International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.1459

(05/2000)

Protection criteria for telemetry systems in the aeronautical mobile service and mitigation techniques to facilitate sharing with geostationary broadcasting-satellite and mobile-satellite services in the frequency bands 1 452-1 525 MHz and 2 310-2 360 MHz

M Series

Mobile, radiodetermination, amateur
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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
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RECOMMENDATION ITU-R M.1459[*],[**]

PROTECTION CRITERIA FOR TELEMETRY SYSTEMS IN THE AERONAUTICAL MOBILE SERVICE AND MITIGATION TECHNIQUES TO FACILITATE SHARING WITH GEOSTATIONARY BROADCASTING-SATELLITE AND MOBILE-SATELLITE SERVICES IN THE FREQUENCY BANDS 1 452-1 525 MHz AND 2 310-2 360 MHz

(Question ITU-R 62/8)

(2000)

Scope

This Recommendation provides information on the protection criteria required for aeronautical telemetry systems operating in the frequency bands 1 452-1 525 MHz and 2 310- 2 360 MHz and potential mitigation techniques that would facilitate sharing with geostationary broadcasting-satellite and mobile-satellite services.

The ITU Radiocommunication Assembly,

considering

a) that in Region 2, frequency allocations to the aeronautical mobile service for telemetry have a primary status in the band 1 435-1 525 MHz and have priority over other mobile services under RR No. 5.343;

b) that WARC-92 adopted an additional allocation in the band 1 429-1 535 MHz, on a primary basis to the aeronautical mobile service for Belarus, the Russian Federation and Ukraine to be used exclusively for aeronautical telemetry subject to RR No. 5.342;

c) that in accordance with the decision by WRC-95, in the United States of America, telemetry stations in the aeronautical mobile service have a primary status in the 2 300-2 390 MHz band and have priority over other mobile services under RR No. 5.394;

d) that in Canada, telemetry stations in the aeronautical mobile service have a primary status in the 2 300-2 483.5 MHz band and have priority over other mobile services under RR No. 5.394;

e) that in France, frequency assignments to telemetry stations in the aeronautical mobile service have a primary status in the 2 310-2 360 MHz band and have priority over other mobile services under RR No. 5.395;

f) that in Europe future airborne telemetry equipment should tune primarily to the frequency range 2 300-2 400 MHz;

g) that the band 1 492-1 525 MHz has been allocated to the MSS (space-to-Earth) in Region 2 taking account of the provisions of RR Nos. 5.348 and 5.348A;

h) that WARC-92 allocated the band 1 452-1 492 MHz on a primary basis to the BSS (digital sound broadcasting (DSB)) (see Note 1) and the broadcasting service (DSB) subject to the provisions of RR Nos. 5.345 and 5.347;

j) that at WARC-92, an additional allocation in the United States of America, India and Mexico of the 2 310-2 360 MHz band to BSS (DSB) and the broadcasting service (DSB) was made on a primary basis under RR No. 5.393;

k) that in the band 1 452-1 525 MHz, WARC-92 adopted an alternative allocation on a primary basis for the fixed and mobile services in the United States of America in accordance with RR No. 5.344;

l) that in Japan in the band 1 492-1 525 MHz, a coordination threshold of -150 dB(W/m^2) in any 4 kHz band for all angles of arrival was adopted at WRC-95 for the protection of specialized land mobile services in accordance with RR No. 5.348A;

m) that coordination is required under RR No. S9.11A and Resolution 528 (WARC-92);

n) that Resolutions 528 (WARC-92) and 213 (Rev.WRC-95) invited the ITU-R to conduct the necessary studies prior to the next competent WRC;

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[*] This Recommendation should be brought to the attention of Radiocommunication Study Group 6.

[**] Radiocommunication Study Group 5 made editorial amendments to this Recommendation in November 2010.

o) that additional studies have been introduced in the ITU-R for determining the probability of interference to telemetry stations in the aeronautical mobile service which could lead to less stringent protection values, and that these studies are expected to continue;

p) that telemetry stations in the aeronautical mobile service have a wide range of characteristics and some may have less stringent protection criteria values than those contained in the *recommends*,

recommends

1 that the values needed for protection of the aeronautical mobile service for telemetry systems in the 1 452-1 525 MHz band shared with geostationary satellites in the BSS (DSB) or the MSS, should be determined by the following (see Note 4):

- for geostationary satellites visible to any aeronautical telemetry receiving station, the protection value corresponds to a pfd at the telemetry receiving station in any 4 kHz band for all methods of modulation:

-181.0 dB(W/m^2) for $0° \leq \alpha \leq 4°$

$-193.0 + 20 \log \alpha$ dB(W/m^2) for $4° < \alpha \leq 20°$

$-213.3 + 35.6 \log \alpha$ dB(W/m^2) for $20° < \alpha \leq 60°$

-150.0 dB(W/m^2) for $60° < \alpha \leq 90°$

where α is the angle of arrival (degrees above the horizontal plane);

2 that the values needed for protection of the aeronautical mobile service for telemetry systems in the 2 310-2 360 MHz band shared with the BSS (DSB) should be determined by the following (see Note 4):

- for geostationary satellites visible to any aeronautical telemetry receiving station, the protection value corresponds to a pfd at the telemetry receiving station in any 4 kHz band for all methods of modulation:

-180.0 dB(W/m^2) for $0° \leq \alpha \leq 2°$

$-187.1 + 23.66 \log \alpha$ dB(W/m^2) for $2° < \alpha \leq 11{,}5°$

-162 dB(W/m^2) for $11.5° < \alpha \leq 90°$

where α is the angle of arrival (degrees above the horizontal plane);

3 that the calculation methods and mitigation techniques given in Annexes 1 and 2 may be used, as applicable, for determining the probability of interference to telemetry systems in the aeronautical mobile service.

