

**Baseline radar values for determining
probability of detection**

Radar	C	K	P	S
Pulse width (µs)	0.95	1	20	1
PRR (pps)	200	3 000	500	200

Step 5: Determine if a detection event occurs by determining if radar pulses in the simulated radar waveform align with the listen periods in the simulated WAS network waveform.

Step 6: Repeat the simulation multiple times, recording the occurrence, or lack of occurrence of detection events, using this data to calculate the probability of detection (i.e., percentage of simulations during which the radar pulse is considered to be detected).

Step 7: Probability of detection in *n* rotations:

p :   probability of detection in one rotation

p_n :   probability of detection in *n* rotations

$p_n = 1 - (1 - p)n.$

Annex 5

Interference assessment using link budget calculations involving a single WAS device and radiodetermination systems in the 5 GHz band

1   Background

This Annex addresses the case of interference from a single WAS. The values derived from the calculations in this Annex were used as starting values in the aggregate modelling (see Annex 6) for determination of a detection threshold.

2   Methodology

The calculations presented in this Annex are based on link budget analysis. The threshold is determined from a link budget analysis, assuming that this threshold must be reached when the radar can be interfered with by emissions of a single WAS device (i.e., when the WAS signal at the radar receiver exceeds the radar tolerable interference level). This is based on the assumption of a symmetrical propagation path between the path and the radar.

This method based on link budget is considered appropriate to study static cases which involve one WAS and one radar. It is based on Recommendations ITU-R SM.337 and ITU-R M.1461 and applied in the specific case of DFS.

3   Calculation based on link budget with radars from Recommendation ITU-R M.1638

The determination of the maximum tolerable interference level from emissions of a single WAS device at the radar receiver is based on Recommendation ITU-R M.1461, where it is said that this level should be lower than $N + (I/N)$ where N is the radar receiver inherent noise level and I/N the interference to noise ratio (taken as –6 dB as given in Recommendations ITU-R M.1461 and ITU-R M.1638).

A calculation table is given in Appendix 1 to this Annex. From that Table, if we ignore radar J, under these conditions, the necessary detection threshold is equal to –52 dBm to protect radars from a single WAS.

4   Calculation based on link budget for some new radars

In addition to the radars described in Recommendation ITU-R M.1638, two new ground radars have been recently deployed by some administrations in Region 1. Some parameters have been made available to perform link budget calculations. These are given in Appendix 2 to this Annex.

From the calculations, it appears that the necessary detection threshold is equal to –62 dBm to ensure non-interference to the considered radars from a single 1 W WAS device.

5   Possibility of a variable detection threshold

In this Annex, the calculations assume a single outdoor WAS with 1 W e.i.r.p., which constitutes a worst-case single interferer analysis. It has been expressed that 1 W e.i.r.p. WAS will not represent the majority of the deployed WAS.

Consequently, the idea of a variable detection threshold value which will vary with the WAS e.i.r.p. level may be introduced. According to the methodology used in this Annex, the detection threshold is proportional to the WAS e.i.r.p.

According to the methodology used in this Annex for scenarios related to a single WAS device, the detection threshold is proportional to the WAS e.i.r.p.

Under these conditions, for example, if a 1 W WAS must detect radar above $-N$ dBm, for a 200 mW WAS, the corresponding threshold can be set up at $-(N - 7)$ dBm.

6   Influence of the WAS architecture on the detection threshold

In the case of a centralized WAS architecture, it may be expected that the DFS will be controlled by one specific device within a network or a cell. There might be circumstances where significant propagation path loss differences occur between a radar and the devices within a network or a cell and the assumption of a symmetrical propagation path between the radar and the detection device is not valid.

Measures should be considered by administrations to ensure that each WAS device within a single network will not interfere with radars.

Appendix 1
to Annex 5

Calculation of detection threshold based on link budget for the radars of Recommendation ITU-R M.1638

Characteristics	A	C	E	F	G	H1	H 2	I1	I1	J	K	L	M	N	O	P	Q
RADAR																	
Function	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search
Platform type	Ground/ship	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ship	Ship
Tx power into antenna peak (kW)	250	250	250	250	250	250	250	250	250	2.25	250	2 800	1 200	1 000	165	360	285
Receiver $\text{IF}_{3\,\text{dB}}$ bandwidth (MHz)	0.5	20	0.91	0.6	0.5	0.7	4	0.1	3	10	1	4.8	4	8	8	1.5	10
Antenna polarization	V	H	H	H	H	H	H	H	H	H	V/left-hand circular	V/left-hand circular	V/left-hand circular	V/left-hand circular	V/left-hand circular	H	H
Antenna main beam gain (dBi)	39	44	50	40	40	30	30	50	50	35	38.3	54	47	45.9	42	28	30
Antenna height (m)	30	10	30	30	30	30	30	30	30	10							
e.i.r.p. radar (dBm)	123.0	128.0	134.0	124.0	124.0	134.0	134.0	134.0	134.0	98.5	122.3	148.5	137.8	135.9	124.2	113.6	114.5
Receiver noise figure (dB)	7	4	2.3	3	3	3.5	3.5	1.5	1.5	3	6	5	5	11	5	5	10
$N = k\,T\,B\,F$ (dBm)	−110.0	−97.0	−112.1	−113.2	−114.0	−112.0	−104.5	−122.5	−107.7	−101.0	−108.0	−102.2	−103.0	−93.9	−99.9	−107.2	−94.0
$N − 6$ dB	−116.0	−103.0	−118.1	−119.2	−120.0	−118.0	−110.5	−128.5	−113.7	−107.0	−114.0	−108.2	−109.0	−99.9	−105.9	−113.2	−100.0
e.i.r.p. (dBm) outdoor	30																
TPC (dB)	0																
Bandwidth (MHz)	18																
Antenna gain (omni) (dBi)	0																

Characteristics	A	C	E	F	G	H1	H 2	I1	I1	J	K	L	M	N	O	P	Q
WAS																	
10 log (Brad/BWAS)	−15.6	0.5	−13.0	−14.8	−15.6	−14.1	−6.5	−7.8	−22.6	−2.6	−12.6	−5.7	−6.5	−3.5	−3.5	−10.8	−2.6
Link budget for WAS signal received at radar receiver	185.0	177.0	198.1	189.2	190.0	198.0	190.5	193.7	208.5	172.0	182.3	192.2	186.0	175.8	177.9	171.2	160.0
$N − 6$ dB	169.4	177.0	185.1	174.4	174.4	183.9	183.9	185.9	185.9	169.4	169.7	186.4	179.4	172.3	174.4	160.4	157.4
Necessary detection threshold	−46.4	−49.0	−51.1	−50.4	−50.4	−49.9	−49.9	−51.9	−51.9	−70.9	−47.4	−38.0	−41.6	−36.4	−50.2	−46.9	−42.9

