RECOMMENDATION ITU-R SA.1158-1*

SHARING OF THE 1 675-1 710 MHz BAND BETWEEN THE METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH) AND THE MOBILE-SATELLITE SERVICE (EARTH-TO-SPACE)

(Question ITU-R 204/7)

(1995-1997)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) has allocated the 1 675-1 710 MHz band on a primary basis in Region 2 to the mobile-satellite service (MSS) (Earth to-space) and maintained the primary status of the meteorological-satellite (METSAT) service (space-to-Earth);

b) that each of these two services may be provided by geostationary satellite systems and non-geostationary satellite systems;

c) that for more than 20 years the international group of METSAT service operators have agreed to separate the band 1 675-1 710 MHz into three sub-bands which are being used and are expected to continue to be used as follows:

1 675-1 690 MHz: main earth stations at fixed locations for reception of raw image data, data collection data and spacecraft telemetry from geostationary meteorological satellites;

1 690-1 698 MHz: user stations for direct readout services from geostationary meteorological satellites. (Some METSAT service operators currently use frequencies below 1 690 MHz to provide direct readout services from geostationary meteorological satellites.);

1 698-1 710 MHz: user stations for direct readout services and prerecorded image data at main earth stations from non-geostationary meteorological satellites;

d) that the 1 675-1 690 MHz band is and will continue to be used primarily but not exclusively by a limited number of main meteorological earth stations (Command and Data Acquisition, CDA);

e) that there exist thousands of METSAT earth stations in the 1 690-1 710 MHz band, many of them using small antennas;

f) that for different functions provided by the METSAT service, meteorological earth stations in the 1 690-1 710 MHz band can be fixed, mobile or transportable;

g) that Recommendation ITU-R SA.1027 provides sharing criteria for current METSAT systems using satellites in low-Earth orbit (LEO);

h) that Recommendation ITU-R SA.1161 provides sharing criteria for current METSAT systems using satellites in geostationary orbit (GSO);

j) that MSS earth station transmitters are expected to be deployed near or within a METSAT service area;

k) that some operators of meteorological satellites plan to increase the channel bandwidths and revise the frequency assignment plans for new generations of METSAT satellites, which would make interleaving of meteorological and mobile satellite channels impracticable;

l) that geostationary METSAT space stations, which initially serve a certain area, may be relocated from time to time in order to provide coverage of another area;

m) that Annexes 1, 2 and 3 provide a view pertaining to the technical sharing aspects of the METSAT and MSS services operating in the 1 675-1 710 MHz band;

* This Recommendation should be brought to the attention of the World Meteorological Organisation (WMO) and Radiocommunication Study Groups 8 and 9.

n) that mobile-satellite techniques are either available or may be able to be developed to automatically and dynamically avoid transmissions from earth stations in the vicinity of receiving METSAT earth stations and that such techniques are described in Annex 3,

recognizing

1 that Resolution 46 (Rev.WRC-95) of the World Radiocommunication Conference (Geneva, 1995) (WRC-95) states that, in the band 1 675-1 710 MHz, stations in the MSS shall not cause harmful interference to, nor constrain the development of, the METSAT and meteorological aids services, and that the use of this band shall be subject to its provisions (see also Footnote S5.377 to the Radio Regulations (RR));

2 that studies (see Annex 1) have indicated that potential interference to meteorological earth stations from co-frequency MSS earth stations would be acceptable when the meteorological earth stations are protected by exclusion zones with radii of up to 55 km for LEO MSS and 70 km for GSO MSS and appropriate technical measures are employed to avoid transmission by mobile earth stations within these exclusion zones;

3 that the control of the mobile earth stations will be achieved with a location determination system forming part of the mobile satellite network; this location determination may require a narrow-band signalling channel transmitted from the mobile earth station to the mobile satellite;

further recognizing

4 that the great number of meteorological earth stations operating in the 1 690-1 710 MHz band and its dense occupation by meteorological data channels, as well as interference caused in particular by non-geostationary meteorological satellites to mobile satellites, would render operation in this band of mobile earth stations impracticable,

recommends

1 that mobile earth stations operating in the 1 675-1 690 MHz band shall not transmit, except on a narrow-band signalling channel, inside the exclusion zones around main meteorological earth stations (Command and Data Acquisition), taking into consideration the radii identified in *recognizing* 2, increased by the precision (in km) of the position determination system referred to in *recognizing* 3 (see Note 1); additional study is required to determine the criteria for coordination between MSS and GVAR stations in this band;

NOTE 1 – The WMO is invited to inform the ITU, at regular intervals, of the geographical position of main meteorological earth stations;

2 that mobile satellite systems be equipped with demonstrated location determination capability, permitting the determination of the position of the mobile earth stations, in order to assure compliance with *recommends* 1;

3 that the narrow-band signalling channel, which may be required worldwide by certain location determination systems, be assigned in agreement with the meteorological operators concerned;

4 that the 1 690-1 698 MHz band not be used by mobile earth stations;

5 that the 1 698-1 710 MHz band not be used by mobile earth stations unless studies prove that sharing on a time separation basis is feasible and practicable.

ANNEX 1

Sharing of the frequency band 1 670-1 710 MHz between the meteorological-satellite service and the mobile-satellite service

1 Introduction

At WARC-92, the 1 675-1 710 MHz band was allocated to the MSS on a primary basis (Earth-to-space) in Region 2. The METSAT had already a primary status in the space-to-Earth direction in all three Regions. The potential for sharing this band has been identified. Based upon Resolution No. 213, the ITU-R has been invited to study as a matter of urgency the technical and operational issues relating to the sharing of this band between the above services. Resolution No. 213 has been modified at WRC-95 in order to emphasize the importance of techniques to protect METSAT earth stations.

Footnote RR S5.377 applies to the MSS allocation in Region 2 and states that the "stations in the mobile-satellite service shall not cause harmful interference to, nor constrain the development of, the meteorological-satellite and meteorological aids services (see Resolution 213 (Rev.WRC-95)) and the use of this band shall be subject to coordination under Resolution 46 (Rev.WRC-95)/No. S9.11A". Resolution 46 (Rev.WRC-95) defines interim procedures for the coordination and notification of frequency assignments of non-geostationary-satellite networks in certain space services and other services to which the bands are allocated.

This study investigates the use of the band 1 670-1 710 MHz by the meteorological services in view of potential sharing with mobile-satellite systems. The international group of METSAT service operators have agreed to divide the band 1 675-1 710 MHz into three distinct sub-bands which are being used in the following way:

1 675-1 690 MHz: main high gain earth stations at relatively few fixed locations for reception of raw image data and data collection from geostationary-meteorological satellites;

1 690-1 698 MHz: user stations for direct read-out services, data collection and spacecraft telemetry from geostationary-meteorological satellites with thousands of stations worldwide;

1 698-1 710 MHz: user stations for direct read-out and prerecorded image data at main earth stations from non-geostationary meteorological satellites with hundreds of stations worldwide.

Both GSO and LEO METSAT satellites are currently in use with firm plans for further expansion of the services provided. The MSS has a variety of plans for the use of the band which involve GSO as well as LEO MOBile SATellites (MOBSATs).

All possible interference constellations in the ground as well as in the space segment have been considered in this study. Seven different types of METSAT earth stations have been taken into account. The station size varies to a large extent and ranges between 1.2 and 15 m. Elevation angles between 3° and 90° can be found. Regarding the interference caused by the MSS terminals, several typical cases have been identified. Terminals with relatively low e.i.r.p. transmitting to LEO satellites (e.g. IRIDIUM type systems) and such with significantly higher e.i.r.p. communicating with GSO MOBSATs (e.g. INMARSAT). For both cases the co-channel interference as well as the adjacent channel interference have been studied.

On the space segment side, four possible interference constellations between LEO and GSO spacecraft of both services have been investigated. For each of the four cases, there exists a proximity and a tangential (quasi antipodal) constellation. Figure 1 shows a summary of all interference constellations considered in this study. MSS terminals can be handheld units or mounted on cars or other moving vehicles. METSAT stations are usually found at elevations several metres above ground as they are typically mounted on buildings.

2 Technical specifications

2.1 METSAT specifications

2.1.1 Earth station characteristics

Regarding types of earth stations, the current and the future generation of user stations and the main stations have been studied. The user stations comprise primary data user stations (PDUS), secondary data user stations (SDUS), meteorological data dissemination (MDD), high resolution picture transmission (HRPT), high rate user stations (HRUS) and low rate user stations (LRUS). Table 1 lists the key technical characteristics used for this study.

