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 2025-2110 MHz and 2200-2290 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 2025-2110 MHz and 2200-2290 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 2025-2110 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 2200-2290 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 2025-2110 MHz and 2200-2290 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

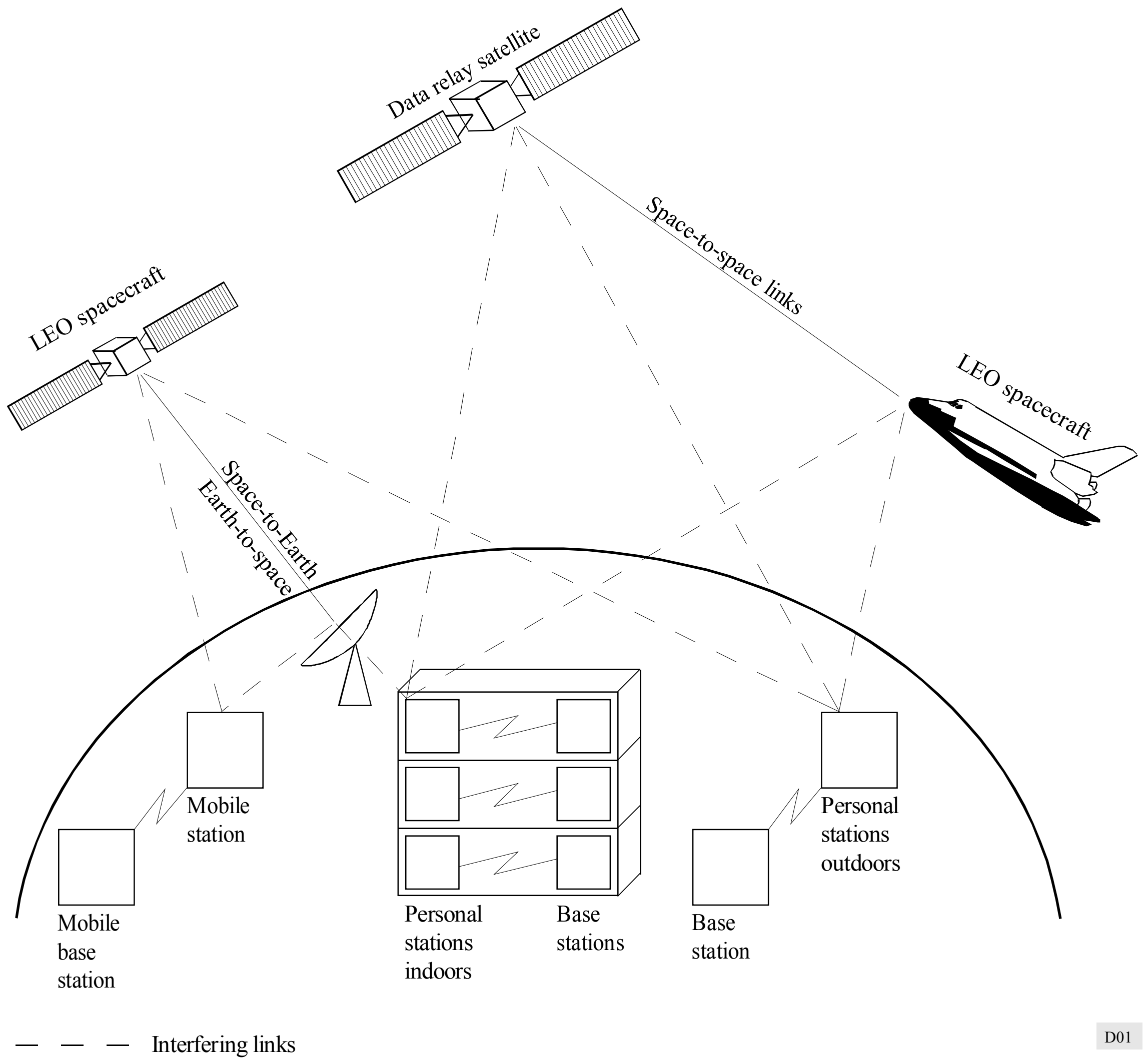
Sharing between high density and conventional land mobile systems on the one hand and space services on the other hand is not feasible. This Annex is based on contributions which lead to this conclusion and provides the underlying analysis. The mobile system considered in this study is the future public land mobile telecommunication system (FPLMTS). The model used is also applicable to conventional type mobile systems.