**Appendix 2
to Annex 5**

**Calculation of detection threshold based on link budget for new
radar deployed by some administrations in Region 1**

	Function	Air search
RADAR	Platform type	Ground/vehicle
	Tx power into antenna peak (kW)	15
	Receiver IF$_{3\,dB}$ bandwidth (MHz)	4
	Antenna polarization	V
	Antenna main beam gain (dBi)	35
	Antenna height (m)	10
	e.i.r.p. (dBm)	106.8
	Receiver noise figure (dB)	5
	$N = k\,T\,B\,F$ (dBm)	−103
	$N - 6$ dB	−109
WAS	e.i.r.p. (dBm) outdoor	30
	TPC (dB)	0
	Bandwidth (MHz)	18
	Antenna gain (omni) (dBi)	0

10 log (Brad/BWAS)	−6.5
Propagation loss for WAS signal received at the radar receiver $N - 6$ dB (dB)	175.0
	168.4
Necessary detection threshold (dBm)	−61.7

It is noted that this Table assumes a single 1 W e.i.r.p. WAS, which may be the highest power value in a statistical distribution of the e.i.r.p. in a deployment of WAS (e.g., as described in Table 6 of Annex 6). For example, consideration of a lower e.i.r.p. (< 100 mW) will lead to a corresponding increase by 10 dB of T_{DFS}.

Annex 6

Parameters and methodology for conducting aggregate interference studies involving WAS including RLANs and radiodetermination systems in the 5 GHz band

The following considerations should be utilized to define the baseline scenario for studies to be conducted in determining DFS parameters:

– Recommendation ITU-R M.1461 was utilized in interference calculations.

– The radar antenna pattern contained in Appendix 1 to this Annex was utilized.

– The WAS antenna pattern contained in Appendix 2 to this Annex was utilized.

– The probability of detection (see Annex 4) was utilized in the sharing studies to determine the aggregate interference into radars. This probability was set for each step interval.

– A step interval of 1° was utilized.

– Three concentric rings were utilized to define the WAS deployment as shown in Table 5. Uniform distribution of devices in each zone should be utilized throughout each volumetric zone including height.

TABLE 5

WAS user distribution

	Urban zone	Suburban zone	Rural zone
Radius from the centre (km)	0-4	4-12	12-25
WAS user (%)	60	30	10
Building height (m)	30	6	6

– A total of 2 753 WAS devices operating on a co-channel basis with a radiodetermination system at a given moment was utilized.

– WAS power distribution in Table 6 was utilized.

TABLE 6

WAS power distribution

| Power level	1 W	200 mW	100 mW	50 mW
WAS users (%)	5	25	40	30

– Tracking radars were modelled starting with random placement and a random start angle and then moving directly overhead to the opposite horizon.

– Maritime radars were modelled starting at the horizon of the rural area and tracked into the centre of the urban zone.

– Airborne radars were modelled starting at the horizon of the rural area and tracked over the centre of the urban zone.

–   The studies focused on the following radars:

   C, I, K, P and S as defined in Recommendation ITU-R M.1638.

–   For ground-based radars a random propagation factor was utilized in determining the propagation path loss to each WAS device. A value from 20 to 35 log D was used. In addition a random building/terrain propagation attenuation was used. A value from 0 to 20 dB was used. A uniform distribution was applied in determining these values.

–   For airborne radars, free space loss +17 dB was used.

–   For maritime radars, free space loss +0 to 20 dB was used.

–   A smooth Earth line-of-sight calculation was utilized. Any WAS devices beyond the line-of-sight were discounted.

Appendix 1
to Annex 6

There are no existing radar antenna reference patterns currently in ITU, therefore the following is provided as a baseline. A statistical gain antenna model is used to determine the radar antenna gain in the azimuth and elevation orientations. The model gives the antenna gain as a function of off-axis angle (θ) for a given main beam antenna gain (G). The model includes separate algorithms for very high-gain, high-gain, and medium-gain antennas, corresponding to antennas with gains greater than 48 dBi, gains between 22 and 48 dBi, and gains between 10 and 22 dBi, respectively. Figure 1 illustrates the general form of the antenna gain distribution. The equations for the angles θ_M (first side-lobe shelf), θ_R (near side-lobe region), and θ_B (far side-lobe region) are given in Table 7. The antenna gains as a function of off-axis angle, are given in Table 8 for very high-gain antennas, in Table 9 for high-gain antennas, and in Table 10 for medium-gain antennas. The angle θ is in degrees and all gain values are given in terms of decibels relative to an isotropic antenna (dBi).

FIGURE 1
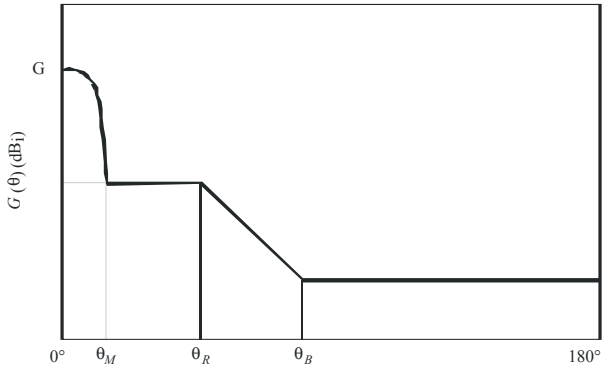
M.1652-01

TABLE 7

Angle definitions

Very high-gain ($G > 48$ dBi)	High-gain ($22 < G < 48$ dBi)	Medium-gain ($10 < G < 22$ dBi)
$\theta_M = 50 \, (0.25 \, G + 7)^{0.5}/10^{G/20}$ $\theta_R = 27.466 \; 10^{-0.3G/10}$ $\theta_B = 48$	$\theta_M = 50 \, (0.25 \, G + 7)^{0.5}/10^{G/20}$ $\theta_R = 250/10^{G/20}$ $\theta_B = 48$	$\theta_M = 50 \, (0.25 \, G + 7)^{0.5}/10^{G/20}$ $\theta_R = 250/10^{G/20}$ $\theta_B = 131.8257 \; 10^{-G/50}$

TABLE 8

Equations for very high-gain antennas ($G > 48$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} \, (10^{G/10}) \, \theta^2$
θ_M to θ_R	$0.75 \, G - 7$
θ_R to θ_B	$29 - 25 \log (\theta)$
θ_B to 180	-13

TABLE 9

Equations for high-gain antennas ($22 < G < 48$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} \, (10^{G/10}) \, \theta^2$
θ_M to θ_R	$0.75 \, G - 7$
θ_R to θ_B	$53 - (G/2) - 25 \log (\theta)$
θ_B to 180	$11 - G/2$

TABLE 10

Equations for medium-gain antennas ($10 < G < 22$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} \, (10^{G/10}) \, \theta^2$
θ_M to θ_R	$0.75 \, G - 7$
θ_R to θ_B	$53 - (G/2) - 25 \log (\theta)$
θ_B to 180	0

Appendix 2
to Annex 6

WAS antenna patterns

The WAS antenna pattern in the azimuth orientations is omnidirectional. The WAS antenna pattern in elevation orientations was determined by examination of WAS antenna patterns. The pattern used is described in Table 11. Note that use of directional WAS antennas, given the same e.i.r.p., may result in less interference to the radiodetermination receiver, but could result in significantly higher interference levels to the WAS receiver if main beam-to-main beam coupling were to occur.