FIGURE 1

Investigated interference constellations

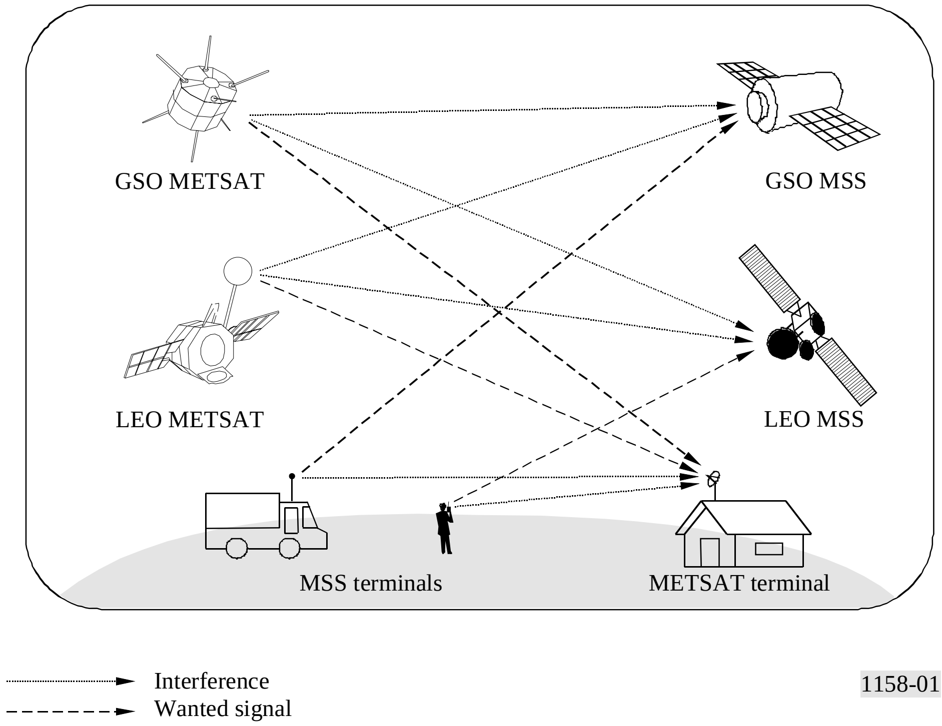


TABLE 1

Typical METSAT station characteristics

METSAT earth station	PDUS	SDUS	MDD	HRPT	HRUS	LRUS	Main
Channel centre frequency (kHz)	1 691 1 694.5	1 694.5 1 691	1 695.74	1 698 1 701 1 702.5 1 704 1 707	1 695.15 1 691	1 691 1 695.15	All user frequencies except HRPT
Bandwidth (kHz)	660	26	4×31.2	2 668 5 334	2 000	660	30 to 5 400
Polarization	Linear	Linear	Linear	RHC, LHC	Linear	Linear	Linear
Antenna diameter (m)	3	1.2	2.4	2.4, 15	4	1.8	15
G/T (dB(K^{-1}))	10.5	2.5	6	6.5	13	5.5	25
Minimum elevation angle (degrees)	3	3	3	5	3	3	5

The required separation distances are a function of the elevation angle. This angle ranges between 5° and 90° for LEO based systems and 3° and 90° for stations receiving data from GSO satellites. Main stations will also not operate at elevation angles of less than 5°. The number of METSAT stations as currently registered with the WMO exceeds 8 000 for the user stations in the 1 690-1 710 MHz band and 15 for the main stations in the 1 675-1 690 MHz band.

2.1.2 GSO satellite characteristics (MOP-series)

Location:	0.0° E
e.i.r.p. spectral density DCP:	–18.5 dB(W/kHz) at 1 675.281 MHz ± 100 kHz
e.i.r.p. spectral density TLM1:	–9.8 dB(W/kHz) at 1 675.929 MHz ± 15 kHz
e.i.r.p. spectral density TLM2:	–9.8 dB(W/kHz) at 1 676.180 MHz ± 15 kHz
e.i.r.p. spectral density raw image:	–26.7 dB(W/kHz) at 1 686.833 MHz ± 2.7 kHz
e.i.r.p. spectral density WEFAX1:	7.2 dB(W/kHz) at 1 691.000 MHz ± 13 kHz
e.i.r.p. spectral density WEFAX2:	7.2 dB(W/kHz) at 1 694.500 MHz ± 13 kHz
e.i.r.p. spectral density HIRES1:	–6.9 dB(W/kHz) at 1 691.000 MHz ± 330 kHz
e.i.r.p. spectral density HIRES2:	–6.9 dB(W/kHz) at 1 694.500 MHz ± 330 kHz
e.i.r.p. spectral density MDD1:	–8.0 dB(W/kHz) at 1 695.6938 MHz ± 16 kHz
e.i.r.p. spectral density MDD2:	–8.0 dB(W/kHz) at 1 695.7250 MHz ± 16 kHz
e.i.r.p. spectral density MDD3:	–8.0 dB(W/kHz) at 1 695.7563 MHz ± 16 kHz
e.i.r.p. spectral density MDD4:	–8.0 dB(W/kHz) at 1 695.7874 MHz ± 16 kHz

2.1.3 GSO satellite characteristics (MSG-series)

Location:	0° E
e.i.r.p. spectral density DCP:	–36.1 dB(W/kHz) at 1 675.281 MHz ± 375 kHz
e.i.r.p. spectral density raw image:	–18.8 dB(W/kHz) at 1 683.330 MHz ± 3.0 kHz
e.i.r.p. spectral density LRIT/HRIT:	–14.5 dB(W/kHz) at 1 692.000 MHz ± 2.0 kHz
e.i.r.p. spectral density HRIT/LRIT:	–14.5 dB(W/kHz) at 1 696.000 MHz ± 2.0 kHz

2.1.4 LEO satellite characteristics (METOP)

Orbit height:	827 km
Inclination:	98.7°
Centre frequency nominal:	1 707 MHz
Centre frequency back-up:	1 701 MHz
e.i.r.p. density level:	–20.7 dB(W/kHz)
Bandwidth:	4.5 MHz
Antenna pattern:	RR Appendix 28

In addition, EUMETSAT, France, Japan, China and Russia have immediate plans for similar systems.

2.2 MSS specifications

For the interference assessment, typical characteristics of small MSS terminals have been assumed. The following Tables show system parameters which have been published amongst others by Radiocommunication Task Group 8/3. These data have been brought to the attention of Radiocommunication Working Party 7C for guidance in sharing studies. From this text, a representative set has been extracted for the purpose of this study. Regarding the antenna gain of a LEO MOBSAT, it has been assumed that antennas with a maximum gain between 19 dBi (Earth coverage) and 29 dBi (spot beam) will be used. For the GSO/MSS, values between 18 and 34 dBi have been considered for the purpose of the study.

2.2.1 Earth terminal characteristics for GSO MSS systems

Table 2 shows some typical transmission characteristics for low gain terminals communicating with a geostationary MOBSAT. Due to the large distances involved, a relatively high power is required to transmit a signal to the GSO. For the same type of service, the required e.i.r.p. is typically 20 to 30 dB higher compared to transmissions to a low-Earth orbiter. It appears that the medium gain systems cause stronger interference due to its higher gain and consequently higher maximum e.i.r.p. However, in practice these terminals have some kind of coarse pointing towards the satellite position. As the interference to the METSAT stations is primarily determined by the amount of energy radiated towards the horizon, some degree of antenna discrimination will occur. Unless the MSS terminal actually operates at low elevation angles, the overall effect will be very similar to the systems using omnidirectional antennas.

TABLE 2

Typical characteristics of INMARSAT low gain earth terminals

MSS earth station type	C	M	Aeronautical high gain	Aeronautical low gain
Antenna gain (dBi)	0	14	12	0
e.i.r.p. per channel (dBW)	11	27	26	12
Channel data rate (bit/s)	600	2 400	9 600	300
e.i.r.p./kbit/s (dB(W/kHz))	13.2	23.2	16.2	17.2
Modulation scheme	BPSK	OQPSK	OQPSK	BPSK
Channel spacing (kHz)	5	10	17.5	2.5
Mean e.i.r.p. in horizontal direction (dBW)	11	13	14	12
e.i.r.p. density (dB(W/kHz)) based on channel spacing	4	3	1.6	8

2.2.2 Earth terminal characteristics for LEO MSS systems

Information has been published on a number of MSS LEO systems in a more or less advanced planning stage with widely varying system characteristics. One of the most advanced representatives is the IRIDIUM system. The characteristics shown in Table 3 have been considered to be typical for LEO MSS systems and have been used for this study.