The bands 2025-2110 GHz and 2200-2290 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

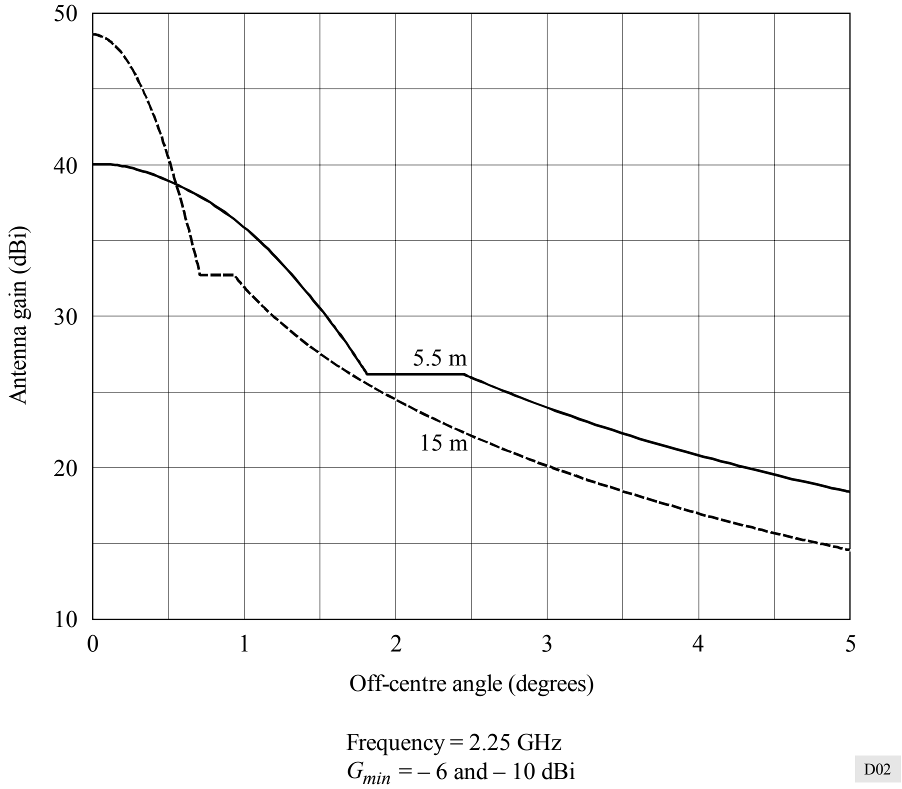
Typical system noise temperatures of spacecraft receivers range around 800 K resulting in a noise spectral density of around –200 dB(W/Hz). Some critical space research missions require noise temperatures down to 600 K.