TABLE 11

WAS elevation antenna pattern

Elevation angle, φ (degrees)	Gain (dBi)
$45 < \varphi \leq 90$	–4
$35 < \varphi \leq 45$	–3
$0 < \varphi \leq 35$	0
$-15 < \varphi \leq 0$	–1
$-30 < \varphi \leq -15$	–4
$-60 < \varphi \leq -30$	–6
$-90 < \varphi \leq -60$	–5

In order for most devices to radiate with 1 W e.i.r.p. an antenna gain of 6 dBi will typically be required. For this pattern the following description is given in accordance with Recommendation ITU-R F.1336:

$$G(\theta) = \max[G_1(\theta), G_2(\theta)]$$

$$G_1(\theta) = G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2$$

$$G_2(\theta) = G_0 - 12 + 10\log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + k\right]$$

$$\theta_3 = 107.6 \times 10^{-0.1G_0}$$

where:

$G(\theta)$:   antenna gain (dBi)

θ :   elevation angle (degrees)

k = 0.5

G_0 = 6 dBi.

Annex 7

Interference assessment results analysis and recommendation on DFS threshold values

A summary of the results of simulations using the methodologies detailed in Annexes 5 and 6, for simulating respectively static interference from one WAS device and aggregate interference from a deployment of WAS into a victim radar receiver, is presented for the relevant 5 GHz radars.

Table 12 shows the values derived from the calculations in Annex 5 for the case of interference from a single WAS.

TABLE 12

Values derived from the calculations in Annex 5

Radar per Annex 5	Link budget analysis per Annex 5	−62 dBm for 1 W device
		−55 dBm for 0.2 W device
		−52 dBm for 0.1 W device

Table 13 shows a summary of required protection threshold levels resulting from the aggregate interference modelling calculations.

TABLE 13

Required protection threshold levels

Radar type	Simulation scenario	DFS threshold for protection (T_{DFS}) (Note 1)
Rotating radars A, C, E, F, G, H, I, J Radars P and Q	Standard per Annex 6	−52 dBm and operational considerations utilized by radar systems
Radar I	Annex 6 but radar antenna height between 500 and 1 000 m	−62 dBm
Radar S	Standard per Annex 6	See Note 2
Radar K	Standard per Annex 6	−67 dBm
	Annex 6 but half population density	−64 dBm
	Annex 6 but all devices 50 mW	−62 dBm

NOTE 1 – Assuming a receive antenna gain normalized to 0 dBi for WAS.

NOTE 2 – The sharing situation between this radar and WAS is extremely difficult. Initial calculations based on the baseline results show that a required DFS detection threshold of values below the operating noise floor of WAS devices would be required. Based on discussions, it was found that these systems were limited to military aircraft only. It was agreed to not consider this case when developing a detection threshold requirement.

Notes on parameters and methodologies used

The impact of the parameters and methodology variations can be summarized as follows:

a)   A reduction in active device density by half results in a 3 dB increase in T_{DFS}. Similarly, doubling the active device density results in a 3 dB decrease in T_{DFS}.

b)   The transmit power of a single interferer in the link budget calculation has a direct dB for dB impact on the required protection threshold. In the aggregate analysis, the impact depends on the distribution of power levels used in the simulation.

c)   In most cases the interaction of variables in the aggregate modelling is not intuitive and therefore simple conclusions cannot be drawn from changes in a single variable.

RECOMMENDATION ITU-R M.1827

Technical and operational requirements for stations of the aeronautical mobile (R) service (AM(R)S) limited to surface application at airports and for stations of the aeronautical mobile service (AMS) limited to aeronautical security (AS) applications in the band 5 091-5 150 MHz

(2007)

Scope

This Recommendation provides technical and operational requirements for stations of the aeronautical mobile (R) service (AM(R)S) limited to surface applications at airports and the aeronautical mobile service (AMS) limited to aeronautical security (AS) applications[1] in the band 5 091-5 150 MHz that should be used by administrations as a technical guideline for establishing conformance requirements for stations for worldwide use.

The ITU Radiocommunication Assembly,

considering

a)   that the aeronautical stations will operate on a national, regional and international basis around the world;

b)   that circulation of aeronautical stations is usually a subject of a number of national and international rules and regulations including satisfactory conformance to a mutually agreed technical standard and operational requirements of ICAO;

c)   that there is a need for identifying the technical and operational requirements for the conformance testing of the aeronautical stations;

d)   that the identification of technical and operational requirements for aeronautical stations would provide a common technical basis for facilitating conformance testing of aeronautical stations by various national, regional and international authorities and the development of mutual recognition arrangements for conformance of aeronautical stations;

e)   that the technical and operational requirements need to achieve an acceptable balance between radiocommunication equipment complexity and the need for effective use of the radio-frequency spectrum,

considering also

a)   that there is a requirement to fully protect all primary services in the band 5 091-5 150 MHz;

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[1] *Terminology*: AS operates in the AMS, and is a new system limited to secure and confidential radiocommunications between aircraft and ground, intended for systems used in response to interruption of aircraft operations that have not been permitted by the appropriate authorities.

b)   that results of the studies conducted in accordance with Resolution 414 (Rev.WRC-03) showed the feasibility of using the band 5 091-5 150 MHz by the AM(R)S limited to surface application at airports and by AMS limited to AS applications on a primary basis under certain conditions;

c)   that the identification by ITU-R of technical and operational requirements for aeronautical stations operating in the band 5 091-5 150 MHz should prevent unacceptable interference to other services;

d)   that technical and operational characteristics should be continuously and accurately measurable and controllable,

        recognizing

a)   that the band 5 000-5 250 MHz is allocated to the aeronautical radionavigation service on a primary basis;

b)   that the band 5 030-5 150 MHz is to be used for the operation of the international standard microwave landing system (MLS) for precision approach and landing; the requirements for this system shall take precedence over other uses of this band in accordance with No. 5.444 of the Radio Regulations (RR),

        recommends

1   that the technical and operational requirements for stations of AM(R)S limited to surface application at airports in the band 5 091-5 150 MHz or for stations of AMS limited to AS applications in the band 5 091-5 150 MHz given in Annexes 1 and 2 should be used by administrations as a guideline for ensuring compatibility with FSS[2].

Annex 1

Essential requirements related to compatibility with FSS networks in the band 5 091-5 150 MHz

For the analyses that follow, Table 1 summarizes the assumed FSS receiver characteristics.