TABLE 3

Typical characteristics of the IRIDIUM system

Maximum antenna gain towards horizon (dBi)	0
e.i.r.p. per channel (dBW)	–4 to 6
Channel data rate (kbit/s)	50
e.i.r.p./kbit/s (dB(W/kHz))	–21 to –11
Modulation scheme	QPSK
Polarization	RHCP
Minimum elevation angle (degrees)	8.3
RF carrier spacing (kHz)	41.67
Modulation bandwidth (kHz)	31.5
Altitude	780
Inclination	86
Orbital planes	6
e.i.r.p. density (dB(W/kHz))	–20 to –10

3 Protection criteria and radio regulatory aspects

Sharing and coordination criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using LEO satellites have been established in Recommendation ITU-R SA.1027. Recommendation ITU-R SA.1161 applies to data dissemination and direct readout systems in the METSAT using GSO satellites. Table 4 lists the corresponding parts of these Recommendations applicable to the systems investigated in this study. The acceptable interference values have been listed both per reference bandwidth (BWr) and as a density (kHz).

TABLE 4

Sharing criteria for meteorological systems

Frequency band (MHz)	Earth station type	Minimum elevation angle, ε (degrees)	Interference signal power density (dB(W/BWr)) for 20% of time	Interference signal power density (dB(W/kHz)) for 20% of time
1 675-1 690	Main station	5	–150.7 per 2 600 kHz	–184.8
1 690-1 698	SDUS	3	–150.1 per 50 kHz	–167
1 690-1 698	PDUS MDD	3	–145.4 per 2 110 kHz	–178.6
1 700-1 710	HRPT	5	–145.0 per 2 668 kHz	–179.3

The ITU has so far only established sharing criteria for existing systems. Footnote RR S5.377 stipulates that the introduction of MSS systems shall not constrain the development of meteorological services. The METEOSAT second generation (MSG) system is currently under development and the following new types of stations have to be considered. A signal-to-interference ratio *C*/*I* of 20 dB has been assumed for the corresponding protection criteria.

TABLE 5

Acceptable interference for second generation systems

Frequency band (MHz)	Earth station type	Minimum elevation angle, ε (degrees)	Interference signal power density (dB(W/BWr)) for 20% of time	Interference signal power density (dB(W/kHz)) for 20% of time
1 690-1 698	LRUS	3	–165 per 2 000 kHz	–186
1 690-1 698	HRUS	3	–158 per 4 000 kHz	–188

4 Interference analyses

4.1 Interference assessment from MSS earth terminals to METSAT earth stations

A transmitting terrestrial MSS terminal may cause interference to a receiving METSAT earth station if transmission is effected in its vicinity. A separation distance is consequently required between the MSS earth station and any of the METSAT stations in order to reduce the received interfering signal below the protection criterion. The separation distance is the boundary distance below which in all likelihood harmful interference will be caused to the receiving METSAT station unless additional blockage of the signal path, for example by buildings or hills, takes place. In addition to the free space loss, the signal will be attenuated due to atmospheric effects, path obstacles and diffraction due to the Earth's curvature and terrain variations. The main additional contribution comes from diffraction losses. Atmospheric attenuation is negligible at 1.7 GHz. The main signal attenuation L_t is then given by the sum of the free space loss L_s and the diffraction loss L_d.

$$L_t = L_s + L_d$$

The free space loss is given by $L_s \cong 20 \log(42\ d\,f)$. Recommendation ITU-R P.526 proposes an estimation of the diffraction losses based on the equations:

$$L_d = -\left(F(X) + G(Y_1) + G(Y_2)\right)$$

$$F(X) = 11 + 10 \log X - 17.6\ X$$

$$G(Y) = 20 \log\left(Y + 0.1\,Y^3\right) \qquad \text{for} \quad 10\,K < Y < 2$$

$$X = 2.2\,\beta\,f^{1/3}\ a_e^{-2/3}\,d$$

$$Y = 9.6 \times 10^{-3}\,\beta\,f^{2/3}\ a_e^{-1/3}\,h$$

where:

d: path length (km)

h: antenna height (m)

f: frequency (MHz)

a_e: equivalent Earth's radius ($\cong$ 8 500 km)

β: polarization parameter ($\cong$ 1)

K: surface admittance factor (<0.01).

The total signal attenuation is a function of the distance (km) and the antenna heights of the transmitting and receiving terminals. For the METSAT stations, a medium height of 10 m has been assumed as most terminals are mounted on buildings or roofs. The height of mobile terminals varies depending on whether it is handheld or mounted on cars, trucks, ships or even aircraft. A medium height of 3 m has been assumed. The equation to be solved for the total signal attenuation with antenna heights of 10 m and 3 m, respectively, is:

$$L_t = 115.05 + 10 \log d + 1.11\ d$$

The resulting required separation distances have been calculated and presented graphically. In order to take into account additional attenuation to the interfering signal caused by trees, buildings, hills, etc. a signal blockage factor of 6 dB has been taken into account for half of the MSS terminals. This results in an average attenuation of 2 dB for the cumulative interference from all MSS terminals within the reference bandwidth of the METSAT earth station receiver.

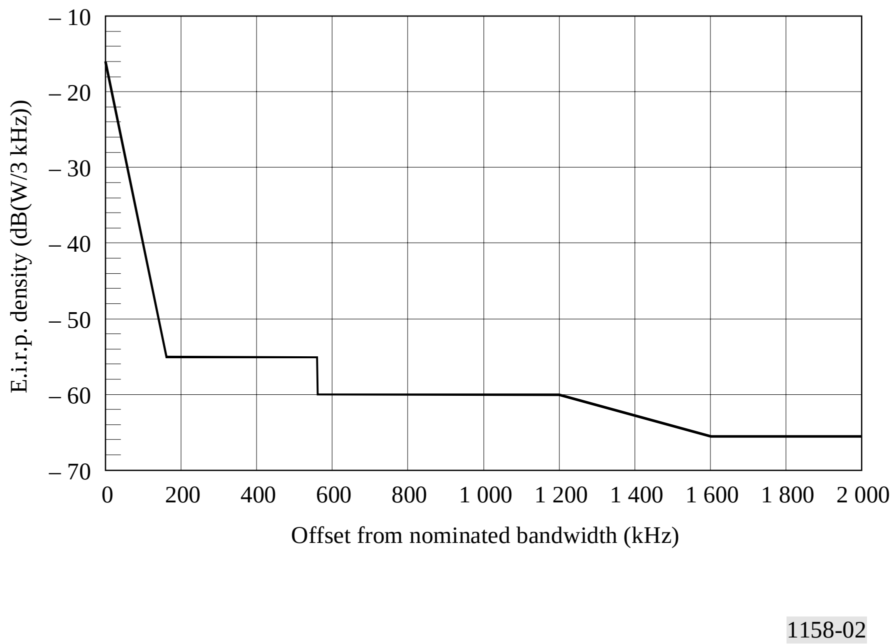
In addition, the probability of several MSS terminals received at maximum antenna gain towards the horizon is decreasing with the elevation angle. The lower the elevation, the lower the likelihood of several terminals being in the main beam. A correction factor has therefore been taken into account amounting to 2 dB for medium elevation angles and 5 dB for low elevation angles.

The signal polarization of most METSAT applications is linear whereas the majority of MSS terminals transmit at circular polarization. A polarization discrimination factor of 3 dB has therefore been included in the calculations for the multiple entry interference.

An important aspect which must not be overlooked is interference caused by MSS terminals which transmit on frequencies outside the reference bandwidth. This is referred to as adjacent channel or non-co-channel interference. It is obvious that the modulated signal spectrum does not drop to zero outside the main channel but follows a certain mask determined by the modulation and pulse shaping method, as well as possible additional filtering. At WRC-95, MSS representatives handed over a spectral mask for unwanted emissions as defined by the European Telecommunications Standards Institute (ETSI). The corresponding mask is given in Fig. 2. It should be noted that this mask is not yet approved but is the best information available at the time.

FIGURE 2

ETSI Standard on unwanted emissions for S-PCN terminals



The envelope for the antenna gain lobes is required to determine the received interference. The radiation patterns have been taken from the RR, Appendix 28. In order to show the derivation of the separation distances, an example is given for the interference from MSS earth terminals to PDUS. The typical antenna gain of a PDUS is of the order of 32 dBi. Elevation angles for these stations range between 3° and 90°. The antenna gain in the horizontal direction ranges typically between –2 and 26 dB depending on elevation and azimuth angles of the station. The required separation distances for the interference caused by multiple MSS stations is given in Fig. 3 for a wide range of e.i.r.p. density levels.