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



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

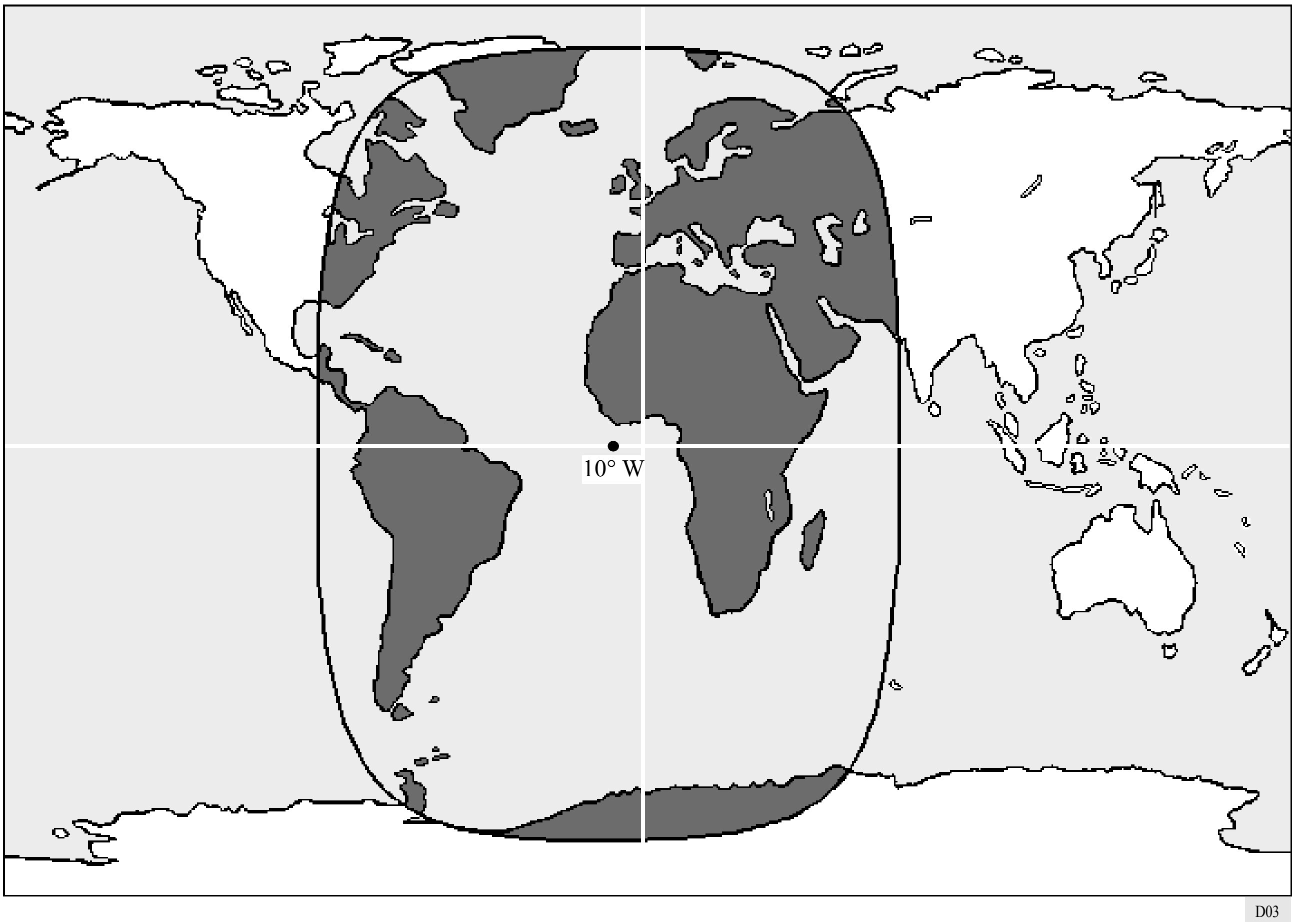
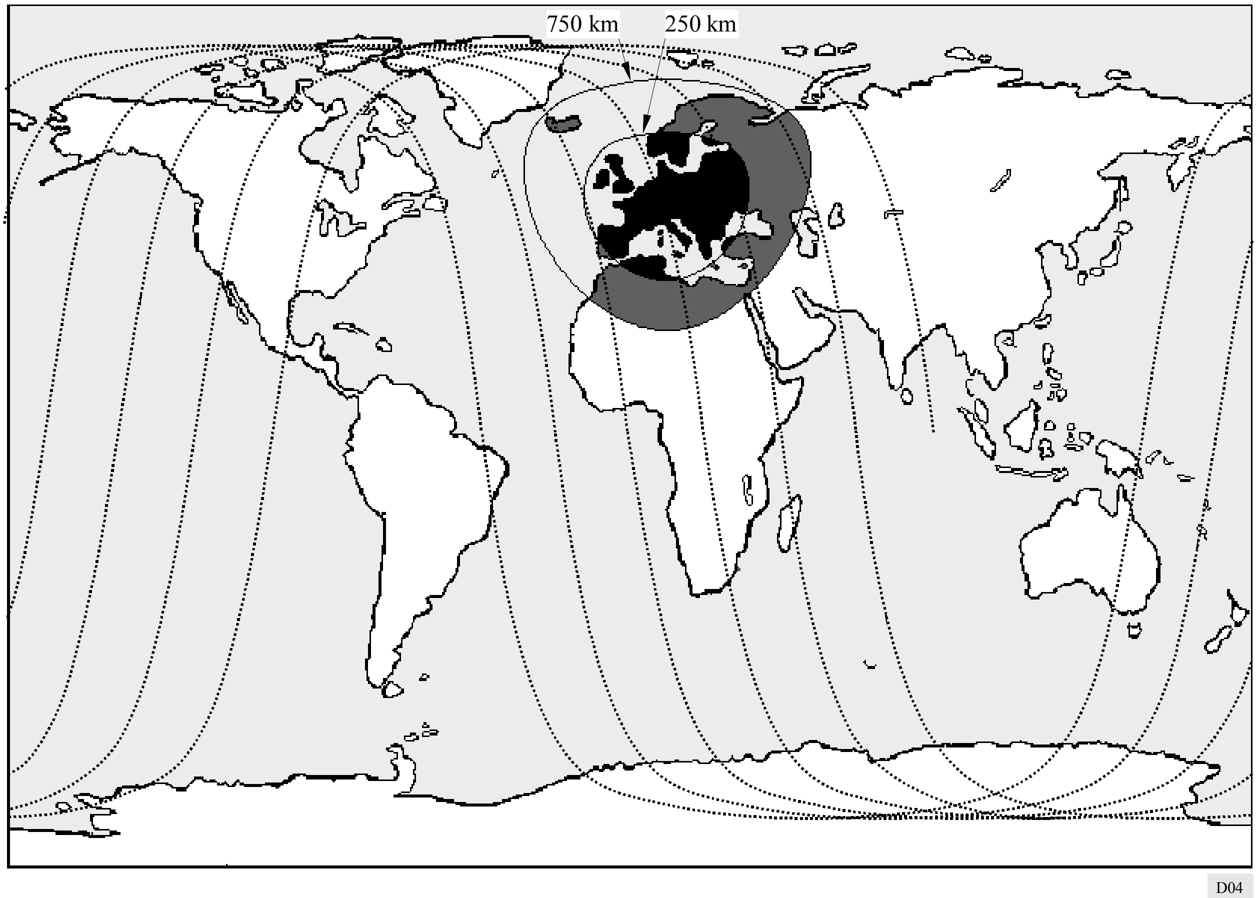