TABLE 1

Parameter values used in satellite interference calculations

Parameter	HIBLEO-4 FL
Satellite receiver noise temperature T (K)	550
Antenna effective area at 5 120 MHz (dBm^2)	−35.6
Polarization discrimination L_p (dB)	1
Feed loss L_{feed} (dB)	2.9
Satellite receiver bandwidth B (MHz)	1.23
Satellite receive antenna gain G_r (dBi)	4

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[2] Due to the fact that other limits may also be acceptable and that all essential requirements are not covered by this Recommendation, further study is required.

NOTE 1 – The compliance with the pfds defined below would be obtained under free-space propagation conditions.

NOTE 2 – An e.i.r.p. mask can be derived from the pfd value by applying the method given in Annex 2 of this Recommendation. Simplification of the resulting e.i.r.p. mask could also be considered.

I In the band 5 091-5 150 MHz, in order not to exceed a $\Delta T_s/T_s$ of 2% allowable for AM(R)S plus AS, stations in the AM(R)S and stations in the AS cannot operate co-frequency at the same time (within the field of view of a single non-GSO satellite). The practical means for ensuring this needs to be developed taking into account that different administrations within a single FSS footprint may be operating AM(R)S and/or AS.

II Additional requirements on the AM(R)S

The requirements that follow represent technical guidelines to be used by administrations for establishing conformance requirements for stations for worldwide use. Other limits may also be acceptable, however further study is required.

The pfd defined in this section is based on ensuring that the increase in noise temperature of the FSS satellite (i.e. $\Delta T_s/T_s$ due to operation of the AM(R)S does not exceed 2% (i.e. −17 dB). The methodology assumes 250^3 co-channel AM(R)S transmitters operating concurrently within the field of view of the FSS satellite.

Pfd limit computation based on the FSS protection criteria ($\Delta T_s/T_s = 2\%$) and 250 AM(R)S

Assuming the Table 1 characteristics for the FSS, the maximum aggregate interference level tolerable at the receiver input is $I_{Agg\text{-}Rec}$:

$$I_{Agg-Rec} = KTB - 17\ \text{dB} = -157.3\ \text{dB(W}/1.23\ \text{MHz)}$$

where:

$\quad$ K: Boltzmann's constant (1.38×10^{-23})

$\quad$ T: represents the receiver noise temperature

$\quad$ B: receiver bandwidth.

Therefore at the satellite receiver antenna input the maximum pfd level produced by one AMRS transmitter is:

$$pfd_{Max} = I_{Agg-Rec} - Gr + L_{Feed} + L_P - 10\log_{10}(250) + 10\log\left(\frac{4\pi}{\lambda^2}\right)$$

$$= -157.3 - 4 + 2.9 + 1 - 23.97 + 35.6$$

$$= -145.77\ \text{dBW}/(\text{m}^2 \times 1.23\ \text{MHz})$$

where:

$\quad$ Gr: FSS receiver antenna gain

$\quad$ 250: maximum number of AM(R)S stations emitting simultaneously in the FSS receiver bandwidth.

---

[3] Based on an assumption of 500 airports and a 50% duty cycle.

III   Additional requirements on the AS

The requirements that follow represent technical guideline to be used by administrations for establishing conformance requirements for stations for worldwide use. Other limits may also be acceptable, however further study is required.

The pfd defined in this section is based on ensuring that the increase in noise temperature of the FSS satellite (i.e. $\Delta T_s/T_s$) due to operation of the AS does not exceed 2% (i.e. −17 dB). The methodology assumes 70 co-channel AS transmitters operating concurrently within the field of view of the FSS satellite.

Pfd limit computation based on the FSS protection criteria ($\Delta T_s/T_s = 2\%$) and 70 AS

Assuming the Table 1 characteristics for the FSS, the maximum aggregate interference level tolerable at the receiver input is $I_{Agg\text{-}Rec}$:

$$I_{Agg-Rec} = KTB - 17 \text{ dB} = -157.3 \text{ dB(W}/1.23 \text{ MHz)}$$

where:

   K: Boltzmann's constant (1.38×10^{-23})

   T: represents the receiver noise temperature

   B: receiver bandwidth.

Therefore, at the satellite receiver antenna input the maximum pfd level produced by one AS transmitter is:

$$pfd_{Max} = I_{Agg-Rec} - Gr + L_{Feed} + L_P - 10 \log_{10}(70) + 10 \log\left(\frac{4\pi}{\lambda^2}\right)$$
$$= -157.3 - 4 + 2.9 + 1 - 18.45 + 35.6$$
$$= -140.25 \text{ dBW}/(\text{m}^2 \times 1.23 \text{ MHz})$$

where:

   Gr: FSS receiver antenna gain

   70:   maximum number of AS station emitting simultaneously in the FSS receiver bandwidth.

Annex 2

Derivation of a higher hemisphere e.i.r.p. mask from a pfd limit

In testing AM(R)S or AS equipment to determine if it meets a given pfd limit, such as those in Annex 1, it may be useful to determine an equivalent e.i.r.p. mask that can be used for testing purposes.

The pfd limit can be used to mathematically determine a higher hemisphere e.i.r.p. mask, e.i.r.p. (θ, H) where θ is the angle above the local horizontal plane and H is the altitude of the aircraft. This conversion proceeds in two steps. First, θ is converted to an equivalent angle below the horizontal at the satellite, γ. Then the length of the propagation path for angle above the horizontal θ is determined and used to calculate the spreading loss for the path and the resulting e.i.r.p.

Step 1: Calculation of an angle below the horizontal at the satellite in degrees, γ, from θ and H:

$$\gamma = \arccos\left((R_e + H) \times \cos\left(\frac{\theta}{R_e + H_{Sat}} \right) \right)$$

where:

θ : angle above the horizontal at the AS

R_e : Earth radius (6 378 km)

H : altitude of the aircraft (km)

H_{sat}: altitude of the FSS satellite (km)

γ : angle below horizontal at the satellite.

Step 2: Calculation of the e.i.r.p. value from the defined pfd limit:

$$d = \left((R_e + H)^2 + (R_e + H_{sat})^2 - 2(R_e + H)(R_e + H_{sat})\cos(\gamma - \theta) \right)^{1/2}$$

$$\text{e.i.r.p.}(\theta, H) = \text{pfd} + 10\log_{10}(4\,\pi\,d^2) + 60$$

where:

d : distance between the AS and the considered point on the Earth's surface (km)

pfd : pfd limit (dB(W/(m^2 · MHz)))

e.i.r.p. : (dB(W/MHz)).

The graph in Fig. 1 shows this function for an aircraft altitudes of 12 km based on the pfd limit provided in Annex 1, Part III Annex 1, and an assumed satellite altitude, H_{sat} of 1 414 km.