The elevation angle has been selected as the parameter. The mathematical model for calculation of this distance takes into account a uniform distribution of MSS terminals over the receiver bandwidth and 3 dB polarization discrimination. The reduced probability of receiving from several MSS terminals at low elevation angles has been taken into account as well as signal blockage by trees, buildings and other obstacles.

For multiple entry interference, it has been assumed that no frequency reuse for MSS terminals will be feasible within the typical separation distance range of a METSAT station as the satellite beamwidths are typically much wider than the exclusion zones. It has therefore been assumed that multiple entry interference is limited to the number of MSS channels fitting within the reference bandwidth of the specific METSAT receiver. Consequently, the corresponding e.i.r.p. values of the MSS terminals have been compared to the applicable interference power density as defined by the protection criteria.

4.2 Interference assessment from LEO METSAT to LEO and GSO MOBSAT

There exist four orbital constellations which have a higher probability of interference compared to all other positions. The first two are tangential (nearly antipodal) positions between the two satellites and the other two occur when the subsatellite points are similar and consequently the distance separation is minimum. Figure 4 shows these constellations. In all other cases in between the above ones, the interference situation will be less critical. As the satellites are moving away from these positions, the additional antenna discrimination will come into effect.

FIGURE 3

Cumulative separation distances for PDUS terminals

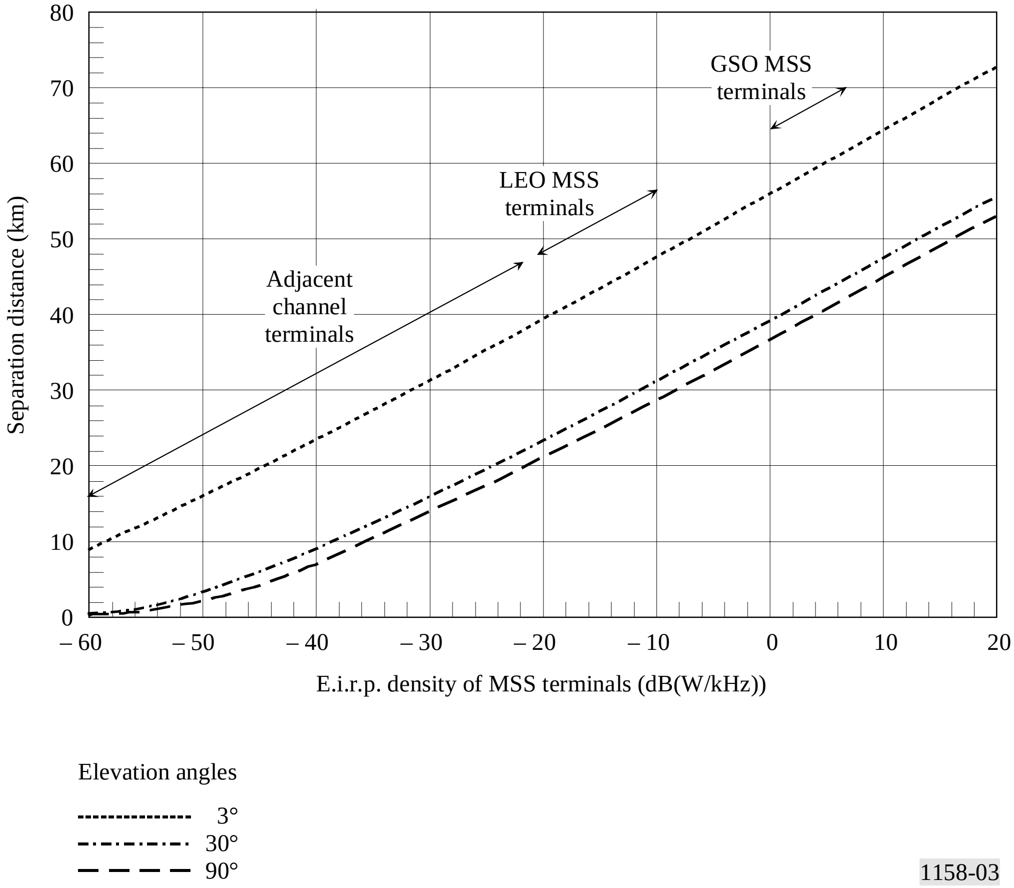
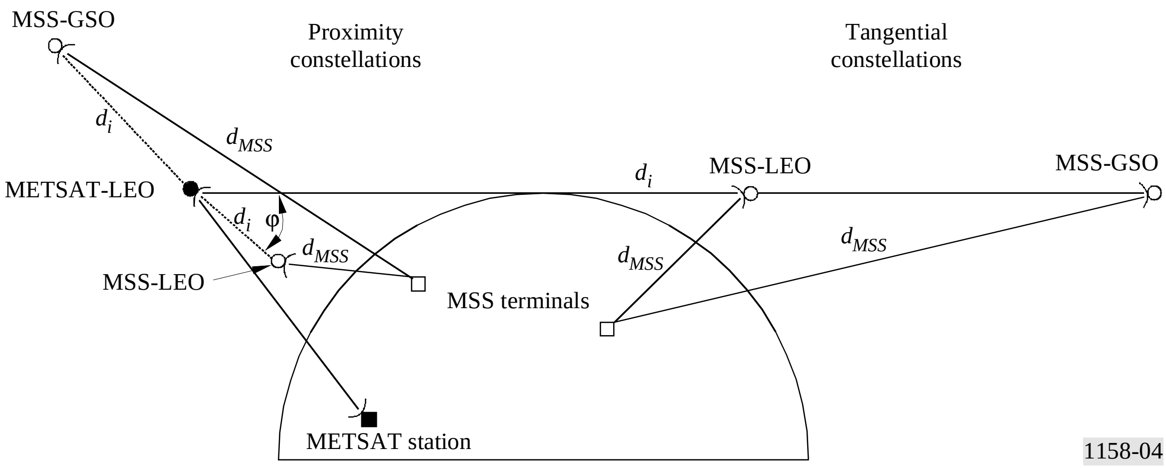


FIGURE 4

LEO METSAT to MOBSAT interference constellations



The ratio between the desired and the interfering signal is given by the following equation:

$$C/I = De.i.r.p._{MSS} - De.i.r.p._{METSAT} + G_{MSS} - G_{MSS(METSAT)} - (d_{MSS} / d_i)^2 + D_\varphi \qquad \text{dB}$$

where:

- $De.i.r.p._{MSS}$: e.i.r.p. density of MSS terminal
- $De.i.r.p._{METSAT}$: e.i.r.p. density of METSAT
- G_{MSS}: gain of MOBSAT antenna towards MSS terminal
- $G_{MSS(METSAT)}$: gain of MOBSAT antenna towards METSAT
- d_{MSS}: distance between MSS terminal and MOBSAT
- d_i: distance between METSAT and MOBSAT
- D_φ: antenna discrimination of METSAT towards MOBSAT.

The appropriate range of values for the above parameters is given in Table 6 and has been used throughout § 4.2 and 4.3:

TABLE 6

Typical applicable system characteristics

	LEO-MSS	GSO-MSS
$De.i.r.p._{MSS}$ (dB(W/kHz))	–21 to –11	13 to 23
$De.i.r.p._{METSAT}$ (dB(W/kHz))	–25 to –21	–25 to –21
G_{MSS} (dBi)	19 to 29	18 to 34
$G_{MSS(METSAT)}$ (dBi)	0 to 26	15
d_{MSS} (km)	780 to 2 000	36 000 to 40 000
d_i (km)	47 to 6 600	45 000
D_φ (dB)	0 to 10	3 to 10

4.2.1 Interference from LEO METSAT to LEO MOBSAT

4.2.1.1 Proximity constellation

Based on the above equation the following results are obtained for the interference received by the LEO MOBSAT in the proximity constellation:

TABLE 7

Results for LEO/LEO proximity constellation

Case	METSAT Service	$De.i.r.p._{MSS}$ (dB(W/kHz))	$De.i.r.p._{METSAT}$ (dB(W/kHz))	G_{MSS} (dBi)	$G_{MSS(METSAT)}$ (dBi)	d_{MSS} (km)	d_i (km)	D_φ (dB)	C/I (dB)
Worst	HRPT	–21	–21	19	0	2 000	47	0	–13.6
Best	HRPT	–11	–25	29	0	780	47	0	18.6
Mean	HRPT	–16	–23	24	0	1 400	47	0	1.5

A significant separation distance is required for this constellation. In the worst case, a separation around 700 km may be required between the two LEOs. The probability for such an event is around 0.2% involving two satellites and the longest interference event may last close to 3 min. It has to be noted in addition that the probability of interference will be multiplied by the number of MSS-LEOs times the number of LEO METSATs. Assuming 66 MSS-LEOs and 10 METSAT LEOs the overall probability of interference could in the worst case be practically 100%. This means that at any time there are always a number of MSS channels that will receive unacceptable interference.