Figure 4 shows the area from which a low-Earth orbiting satellite at orbit heights between 250 and 750 km will receive signals. The position of the spacecraft has in this case been assumed to be above the middle of Europe. The resulting “window” will move along the ground track given in dotted lines. 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).

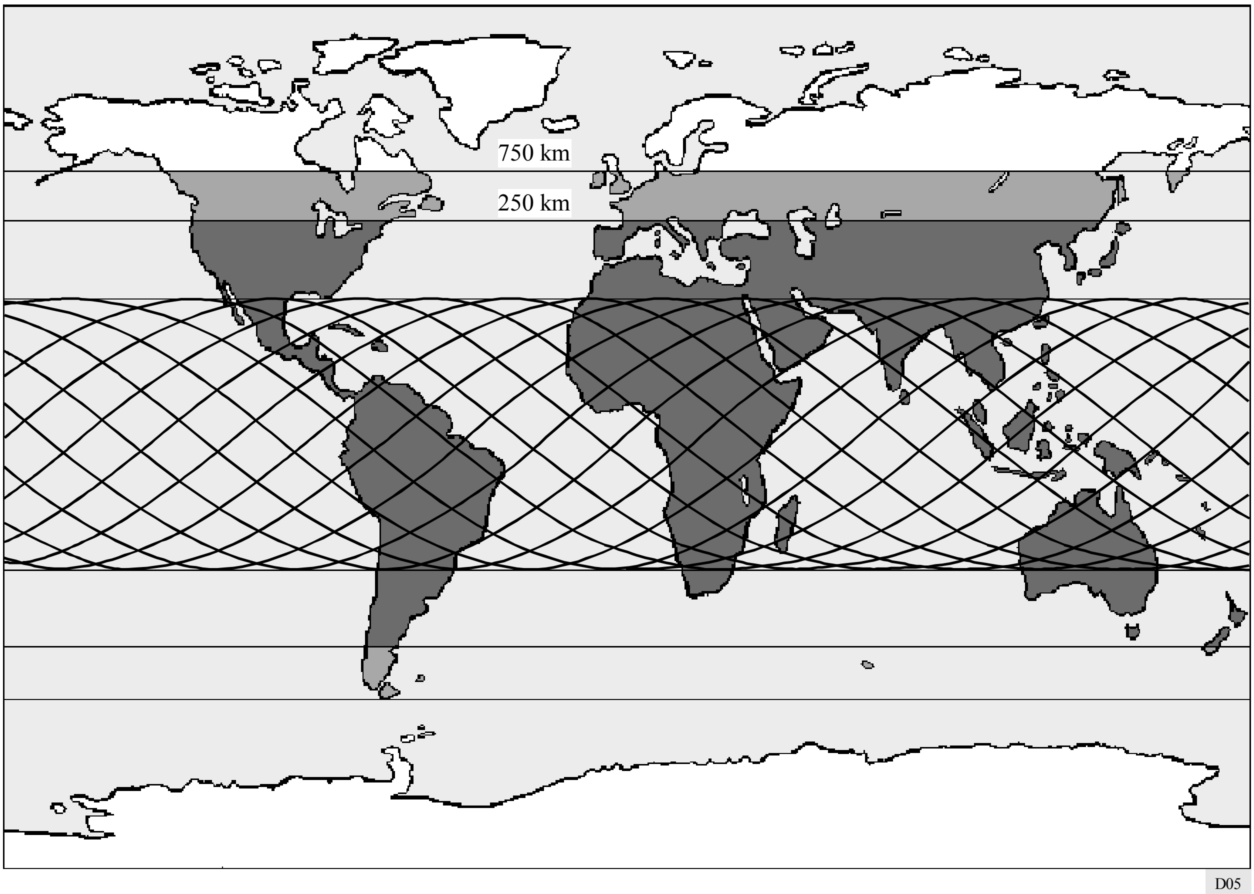
At an altitude of 250 km the spacecraft will receive interference from an area of 9.6 million km^2. This number increases to 27 million km^2 for an orbit height of 750 km. The maximum area seen by a geostationary satellite is 217 million km^2.

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:

$$P_{\Sigma i} = \int_{x=h}^{d_m} \frac{n_a P_i B_i h^2 \, \mathrm{d}A_{(x)}}{B_m A_i x^2} \mathrm{d}x = \frac{n_a E_i c^2}{(4\pi f)^2 B_m A_i} \int_{x=h}^{d_m} \frac{\mathrm{d}A_{(x)}}{x^2} \mathrm{d}x$$

$$A_{(x)} = \frac{\pi R (x^2 - h^2)}{R + h}$$

$$\frac{\mathrm{d}A_{(x)}}{\mathrm{d}x} = \frac{2\pi R}{R + h} x$$

$$d_m = \sqrt{(R + h)^2 - R^2}$$

$$P_{\Sigma i} = \frac{n_a E_i c^2}{(4\pi f)^2 B_m R h} [\ln(d_m) - \ln(h)]$$

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/km^2)	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 km^2	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 km^2 (E/km^2)	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:

$$P_{\Sigma i} = \int_{x=d_1}^{d_2} \frac{md_a \, P_i \, B_i \, \mathrm{d}A_{(x)}}{B_m} \, \mathrm{d}x = \frac{md_a \, E_i \, c^2}{(4\pi f)^2 \, B_m} \int_{x=d_1}^{d_2} \frac{\mathrm{d}A_{(x)}}{x^2} \, \mathrm{d}x$$

$$A_{(x)} = \pi x^2$$

$$\frac{\mathrm{d}A_{(x)}}{\mathrm{d}x} = 2\pi x$$

$$P_{\Sigma i} = \frac{md_a \, E_i \, c^2}{8\pi f^2 \, B_m} \, [\ln(d_2) - \ln(d_1)]$$

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)		7.5		7.5		7.5
Maximum horizontal gain of earth station (3°) (dBi)	24.0		24.0		24.0	
Active units per km^2 (E/km^2)		2.800		2.800		0.560
Active unit density per channel per km^2		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))	–208.0	–191.5	–208.0	–191.5	–208.0	–191.5
Interference of units between 1 and 10 km (dB(W/kHz))		–152.4		–144.7		–140.9
Interference of 1 unit at 10 km distance (LOS) (dB(W/kHz))	–161.5		–153.3		–133.3	
Excess of acceptable interference (dB)	46.5	39.1	54.7	46.8	74.7	50.6

Table 3b: Space research	Indoor personal station		Outdoor personal station		Mobile station	
Average horizontal gain of earth station (15 m) (dBi)		2.4		2.4		2.4
Maximum horizontal gain of earth station (5°) (dBi)	14.5		14.5		14.5	
Active units per km^2 (E/km^2)		2.800		2.800		0.560
Active unit density per channel per km^2		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))	–234.5	–222.4	–234.5	–222.4	–234.5	–222.4
Interference of units between 1 and 10 km (dB(W/Hz))		–182.4		–174.7		–170.9
Maximum interference of 1 unit at 10 km distance (dB(W/Hz))	–191.5		–183.3		–163.3	
Excess of acceptable interference (dB)	43.0	40.0	51.2	47.7	71.2	51.5