FIGURE 1
e.i.r.p. max versus angle above the horizontal
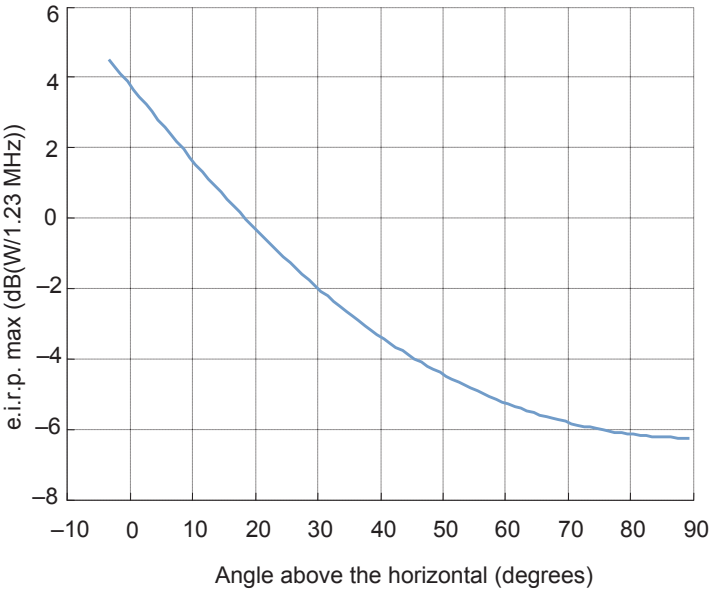
RECOMMENDATION ITU-R M.2013

Technical characteristics of, and protection criteria for non-ICAO aeronautical radionavigation systems, operating around 1 GHz

(2012)

Scope

This Recommendation describes the technical characteristics of, and protection criteria for, non-International Civil Aviation Organisation (ICAO) aeronautical radionavigation service (ARNS) systems operating around 1 GHz for use in compatibility studies. It concerns with non-ICAO ARNS systems operating in countries referred to in RR No. **5.312** and TACAN systems.

The ITU Radiocommunication Assembly,

considering

a) that the tactical air navigation system (TACAN) is an aeronautical radionavigation system used on a national basis and operates in the frequency band 960-1 215 MHz;

b) that the TACAN system is used by both civil and state aircraft;

c) that when used by civil aviation, TACAN functionally is equivalent to the ICAO standardized distance measuring equipment (DME);

d) that the TACAN system provides additional functionality to that of DME, i.e. obtaining bearing information;

e) that this additional functionality results in technical characteristics that differ from those of DME and may require additional consideration in future compatibility studies,

f) that the use of TACAN also includes shipborne and air-to-air applications,

noting

a) that according to Resolution 417 (WRC-07) precedence must be given to the ARNS operating in the frequency band 960-1 164 MHz;

b) that ITU-R studies have shown that following the introduction of aeronautical mobile (route) service (AM(R)S) in the frequency band 960-1 164 MHz, more detailed site-specific compatibility studies between TACAN and AM(R)S systems need to be performed,

recommends

that for compatibility studies the characteristics and protection criteria in the annexes should be used.

Annex 1

Tactical air navigation system

TACAN is an aeronautical radionavigation system used on a national basis operating between 960 and 1 215 MHz. A TACAN system consists of an interrogator on-board an aircraft and a beacon which gives the replies. In most cases the TACAN beacons are fixed ground based installations but there are maritime mobile and aeronautical mobile beacons in use as well. Depending on the generated e.i.r.p. and design of the interrogator slant ranges up to 400 nm (740 km) can be achieved but in practice the range is limited to the maximum radio line-of-sight (RLOS). The aircraft unit transmits regular pulse pairs, so-called interrogation pulses which are received by ground based installations (beacons). The TACAN pulses have a pulse width of 3.5 µs at the 50% amplitude points. The spacing between the pulses of an interrogation pulse pair is 12 µs (X channel) or 36 µs (Y channel). After receiving an interrogator pulse pair a ground station will test the pulse shape and spacing. If these fall within the acceptance limits, it will respond by transmitting a reply after a fixed delay with a ±63 MHz frequency offset from the interrogation frequency depending on selected channel on pulse code. The beacon has a spacing between the reply pulses of 12 µs (X channel) and 30 µs (Y channel). After receipt of the reply, the interrogator will calculate the momentary slant range distance to the beacon from the time elapsed between transmitting interrogation and receiving reply pulse pairs.

The beacon will receive interrogations from many aircraft and therefore will send out many replies. Each interrogator creates a unique pattern by varying, within certain limits, the time between the pulse pairs to avoid generation of synchronic replies. By this principle each platform is able to recognize among all pulse pairs the replies that are initiated by its own interrogator.

For identification purposes, a TACAN beacon transmits a Morse ID code. The ID tone is used at the airborne interrogators to verify if the range readouts are provided by the correct beacon. Besides the pulse responses, proper reception of the ID tone is also an important condition for TACAN interrogators to properly function.

In addition to the range measurements TACAN also offers azimuth bearing information. The bearing information is provided by applying a modulation in the amplitude of the pulses transmitted by the ground beacon. This pulse amplitude modulation (PAM) is created using either a mechanically or electronically scanning beacon antenna. The variation in the azimuth pattern in the form of 15 Hz and 135 Hz antenna lobes at the maximum allowable modulation index of 55% will reduce the signal level of the reply pulses by up to 10.7 dB below the maximum e.i.r.p. level of pulses without PAM. In order for the interrogator to decode the orientation of the antenna pattern in reference to north from the PAM, an additional 900 pulse pairs, consisting of a north-reference-pulse-group (NRPG) and additional fine reference pulse groups (RPG) are transmitted by the beacon. In order to obtain accurate bearing information and be able to reply to at least 100 aircraft with 70% reply efficiency a constant number of at least 3 600 pulse pairs have to be transmitted.

The TACAN system is used for aeronautical navigation for both state aircraft as well as civil aviation. When used by civil aviation, the TACAN equipment is functionally equivalent to the ICAO standardized DME. TACAN characteristics are given in Table 1.

TABLE 1

Typical characteristics of TACAN stations

Purpose	Units	Radio systems for air navigation (960-1 215 MHz)				
		Earth-aircraft	Aircraft-Earth	Earth-aircraft maritime	Aircraft-Earth maritime	Aircraft –aircraft
Radio transmission direction		Earth-aircraft	Aircraft-Earth	Earth-aircraft maritime	Aircraft-Earth maritime	Aircraft –aircraft
Operating frequency range	(MHz)	962-1 213	1 025-1 150	962-977	1 025-1 088	1 025-1 151
Operation range (limited to RLOS)	(km)	up to 600	up to 600	up to 600	up to 600	up to 740
Transmitted information		Range and bearing response signals, Identification information	Range and bearing request signal	Range and bearing response signals, Identification	Range and bearing request signal	Range and bearing response signals, Identification
Transmitter characteristics						
Station name		Beacon	Interrogator	Beacon	Interrogator	Beacon
Height above the ground	(m)	3 (10 ft)	up to 18 288 (60 000 ft)	3 (10 ft)	up to 18 288 (60 000 ft)	up to 18 288 (60 000 ft)
Signal type		Pulsed	Pulsed	Pulsed	Pulsed	Pulsed
Channel spacing	(MHz)	1	1	1	1	1
Type of modulation		Pulse form and pulse pair spacing	Pulse form and pulse pair spacing	Pulse form and pulse pair spacing	Pulse form and pulse pair spacing	Pulse form and pulse pair spacing
Transmitter power (pulsed)	(dBW)	39 (max)	33 (max.)	39 (max)	33 (max)	33 (max)
Pulse length	(μs)	3.5 ± 0.5 (50% amplitude)	3.5 ± 0.5 (50% amplitude)	3.5 ± 0.5 (50% amplitude)	3.5 ± 0.5 (50% amplitude)	3.5 ± 0.5 (50% amplitude)
Typical duty factor	(%)	2.52	0.105	2.52	0.105	0.735
Antenna type		Circular array	Omnidirectional	Circular array	Omnidirectional	Circular array
Typical antenna gain	dBi	6	0	6	0	6