Coordination by means of dynamic frequency selection has been proposed in the past to solve this problem. This may be difficult in practice as the HRPT transmissions are wideband over several MHz and may require to switch off a large number of MSS channels at regular intervals.

4.2.1.2 Tangential constellation

Table 8 shows the results for the interference received by the LEO MOBSAT in the tangential constellation. The distance between the two LEOs is sufficiently high to achieve a C/I in excess of 20 dB in all cases.

TABLE 8

Results for LEO/LEO tangential constellation

Case	METSAT service	$De.i.r.p._{MSS}$ (dB(W/kHz))	$De.i.r.p._{METSAT}$ (dB(W/kHz))	G_{MSS} (dBi)	$G_{MSS(METSAT)}$ (dBi)	d_{MSS} (km)	d_i (km)	D_{φ} (dB)	C/I (dB)
Worst	HRPT	–21	–21	19	13	2 000	6 600	6	22.4
Best	HRPT	–11	–25	29	23	780	6 600	6	44.5
Mean	HRPT	–16	–23	24	18	1 400	6 600	6	32.5

4.2.2 Interference from LEO METSAT to GSO MOBSAT

4.2.2.1 Proximity constellation

In both considerations, proximity as well as tangential, a C/I in excess of 20 dB is always achieved.

4.3 Interference from GSO METSAT to LEO and GSO MOBSAT

GSO METSATs have been essential for worldwide weather forecasts for many years. International agreements have been reached with respect to frequency channels and transmission formats. Several of them can be found on the GSO. There exist four orbital constellations with a probability maximum for interference. Two of them are tangential and two are proximity constellations. Figure 5 shows these constellations.

The same equation and system characteristics as in § 4.2 apply. Attention should be paid to the fact that METEOSAT transmits at e.i.r.p. levels which are typically several dB lower than other GSO METSATs, e.g. GOES. This leads to higher interference levels to the MOBSAT compared to the results derived in this study. Data for sharing with other satellites are contained in Annex 2. Because of the high number of possible combinations, only typical cases have been considered mainly based upon a mean value for the MSS e.i.r.p.

4.3.1 Interference from GSO METSAT to LEO MOBSAT

In the proximity constellation, a C/I of 20 dB is exceeded for all cases. The situation is similar for the tangential constellation. Except in the case of WEFAX transmissions, a C/I of 20 dB is exceeded for all other cases although some of the levels are just met. The WEFAX service occupies two slots of 26 kHz around 1 691 and 1 694.5 MHz.

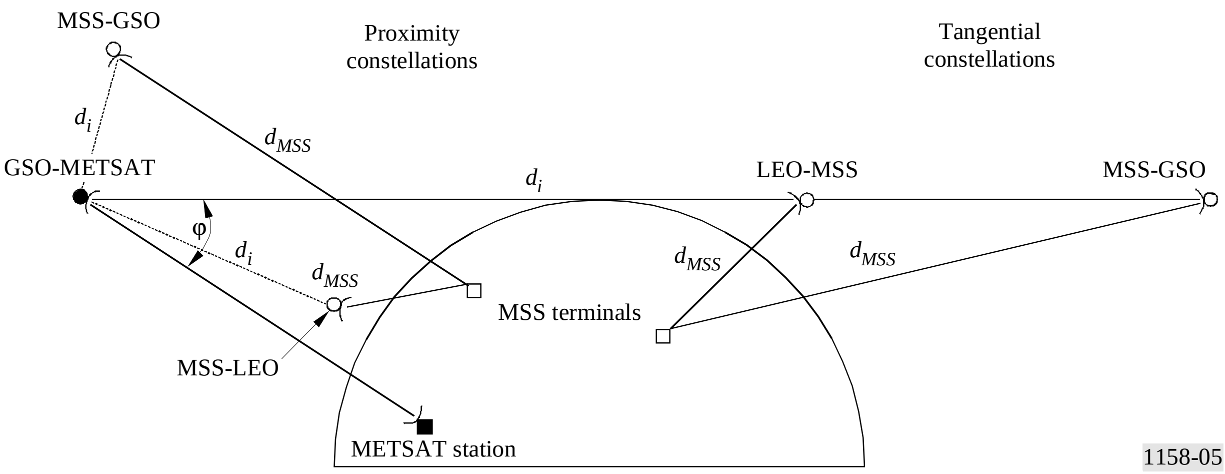
4.3.2 Interference from GSO METSAT to GSO MOBSAT

In the proximity constellation, it is evident that some separation distance on the GSO is required if transmission and reception on the same channel takes place. In order to achieve the desired C/I, significant distances ranging typically between 1 000 and 1 600 km for the majority of METSAT applications have to be kept. This translates into an angle separation between ±1.3° and ±2°, respectively. WEFAX is again a special case requiring more than 8 000 km or an angle separation of ±11° on the GSO. As the bandwidth affected is very small, it may not be considered a driving requirement.

In the tangential constellation, the WEFAX case does not meet the *C*/*I* criterion by about 2 dB but this is not considered to be essential.

FIGURE 5

GSO METSAT to MOBSAT interference constellations



5 Discussion

5.1 Separation distance range for LEO-MSS terminals

The expected majority of MSS terminals will be used with LEO systems. Because of their high density they may practically determine the sharing situation, even though the e.i.r.p. levels of the GSO type systems are higher. Figure 6 shows best-, mean- and worst-cast situations. The best case, which is the most favourable case in terms of interference, is the combination of the highest METSAT antenna elevation angle and the lowest MSS e.i.r.p. spectral density level. The mean case is based upon a medium e.i.r.p. spectral density together with a typical elevation angle of 30° and the worst case assumes the highest e.i.r.p. spectral density at the lowest elevation angle.

It can be seen that the separation distances are relatively independent of the METSAT station type. Typical separation distances between 30 and 40 km with occasional worst cases exceeding 50 km make it practically impossible to share frequency bands with medium density distribution of METSAT stations.

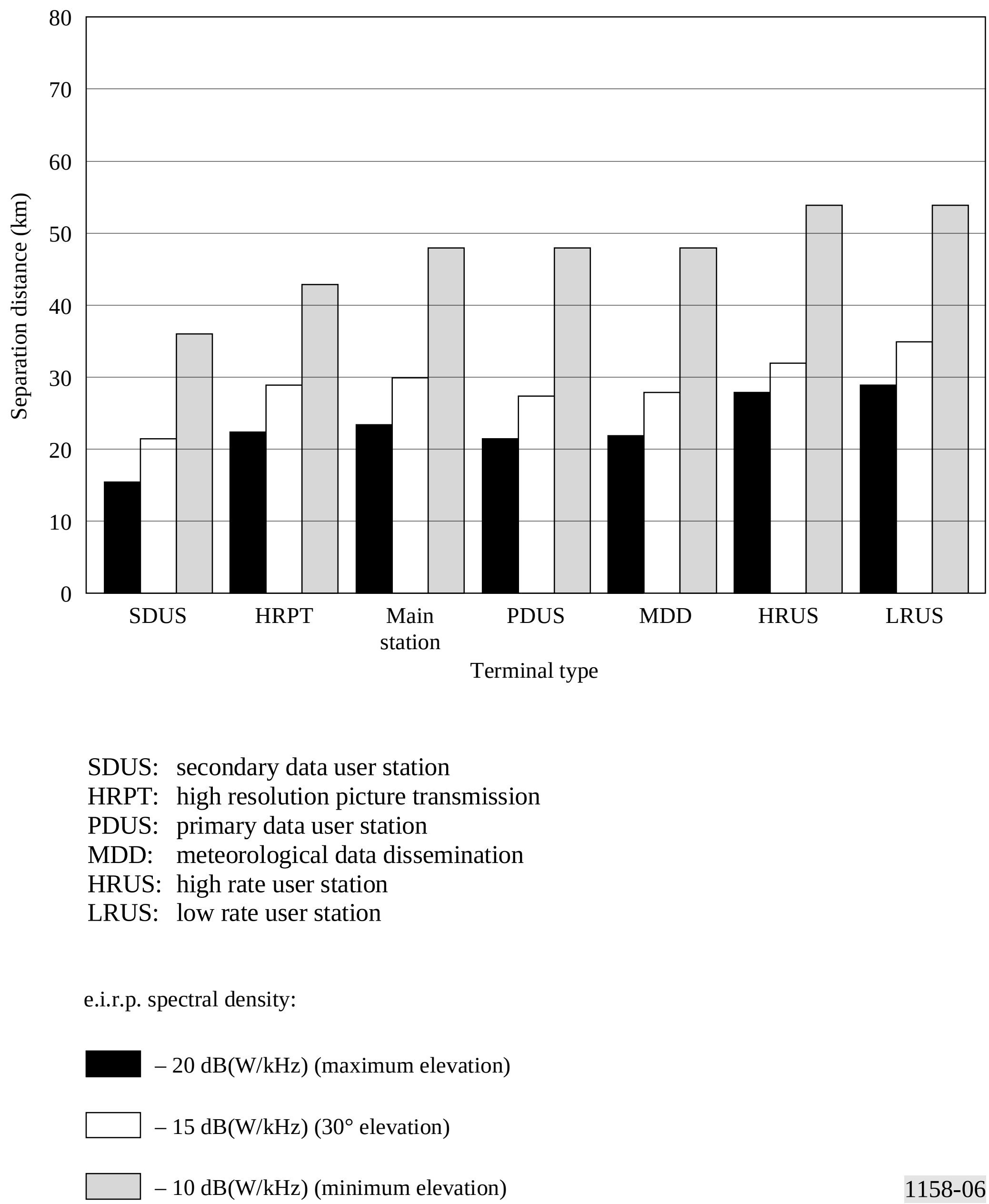
The new generation of METSAT stations is more sensitive than the currently deployed stations. In agreement with good frequency management this is basically due to the use of reduced e.i.r.p. density level on the satellite. The effect of the consequently reduced power in the receiver is compensated by the use of channel coding. In order to keep a constant *C*/*I* ratio, the level of acceptable interference has to be reduced.