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

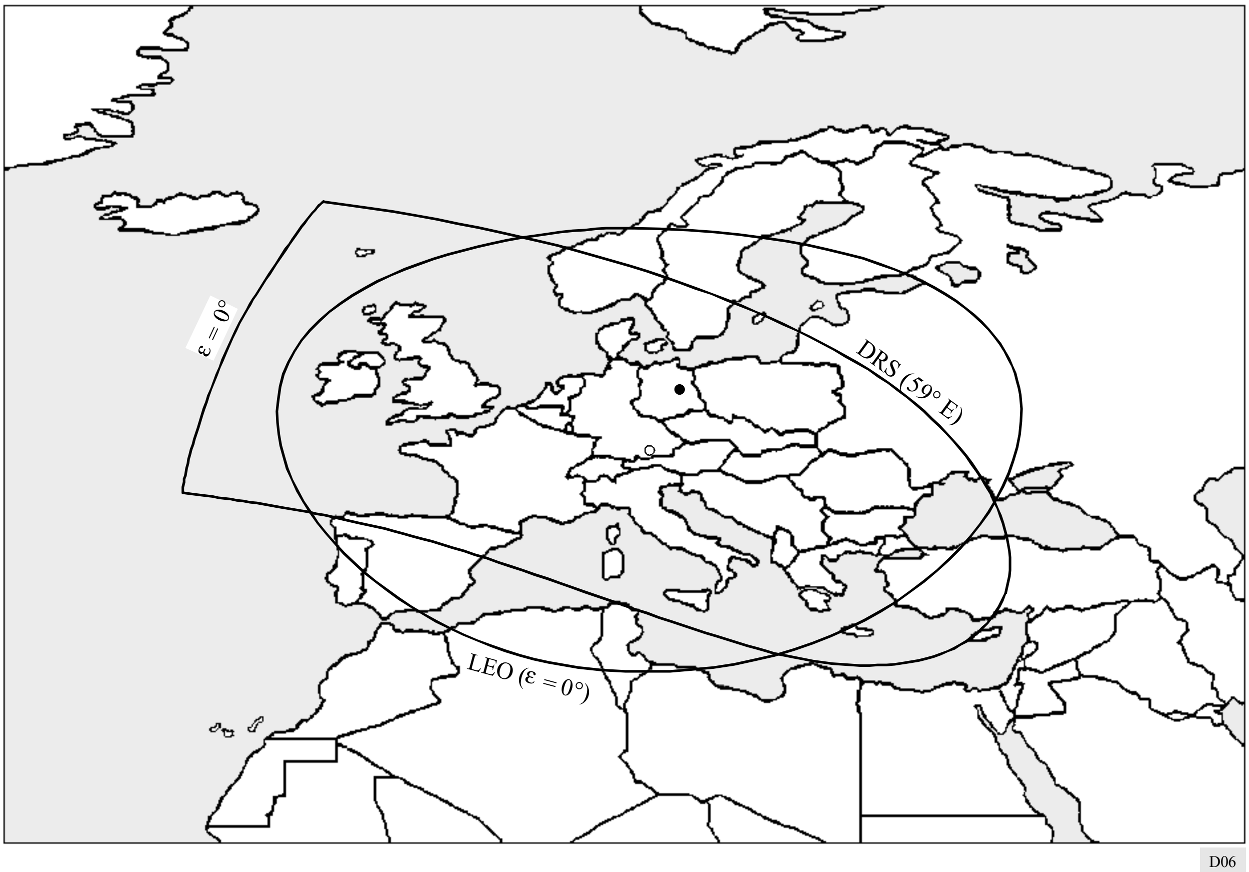


Table 5 lists the detailed results. Also in this case sharing is unfortunately impossible.

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/km^2)	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 km^2	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 km^2 (erlangs/km^2)	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