TABLE 1 *(end)*

Radio systems for air navigation (960-1 215 MHz)

| Purpose	Units	Aircraft station	Airport and en-route ground station	Aircraft stations	Maritime station	Aircraft station
Receiver characteristics						
Receiving station						
Operating frequency range	(MHz)	962-1 213	1 025-1 150	962-977	1 025-1 088	1 025-1 151
Height above the ground	(m)	up to 20 880 (60 000 ft)	3 (10 ft)	up to 20 880 (60 000 ft)	3 (10 ft)	up to 20 880 (60 000 ft)
Receiver 3 dB bandwidth	(MHz)	2	2-4.5	2	2-4.5	2-4.5
Max/min antenna gain	(dBi)	5.4/0	9.1/4.1	5.4/0	9.1/4.1	5.4/0
Polarization		Vertical	Vertical	Vertical	Vertical	Vertical
Receiver sensitivity	(dBW)	−122	−122	−122	−122	−122
Maximum acceptable interference level based on received power	(dBW)	−129	−130	−129	−130	−129

NOTE – The protection ratios shown in Table 1 were obtained for non-pulsed signals. In case of pulsed signals it is required to carry out additional studies. In this respect signals with a pulse length of more than 50 μs are considered non-pulsed or continuous signals.

NOTE – The airborne antenna gain is taken from Recommendation ITU-R M.1642-1.

NOTE – Measurements on some TACAN devices showed that the TACAN sensitivity for the distance and angular measurements only differ by 3 dB for the TACAN interrogator receiver (−90 dBm for distance and −87 dBm for angular measurement).

There is a large installed base of TACAN equipment, both ground stations (beacons) as well as aircraft stations (interrogators), in various administrations. The actual technical characteristics of the various types of equipment vary. One important factor, that determines the interference effect, is the receiver selectivity curve. Figure 1 shows the receiver selectivity curves of five types of TACAN interrogator equipment. It can be seen that there is a great spread in the selectivity of the different TACAN type receivers. In the compatibility studies all TACAN type interrogators should be taken into account in order to guarantee sufficient protection of this aeronautical radionavigation service (ARNS) application including both range and azimuth determination functionality.

Figure 2 shows a receiver selectivity curve for a typical TACAN beacon. The TACAN beacon selectivity is worse than those of the TACAN interrogator receivers.

FIGURE 1

Airborne station (interrogator) receiver RF-selectivity curves
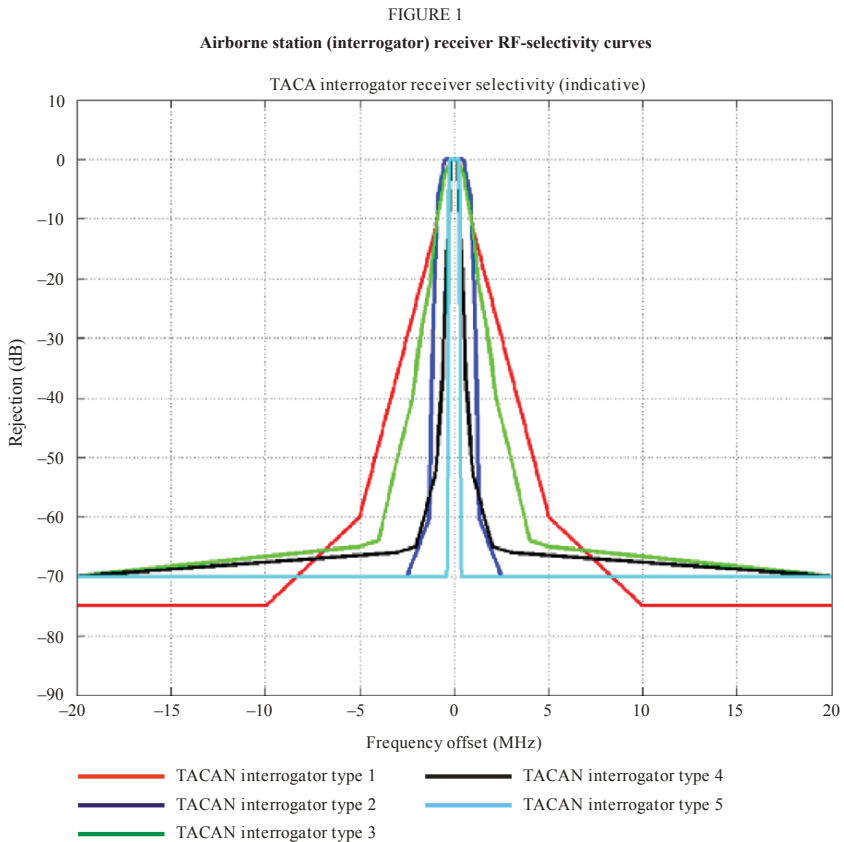
F.5-1007-01

FIGURE 2

Ground station (beacon) receiver RF selectivity curves

TACAN beacon receiver RF-selectivity

Frequency Offset (MHz)
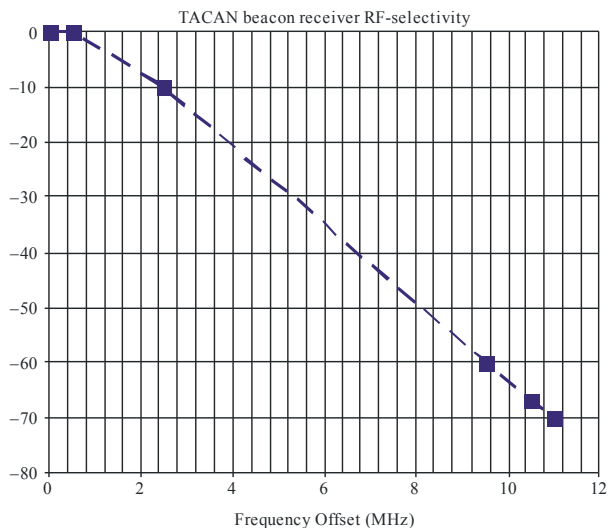
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Annex 2

Non-ICAO aeronautical radionavigation ystems operating in countries referred to in RR No. 5.312