5.2 Separation distance range for GSO-MSS terminals

Figure 7 shows the separation distance range for MSS terminals transmitting to a GSO satellite. The e.i.r.p. spectral density levels are consequently higher resulting in separation distances which are typically around 15 km above the ones in the LEO case. Again, best-, mean- and worst-case situations have been summarized based on the same assumptions as in the LEO case. Distances between typically 40 and 60 km make it practically impossible to share a frequency band used by a METSAT application even in areas with low to medium station density.

FIGURE 6

Separation distances range for LEO-MSS terminals



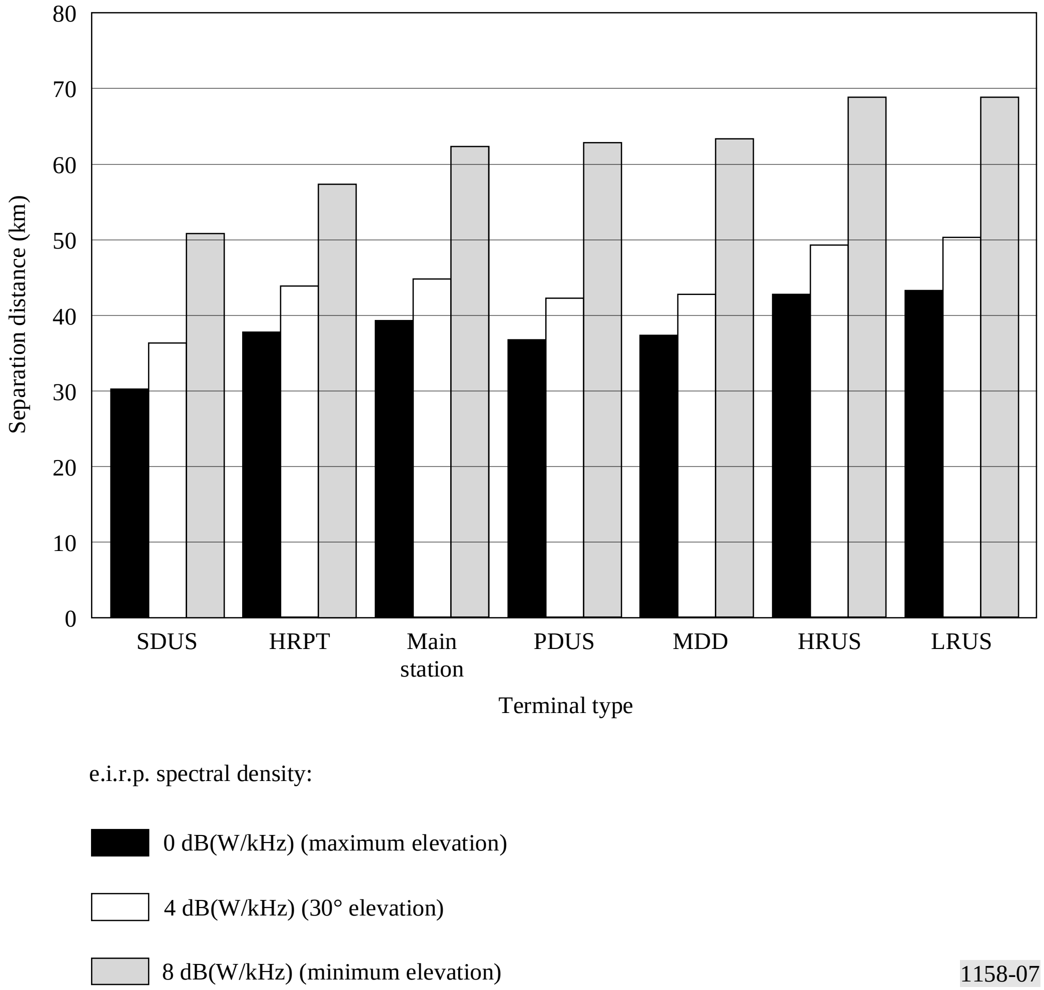
5.3 Separation distance range for adjacent channel interference

The above two cases were based on the assumption that the METSAT station and the MSS terminal were operating on the same channel (co-channel interference). In practice, also adjacent channels will have a remaining spectral density level which can be strong enough to cause unacceptable interference to a METSAT receiver. Figure 8 shows a summary of the results for adjacent channel interference based on the mask as currently proposed by ETSI.

Depending on the spectral separation from the channel centre frequency, an attenuation between 6 and 45 dB is obtained with respect to the maximum level of a LEO system terminal. It is interesting to note that there still remains a significant separation distance for adjacent channel transmissions. The design of MSS terminals shall therefore be optimized in order to minimize interference caused by out-of-band emissions. Only with e.i.r.p. density levels below –60 dB(W/kHz) would sharing of a common frequency band become viable in areas with medium to high densities of METSAT stations.

FIGURE 7

Separation distances range for GSO-MSS terminals



5.4 Exclusion zones around METSAT stations

Of primary interest is the number and the distribution of stations which are currently deployed as well as those which are planned to be deployed in the future. The number of stations registered to date with the WMO is in excess of 8 000.

For a brief estimation of the situation in Europe, the following assumptions can be made. The European Union countries comprise an area of approximately 3 million km^2. There are currently more than 3 000 stations registered with the WMO in these countries. This results, on average, in a density of around one station per 1 000 km^2. As the minimum exclusion zone for protection of the METSAT earth stations is higher in all cases considered, it is evident that coordination with MSS terminals in a commonly shared band is practically almost impossible.