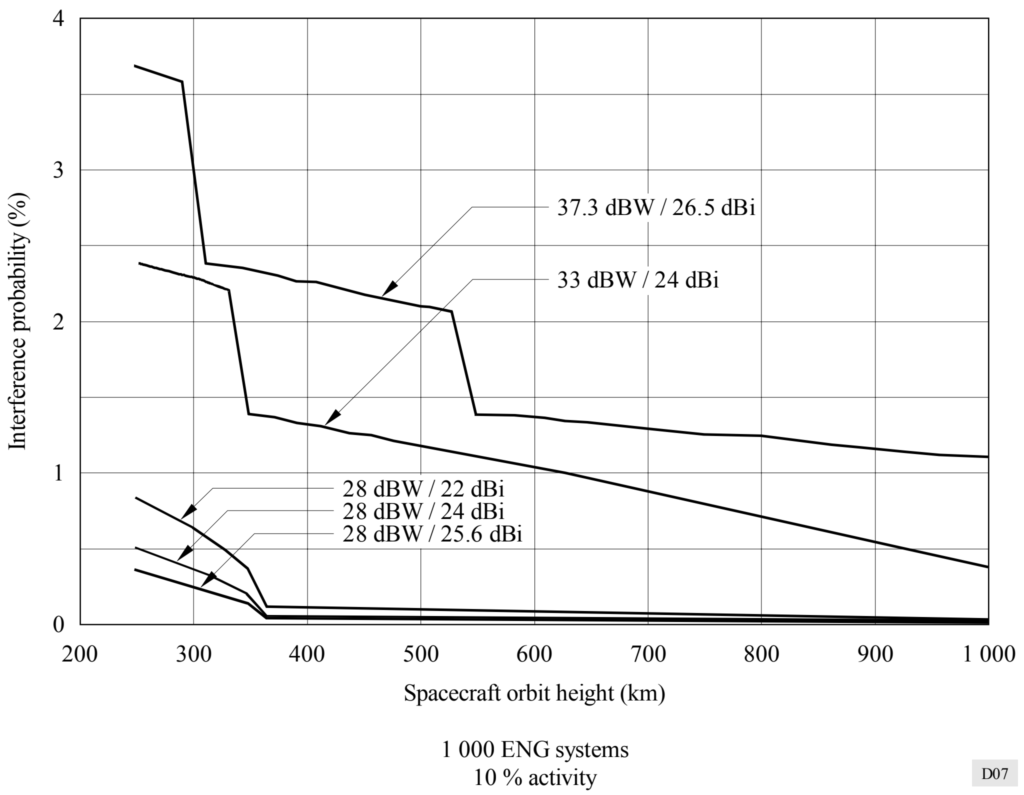


TABLE 7

	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

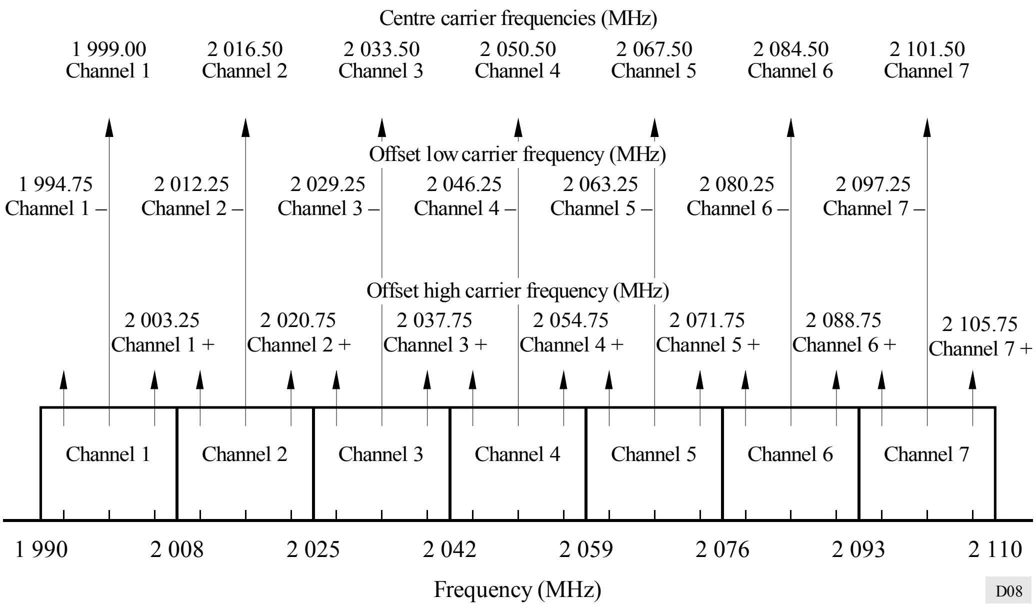
The 1 990-2 110 MHz band is used as the primary ENG band because of favourable propagation characteristics. These include the lower levels of foliage attenuation that apply at higher frequencies and the ability to "building bounce" a signal to achieve a temporary link to a fixed receive site despite 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



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.

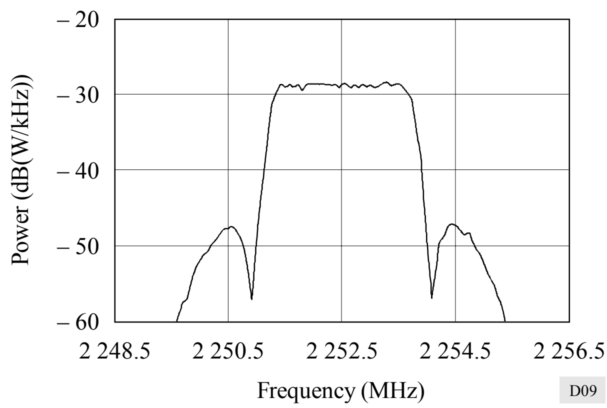
Aeronautical telemetry operations are currently protected by coordination between the various users. The territory of the United States of America is divided into coordination areas. Area frequency coordinators assign and schedule frequency use within these areas.

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.