Specifically the countries referred to in RR No. **5.312** of the Radio Regulations operate the aeronautical radionavigation systems of the following three types:

–   Type 1: the ARNS systems of the first type refer to direction-finding and ranging systems. The systems are designed for finding an azimuth and a slant range of an aircraft as well as for area surveillance and inter-aircraft navigation. They are composed of airborne and ground-based stations. The airborne stations generate requesting signals transmitted via omnidirectional antennae and received at ARNS ground stations which also operate in an omnidirectional mode. The ground stations generate and transmit response signals containing azimuth/ranging information. Those signals are received and decoded at the ARNS airborne stations. The first type stations transmit the signals requesting the azimuth/ranging data outside the 960-1 164 MHz frequency band. After receiving a requesting signal the ARNS ground stations use the 960-1 164 MHz frequency band only for transmitting the ranging data to be received at the ARNS airborne stations. Thus the ARNS systems of the first type use the 960-1 164 MHz frequency band only for transmitting the signals in the surface-to-air direction. The maximum operation range for

the first type ARNS systems is 400 km. It is expected that in some of the countries mentioned in RR No. 5.312 the usage of Type 1 of ARNS mentioned above may be discontinued.

– Type 2: the ARNS direction-finding and ranging systems of the second type are designed for the same missions as the first type ARNS systems. The primary difference of the second type stations refers to the fact that requesting signals are transmitted by the airborne stations in the same frequency band as responding signals transmitted from the ground stations. Moreover, the ground-based ARNS stations of the second type can operate in both directional and omnidirectional modes. Directional mode provides increased number of operational channels at the ARNS stations. The maximum operation range for the first type ARNS systems is 400 km. It is planned to use the overall frequency band 960-1 164 MHz allocated to the ARNS in order to increase flexibility of operation of the second type ARNS systems. Application of the wideband tuning filter on the ARNS receiver front end is the design peculiarity of the second type ARNS systems which is stipulated by the necessity to receive signals on several channels simultaneously. The 3 dB bandwidth of this filter is 22 MHz and it allows receiving simultaneously up to five channels among 30 overlapping channels of 4.3 MHz each. The simultaneous usage of wideband filter and correlator allows increase in the accuracy of aircraft position data measurement and C/N ratio at the receiver front end as well. Type 2 of the ARNS system can operate in a limited number of countries mentioned in RR No. 5.312.

– Type 3: the ARNS systems of the third type are designed for operating at the approach and landing stages of flight. The system provides control functions of heading, range and glide path at aircraft approach and landing. The ARNS ground stations of the third type operate in both directional and omnidirectional modes. Operation range of the third type ARNS systems does not exceed 60 km. The 960-1 164 MHz frequency band is used for operation of the channels designed for control of the glide path and range between airborne and ground ARNS stations. Type 3 of the ARNS system can operate in a limited number of countries mentioned in RR No. 5.312.

Table 2 provides a brief technical description of the ARNS stations.

Thus the stations of the non-ICAO systems operate using the air-to-surface and surface-to-air links are made up of ground and airborne receivers and transmitters.

TABLE 2

**Typical characteristics of the ARNS stations operating in
the countries referred to in RR No. 5.312**

ARNS system characteristics	Type 1	Type 2			Type 3	
Purpose	Radio systems of short-range navigation	Radio systems of short-range navigation			Radio systems of approach and landing	
Operating frequency range	960-1 000.5	960-1 164				
Radioline direction (MHz)	"Earth-aircraft"	"Earth-aircraft"	"aircraft-Earth"	"Earth-aircraft"	"aircraft-Earth"
Operation range	up to 400	up to 400	up to 400	up to 45	up to 45
Transmitted information (km)	Transmission of azimuthal signals, range response signals and request to indication	Transmission of azimuthal signals, range response signals and request to indication	Transmission of range request signal and indication response signal	Transmission of signals in glide path and course channels and range response signals	Transmission of range request
Transmitter characteristics						
Station name	Airport and en-route path ground stations	Airport and en-route path ground stations	Aircraft station	Airport ground station	Aircraft station
Class of emission	700KPXX	4M30P1N	4M30P1D	700KP0X; 4M30P1N	700KP0X; 4M30P1N
Channel spacing (MHz)	0.7	0.7	0.7	0.7	2
Type of modulation	pulsed	pulsed	pulsed	pulsed	pulsed
Transmitter power (pulsed) (dBW)	20-45	29-39	27-33	3-30	5-33
Duty factor (%)	0.018; 0.066	0.064 - 0.3	0.00765	0.04; 0.025	0.009
Mean output Power (min/max) (dBW)	7.6/13.2	7.1/13.8	-8.2	$-4/-6$	-7.5
Pulse length (µs)	1.5; 5.5	1.25; 1.5; 5.5	1.5	1.7	1.7
Antenna type	Omnidirectional	array antenna	omnidirectional	array antenna	omnidirectional
Max/min antenna gain (dBi)	6/0	15.6	3/-10	10/0	1.5/-3
Height above the ground (m)	10	10	up to 12 000	10	up to 12 000

TABLE 2 *(end)*

ARNS system characteristics	Type 1	Type 2		Type 3	
Purpose	**Radio systems of short-range navigation**	**Radio systems of short-range navigation**		**Radio systems of approach and landing**	
Receiver characteristics					
Receiving station	Aircraft station	Aircraft station	Airport and en-route path ground stations	Aircraft station	Airport ground station
Height above the ground (m)	up to 12 000	up to 12 000	10	up to 12 000	10
Receiver 3 dB bandwidth (MHz)	1.5	22	22	7	7
Receiver noise temperature, K (K)	400	1 060	550	400	400
Max/min antenna gain (dBi)	1.5/−3	3/−10	14	1.5/−3	10/0
Polarization	horizontal	horizontal	horizontal	horizontal	horizontal
Receiver sensitivity (dBW)	−120	−118	−125	−110…−120	−113
Protection ratio *C/I* (dB)	25	17	20	25	25

NOTE – The protection ratios shown in Table 2 were obtained for non-pulsed signals. In case of pulsed signals it is required to carry out additional studies. In this respect signals with a pulse length of more than 50 μs are considered non-pulsed or continuous signals.