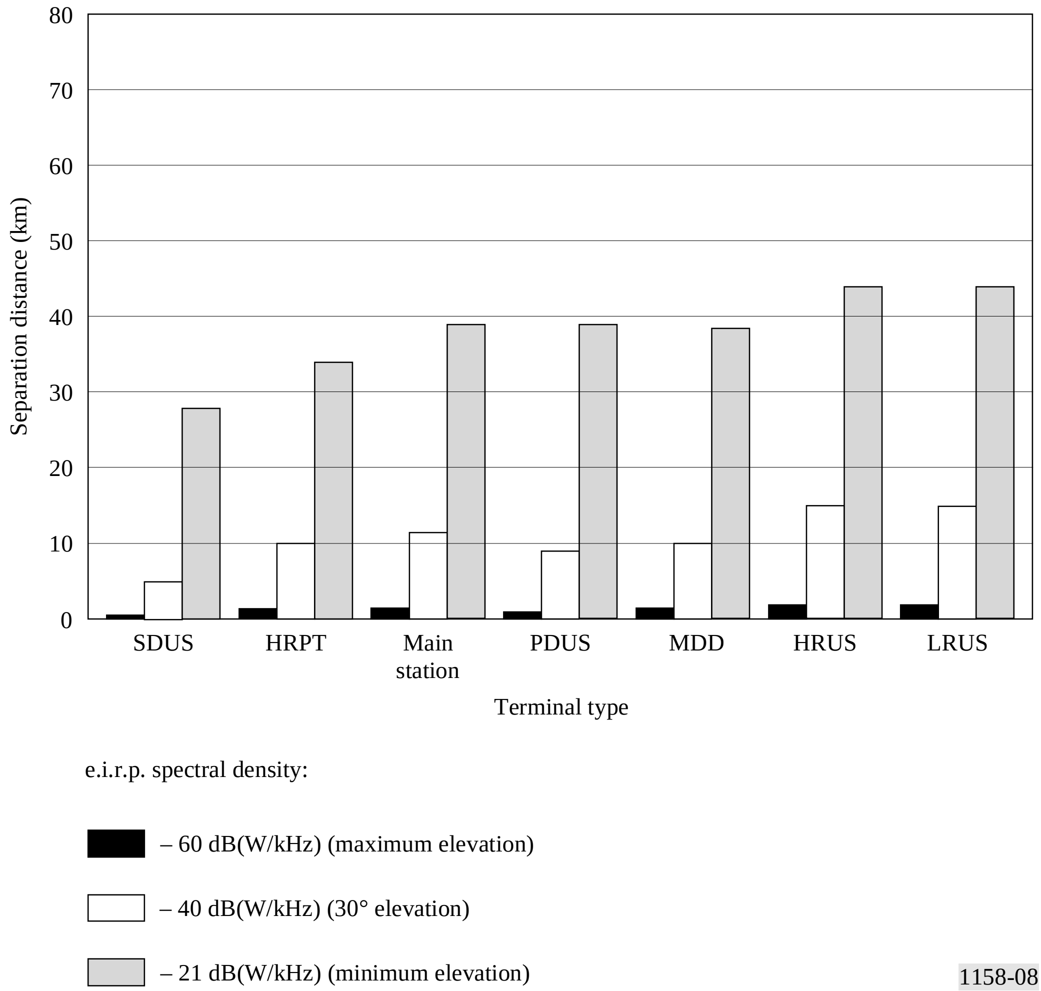
The situation on a worldwide basis is similar. The global density of the stations is smaller but there remain large areas where MSS terminals would have to respect protection zones.

The only band where a relatively low number of stations is deployed is the 1 675-1 690 MHz band. The estimated number of stations is around 15 worldwide. However, it must be emphasized that these are the main stations with all essential command and data acquisition functions. They are also the dissemination stations for the many thousands of user stations and any interference caused to these stations will have a manifold effect. Furthermore, the method of data collection is such that a whole frame of information is received within a time-frame of typically 20 min. Any interruption during this time will in the best case create a “black hole” in the weather chart or in the worst case result in the total loss of the picture if resynchronization cannot be accomplished within a reasonable time-frame.

Figure 9 shows a summary of the METSAT service channels and the related station types.

FIGURE 8

Separation distances range for adjacent MSS terminals



5.5 Space-to-space interference constellations

The most severe interference case is the METSAT LEO/MOBSAT LEO constellation where both satellites are in close proximity. It is not possible to reach an interference free situation even with the best possible system parameters. In the worst case a separation around 700 km may be required between the two LEOs. The probability for such an event is around 0.2% but this multiplies with the product of METSAT and MOBSAT spacecraft. For a typical system configuration comprising 66 MSS LEOs and 10 METSAT LEOs the overall probability of interference could in the worst case be 100% for the system as a whole.

Coordination by means of dynamic frequency selection may be difficult in practice as the HRPT transmissions are wideband over several MHz. This may require the MSS system operators to switch off a large number of channels over regular time intervals which does not appear to be practical.

In two cases involving a GSO METSAT, the desired C/I of 20 dB cannot be achieved under all possible conditions. The affected frequency band is small, however. In most other cases, the desired C/I can be achieved even for the pessimistic system parameter assumptions. Table 9 shows a summary of the constellations where interference occurs for a worst, best and mean case.

FIGURE 9

METSAT service bandwidth occupation

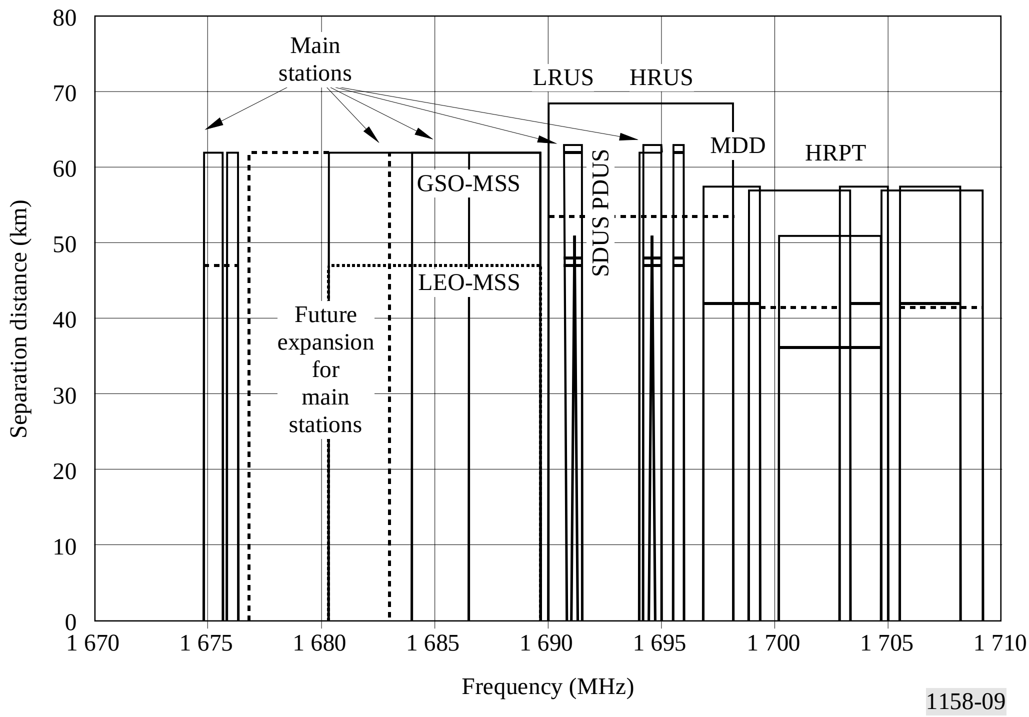


TABLE 9

Space segment interference summary

Frequency band (MHz)	METSAT	MSS	Best *C*/*I*	Mean *C*/*I*	Worst *C*/*I*
1 696.6-1 709.4	LEO	LEO	18.6	1.5	–13.6
1 690.9-1 691.1	GSO	LEO	14.8	9.8	4.8
1 694.4-1 694.6	GSO	GSO	23.1	18.1	13.1

In addition, for any GSO/GSO constellation, a separation on the geostationary orbit is required if transmission and reception takes place on the same frequency channel. The angular separation lies typically between ±1.3° and ±2°. On the WEFAX channels, the required angular separation would be around ±11°. The bandwidth used for WEFAX transmissions is small, however, so that this should not be considered a driving requirement.

It should be noted that the METEOSAT series of spacecraft transmit their services at e.i.r.p. levels which are typically 6 dB below the GOES series. There would consequently be cases experienced in practice where higher interference levels would occur than the ones calculated in this Recommendation.

6 Summary

– The separation distance around METSAT stations is typically around 35 km for LEO-MSS and 50 km for GSO-MSS terminals and is relatively independent of the station type. For low elevation angles, these values can go up to 54 and 68 km, respectively. Exclusion zones around METSAT stations are thus typically several thousand km^2 which makes sharing in those parts of the band with hundreds to thousands of stations worldwide practically impossible.

– Adjacent channel interference still results in a separation distance up to 14 km for a typical constellation and 44 km in the worst case. An MSS e.i.r.p. density of –60 dB(W/kHz) shall not be exceeded. Consequently, a guardband of at least 200 kHz between MSS transmit and METSAT receive channels is required.

– A restricted sharing potential exists for the band 1 675-1 690 MHz, where a limited number of main stations is operated. Sharing may be feasible if a distance of around 45 to 62 km is kept to these stations at all times. This may not be a trivial task as the MSS terminal location would have to be determined with a reasonable accuracy relative to the required distances. Practical solutions remain to be identified.

– No sharing is feasible in the band 1 690-1 698 MHz which is heavily used by thousands of stations worldwide.

– Sharing is also not feasible in the band 1 698-1 710 MHz due to a worldwide distribution of hundreds of HRPT stations.