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Cross-reference list of the regulatory provisions, including footnotes and Resolutions, incorporating ITU-R Recommendations by reference

Recommendation ITU-R	Title of the Recommendation	RR provisions and footnotes with ITU-R Recommendations contained in RR Volume 4
TF.460-6	Standard-frequency and time-signal emissions	No. **1.14**
M.476-5	Direct-printing telegraph equipment in the maritime mobile service	Nos. **19.83**, **19.96A**, **51.41**
M.489-2	Technical characteristics of VHF radiotelephone equipment operating in the maritime mobile service in channels spaced by 25 kHz	Nos. **51.77**, **52.231**, Appendix **18** (*General notes e)*)
M.492-6	Operational procedures for the use of direct-printing telegraph equipment in the maritime mobile service	No. **56.2**
P.525-2	Calculation of free-space attenuation	No. **5.444B** (via Resolution **748** (**Rev.WRC-12**))
P.526-11	Propagation by diffraction	No. **5.444B** (via Resolution **748** (**Rev.WRC-12**))
M.541-9	Operational procedures for the use of digital selective-calling equipment in the maritime mobile service	Nos. **51.35**, **52.112**, **52.149**, **52.153**, **54.2**
M.585-6 (Annex 1)	Assignment and use of identities in the maritime mobile service	Nos. **19.99**, **19.102**, **19.111**
M.625-3	Direct-printing telegraph equipment employing automatic identification in the maritime mobile service	Nos. **19.83**, **51.41**
M.633-4	Transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through a satellite system in the 406 MHz band	No. **34.1**
S.672-4	Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites	TABLE **22-2** (and No. **22.5D.3**), TABLE **22-3** (and No. **22.5F.3**)
M.690-1	Technical characteristics of emergency position-indicating radio beacons (EPIRBs) operating on the carrier frequencies of 121.5 MHz and 243 MHz	Appendix **15** (Table 15-2)
P.838-3	Specific attenuation model for rain for use in prediction methods	Appendix **30A** (Annex 3 § 2.2 Step 6)
M.1084-4	Interim solutions for improved efficiency in the use of the band 156-174 MHz by stations in the maritime mobile service	Appendix **18** (NOTE B) (prior to the table)
SM.1138-2	Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions	Appendix **1** (§ 1 and § 2)
SA.1154	Provisions to protect the space research (SR), space operations (SO) and Earth-exploration satellite services (EES) and to facilitate sharing with the mobile service in the 2 025-2 110 MHz and 2 200-2 290 MHz bands	No. **5.391**

Recommendation ITU-R	Title of the Recommendation	RR provisions and footnotes with ITU-R Recommendations contained in RR Volume 4
M.1171	Radiotelephony procedures in the maritime mobile service	Nos. **52.192**, **52.195**, **52.213**, **52.224**, **52.234**, **52.240**, **57.1**
M.1172	Miscellaneous abbreviations and signals to be used for radiocommunications in the maritime mobile service	No. **19.48**
M.1173	Technical characteristics of single-sideband transmitters used in the maritime mobile service for radiotelephony in the bands between 1 606.5 kHz (1 605 kHz Region 2) and 4 000 kHz and between 4 000 kHz and 27 500 kHz	Nos. **52.181**, **52.229**, Appendix **17** (Annex 1, Part B, Section I § 2 and § 6)
M.1174-2	Technical characteristics of equipment used for on-board vessel communications in the bands between 450 and 470 MHz	Nos. **5.287**, **5.288**
M.1187-1	A method for the calculation of the potentially affected region for a mobile-satellite service (MSS) network in the 1-3 GHz range using circular orbits	Appendix **4** (Annex 2 item C.11.b)
S.1256	Methodology for determining the maximum aggregate power flux-density at the geostationary-satellite orbit in the band 6 700-7 075 MHz from feeder links of non-geostationary satellite systems in the mobile-satellite service in the space-to-Earth direction	No. **22.5A**
RS.1260-1	Feasibility of sharing between active spaceborne sensors and other services in the range 420-470 MHz	No. **5.279A**
BO.1293-2	Protection masks and associated calculation methods for interference into broadcast-satellite systems involving digital emissions	Appendix **30A** (Annex 3 § 3.3), Appendix **30** (Annex 5 § 3.4)
S.1340	Sharing between feeder links for the mobile-satellite service and the aeronautical radionavigation service in the Earth-to-space direction in the band 15.4-15.7 GHz	No. **5.511C**
S.1341	Sharing between feeder links for the mobile-satellite service and the aeronautical radionavigation service in the space-to-Earth direction in the band 15.4-15.7 GHz and the protection of the radio astronomy service in the band 15.35-15.4 GHz	No. **5.511A**
S.1428-1	Reference FSS earth-station radiation patterns for use in interference assessment involving non-GSO satellites in frequency bands between 10.7 GHz and 30 GHz	TABLE **22-1A**, TABLE **22-1B**, TABLE **22-1C** (and No. **22.5C.6**)
BO.1443-2	Reference BSS earth station antenna patterns for use in interference assessment involving non-GSO satellites in frequency bands covered by RR Appendix 30	TABLE **22-1D** (and No. **22.5C.11**)
M.1583-1	Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites	No. **5.443B** (via Resolution **741 (Rev.WRC-12)**), App**4** Annex 2 (item A.17.b.3) (via Resolution **741 (Rev.WRC-12)**)

Recommendation ITU-R	Title of the Recommendation	RR provisions and footnotes with ITU-R Recommendations contained in RR Volume 4
S.1586-1	Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites	No. **5.551H**
F.1613	Operational and deployment requirements for fixed wireless access systems in the fixed service in Region 3 to ensure the protection of systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 250-5 350 MHz	No. **5.447E**
RA.1631	Reference radio astronomy antenna pattern to be used for compatibility analyses between non-GSO systems and radio astronomy service stations based on the epfd concept	No. **5.208B** (via Resolution **739 (Rev. WRC-07)**, No. **5.443B** (via Resolution **741 (Rev.WRC-12))**, No. **5.551H**, App4 Annex 2 (item A.17.b.3) (via Resolution **741 (Rev.WRC-12))**
RS.1632	Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service	No. **5.447F**
M.1638	Characteristics of and protection criteria for sharing studies for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5 250 and 5 850 MHz	Nos. **5.447F, 5.450A**
M.1642-2	Methodology for assessing the maximum aggregate equivalent power flux-density at an aeronautical radionavigation service station from all radionavigation-satellite service systems operating in the 1 164-1 215 MHz band	Nos. **5.328A** (via Resolution **609 (Rev. WRC-07))**
M.1643	Technical and operational requirements for aircraft earth stations of aeronautical mobile-satellite service including those using fixed-satellite service network transponders in the band 14-14.5 GHz (Earth-to-space)	No. **5.504B** (refers to Annex 1, Part C of Rec. ITU-R M.1643), Nos. **5.504C, 5.508A** and **5.509A** (refer to Annex 1, Part B of Rec. ITU-R M.1643)
M.1652-1 (Annex 1)	Dynamic frequency selection in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band	No. **5.446A** (via Resolution **229 (Rev.WRC-12))**
M.1827	Technical and operational requirements for stations of the aeronautical mobile (R) service (AM(R)S) limited to surface application at airports and for stations of the aeronautical mobile service (AMS) limited to aeronautical security (AS) applications in the band 5 091-5 150 MHz	No. **5.444B** (via Resolution **748 (Rev.WRC-12))**
M.2013	Technical characteristics of, and protection criteria for non-ICAO aeronautical radionavigation systems, operating around 1 GHz	No. **5.327A** (via Resolution **417 (Rev.WRC-12))**