– In the space segment, unacceptable interference to MOBSATs has to be expected in the LEO/LEO constellation between 1 698-1 710 MHz. In addition, WEFAX transmissions via GSO METSATs will make two relatively small bands around 1 691-1 694.5 MHz unusable. For the GSO/GSO proximity constellation, at least ±2° of angular separation are required with respect to METEOSAT e.i.r.p. levels. Some other GSO METSATs (e.g. GOES) will require more separation.

ANNEX 2

Information on worldwide METSAT systems

METSAT system	Function	Frequency (MHz)	RF bandwidth (MHz)	e.i.r.p. (dBW)
GMS (GSO)	Sensor	1 681.600	20.000	27.0
	S-VISSR	1 687.100	6.000	25.0
	WEFAX 1	1 691.000	0.260	17.0
	WEFAX 2	1 691.000	0.032	7.0
	Ranging 1	1 684.000	1.000	17.0
	Ranging 2	1 688.200	1.000	–4.5
	Ranging 3	1 690.200	1.000	–4.5
	DCP report	1 694.500	0.400	4.0
	Telemetry	1 694.000	0.400	10.0
GOES (GSO)	Sensor W/B	1 676.000	5.000	19.0
	Sensor raw image	1 681.600	25.000	27.9
	Sensor multi	1 681.478	0.500	19.0
	Sensor mode AAA	1 685.700	5.000	19.0
	Ranging 1	1 684.000	1.000	27.9
	Ranging 2	1 688.200	1.000	27.9
	Ranging 3	1 690.200	1.000	27.9
	Direct readout	1 687.100	3.500	27.9
	WEFAX	1 691.000	0.026	27.9
	Telemetry	1 694.000	0.020	19.0
	DCP report 1	1 694.450	0.400	19.0
	DCP report 2	1 694.500	0.400	21.1
	DCP report 3	1 694.800	0.400	19.0

Information on worldwide METSAT systems *(continued)*

METSAT system	Function	Frequency (MHz)	RF bandwidth (MHz)	e.i.r.p. (dBW)
METEOSAT (OSG)	DCP reports	1 675.281	0.435	12.5
	Telemetry	1 675.929	0.030	5.0
	Sensor	1 686.833	5.300	10.7
	Ranging 1	1 691.000	0.660	21.3
	Ranging 2	1 694.500	0.660	21.3
	Fax high resolution 1	1 691.000	0.660	21.3
	Fax high resolution 2	1 694.500	0.660	21.3
	WEFAX 1	1 691.000	0.026	21.3
	WEFAX 2	1 694.500	0.026	21.3
	MDD	1 695.770	0.720	9.0
	HRIT	1 695.150	1.960	18.4
	LRIT	1 691.000	0.660	16.6
GOMS(GSO)	Sensor	1 685.000	5.000	23.0
	WEFAX 1	1 671.48 1 690.8	0.018	18.8
	WEFAX 2	1 674.48 1 691.4	0.018	18.8
	Fax high resolution 1	1 672.48 1 691.0	0.0024	12.3
	Fax high resolution 2	1 673.48 1 691.2	0.0024	12.3
	DCP 1	1 697.0	2.000 (300 × 3 kHz)	9.7
	DCP 2	1 688.5	1.000 (100 × 10 kHz)	12.0
Typical LEO METSAT	Worst case	–	3.000	9.0

ANNEX 3

Sharing techniques for MSS and METSAT earth stations in the 1 675-1 710 frequency band

A number of techniques have been studied by the ITU-R to enhance the capability to share the radio spectrum between mobile or mobile-satellite systems and systems of other services. The basic problem addressed in these studies is that when the mobile service or MSS shares a frequency band with another service, the mobile station or the mobile-satellite earth station has been assumed to be operating anywhere in the service area of the victim system, whilst transmitting at the same frequency as the victim unit receives. Thus, these studies found that within the service area, the mobile or MSS earth station could cause harmful interference to stations of the other service.

These mobile or MSS earth stations must be assumed to be used by persons not accustomed to taking measures to avoid harmful radio interference between stations. For that reason the techniques implemented to control the magnitude of the interference within agreed-to limits must function without action being required by the user of the mobile or MSS earth station. Several such techniques that could be applied to limit the interference from a transmitting MSS earth station into a receiving METSAT earth station are described briefly here. The techniques which can be employed individually or jointly are:

– frequency assignment by location,
– beacon-actuated protection zones,
– interference avoidance by frequency selection,
– using frequencies in an MSS beam coverage area only when the METSAT earth stations are not using them (i.e., time sharing).

1 Frequency assignment by location

1.1 Method of assuring adequate frequency-distance separation (for the fixed exclusion zone case)

Using an interference-free signalling channel, the mobile earth station reports its location to the network operations centre (this capability is inherent in some planned non-GSO MSS systems). Interference-free working channels are then assigned, based on a computer "look-up" table indicating the frequencies whose use will not cause interference in the reported location and a list of frequencies not already assigned in the beam coverage area. The "look-up" table is based on known location and frequency assignments for the METSAT earth stations.

1.2 Comments

– MSS signalling channels that will not cause harmful interference must be available for use throughout each MSS satellite coverage area.
– MSS earth stations must inherently have, or be equipped with, position determination capabilities.
– MSS earth station location must be known by the network control centre prior to being assigned a service channel.
– Software and a database for assignment based on MSS earth station location must be integrated with the provisions for other channel assignment algorithms.
– The network control computer system should be able to maintain acceptable network access delay.

2 Beacon-actuated protection zones

2.1 A flexible method of assuring adequate frequency-distance separation

A beacon transmitter is co-located with each METSAT receiving earth station to be protected with minimum acceptable frequency offsets between the beacon and the METSAT earth station receiver. The MSS earth station uses the beacon signal to determine whether it is in a restricted-frequency zone. This information is conveyed to the network operation centre, which assigns a channel that will not cause interference for use in the restricted-frequency zone when necessary.

2.2 Comments

– MSS signalling channels that will not cause harmful interference must be available for use throughout each MSS satellite coverage area.
– Beacons must be installed (practical only if there are a small number of receivers to be protected) at each METSAT earth station to be protected.
– MSS earth stations must be equipped with beacon-signal processing capabilities.
– MSS earth stations location (or the specific beacon zone the MSS earth station is within) must be known by the network operation centre prior to channel assignment.
– Software and a database for assignment based on MSS earth station location in relation to specific beacons must be integrated with the provisions for other channel assignment algorithms.

– The network control computer system should be able to maintain acceptable network access delay.

– The technique also may facilitate time sharing.

3 Interference avoidance by frequency selection

3.1 Method to avoid interference to METSAT earth station types with many installations

The above interference avoidance techniques are appropriate for the case where only a few METSAT earth stations are used to receive signals from a METSAT (e.g., raw image data). However, these techniques are not suitable for the case where there are hundreds or thousands of small earth stations used in meteorological data distribution, e.g., for WEFAX, HRPT etc. These frequencies may be different for different METSAT systems and moreover, there may be some METSAT data distribution services that may not become ubiquitous.

These data distribution channels are generally quite narrow. Interference to these ubiquitous METSAT earth stations is avoided by having the MSS system not use the frequencies employed by the METSAT data distribution channels and a suitable guardband around them.

3.2 Comments

– MSS signalling channels that will not cause harmful interference must be available.

– Because the data distribution channels have a narrow bandwidth, the diminution of frequencies and capacity to an MSS system will probably be acceptable.

– For non-GSO MSS systems, their network control centres must have the capability to recognize and adopt flexible frequency assignment protocols because different METSAT systems with different coverage areas may employ different frequencies and bandwidths for their data distribution channels.

– Some parts of the world may not ubiquitously install small meteorological data distribution earth stations. MSS earth stations may be useful in such areas.

4 Using frequencies in an MSS beam coverage area only when the METSAT earth stations are not using them

4.1 Time sharing of frequencies

This is an old idea that has been in use in the METSAT field by non-GSO space stations for some time. That is, a non-GSO space station only serves a small part of the Earth's surface at any instant of time. Thus, the same frequencies employed by the space station at that time can be employed on the rest of the world's surface at that time. In other words, time-share the use of the frequencies at all locations on the surface of the Earth between non-GSO METSATs and MSS systems.

4.2 Comments

– MSS signalling channels that will not cause harmful interference must be available.

– In the case at hand, there is a potential for interference from the METSAT space stations into the receivers of the MSS space stations. That concern is discussed in Annex 2.

– The MSS network control centre must keep track of orbital locations and coverage of its own as well as the non-GSO METSAT space stations.

– This technique may be used in conjunction with the beacon and fixed exclusion zone methods described above.

– Good liaison channels must be established between MSS and METSAT system operators.

– For multibeam MSS systems, this method may be used on a beam-by-beam basis.