NOTE 1 – DSB refers to digital audio broadcasting as per RR Nos. 5.345 and 5.393.

NOTE 2 – The example calculation used to derive the protection values as set out in Annex 1 represent a worst-case scenario. Mitigation techniques given in Annex 2 may enhance sharing.

NOTE 3 – As safety of life aspects are to be considered with mobile aeronautical telemetry systems and efficient use of the spectrum allocated by WARC-92 to the BSS (sound) appears not to be possible, attention is drawn to studies being conducted under Question ITU-R 204/10 (see Recommendation ITU-R BO.1383).

NOTE 4 – Administrations are encouraged to submit information to ITU-R concerning performance and availability targets for the mobile aeronautical telemetry service with a view to developing an appropriate ITU-R Recommendation.

ANNEX 1

Calculation of pfd interference levels to aeronautical mobile telemetry systems from geostationary satellite emissions

1 Introduction

The analyses and results given in the following sections of this Annex are for the purpose of calculating interference to aeronautical mobile telemetry systems.

2 Development of values

The following development can be used in general, but the numerical values are for the 1 452-1 525 MHz band.

2.1 Telemetry system characteristics

General system characteristics are given in the CPM Report to WARC-92 and are as follows. Aeronautical telemetry and telecommand operations are used for flight testing of manned and unmanned aerospace vehicles. Vehicles are tested to their design limits, thus making safety of flight dependent on the reliability of information received on a real-time basis. When being tested to design limits, signal strength loss can exceed 30 dB due to nulls in the aircraft antenna pattern caused by aircraft attitude changes.

Required *C*/*N*:	9-15 dB
Transmitter power:	2-25 W
Modulation type:	PCM/FM
Transmission path length:	up to 320 km
Receiving system noise temperature:	200-500 K
Receiving antenna gain:	20-41 dB

Receive antenna first side-lobe levels for two antennas:

10 m (diameter):	20 dBi (antenna gain) 2.4° (from centre)
2.44 m (diameter):	7-14 dBi (antenna gain) 10° (from centre)

A number of antenna diameters are employed between the 20-41 dB limits. Left-hand and right-hand circular, as well as linear polarizations, are used.

Channel assignments are made in 1 MHz increments. Typical emissions are 1, 3 and 5 MHz in bandwidth with wider assignments made for video and other complex measurements.

The maximum air space for a telemetry receiving site is defined as a cylinder with a horizontal radius of 320 km around the site, with the lower bound determined by visibility and the upper bound determined by an altitude of 20 km. The minimum air space for a particular mission is defined as a vertical cylinder with a radius of 20 km within the maximum air space with the same lower and upper bounds as for the maximum air space.

Continuous RF tracking is employed using both monopulse and conical scan techniques.

Two antenna diameters are given a 2.44 m and a 10 m diameter. Figure 1 shows measured gain values for three 2.44 m antennas. Since these antennas track a moving vehicle so that the antenna gain toward a geostationary satellite is variable, there is a side lobe and backlobe gain which is exceeded or not exceeded 50% of the time. The following composite pattern is developed on this basis for antenna gains from 29 dB to 41.2 dB.

$$G(\theta) = 41.2 + 20 \log \left(\frac{\sin 1.952\,\theta}{1.952\,\theta} \right) \quad \text{dBi} \quad \text{for} \quad 0° \leq \theta \leq 0.94° \tag{1a}$$

$$G(\theta) = 35.1 - 20 \log \theta \quad \text{dBi} \quad \text{for} \quad 0.94° < \theta \leq 3.82° \tag{1b}$$

$$G(\theta) = 29 + 20 \log \left(\frac{\sin 0.479\,\theta}{0.479\,\theta} \right) \quad \text{dBi} \quad \text{for} \quad 3.82° < \theta \leq 5.61° \tag{1c}$$

$$G(\theta) = 27.27 - 18.75 \log \theta \quad \text{dBi} \quad \text{for} \quad 5.61° < \theta \leq 12.16° \tag{1d}$$

$$G(\theta) = 34.05 - 25 \log \theta \quad \text{dBi} \quad \text{for} \quad 12.16° < \theta \leq 48° \tag{1e}$$

$$G(\theta) = -8 \quad \text{dBi} \quad \text{for} \quad 48° < \theta \leq 180° \tag{1f}$$

The values of 1.952 and 0.479 associated with angle θ are in radians.

The telemetry transmitting antennas are mounted on airborne vehicles and, ideally, would be isotropic radiators to cover all possible radiation angles toward the telemetry receiving station. However, in practice, multiple reflections and blockage from the airborne vehicles cause large variations in the gain pattern. Multiple reflections generally result in a Raleigh fading distribution, and measured gain functions have shown that this is approximately the case as shown in Fig. 2. Using Fig. 2 for a near-worst case, including propagation effects, the probability (portion of time), P_1, that a given gain, G_1, is not exceeded can be expressed as:

$$P_1 \, (G \le G_1) = (1 - e^{-3.46 \, G_1})^{1.25} \text{ (numerical)} \qquad (2)$$

Distributions corresponding to an exponent of $(-5G_1)$ are observed.

The received C/N and carrier power, C, at output of the telemetry receiving antenna are proportional to this function.

FIGURE 1

Measured data on 2.44 m diameter antennas

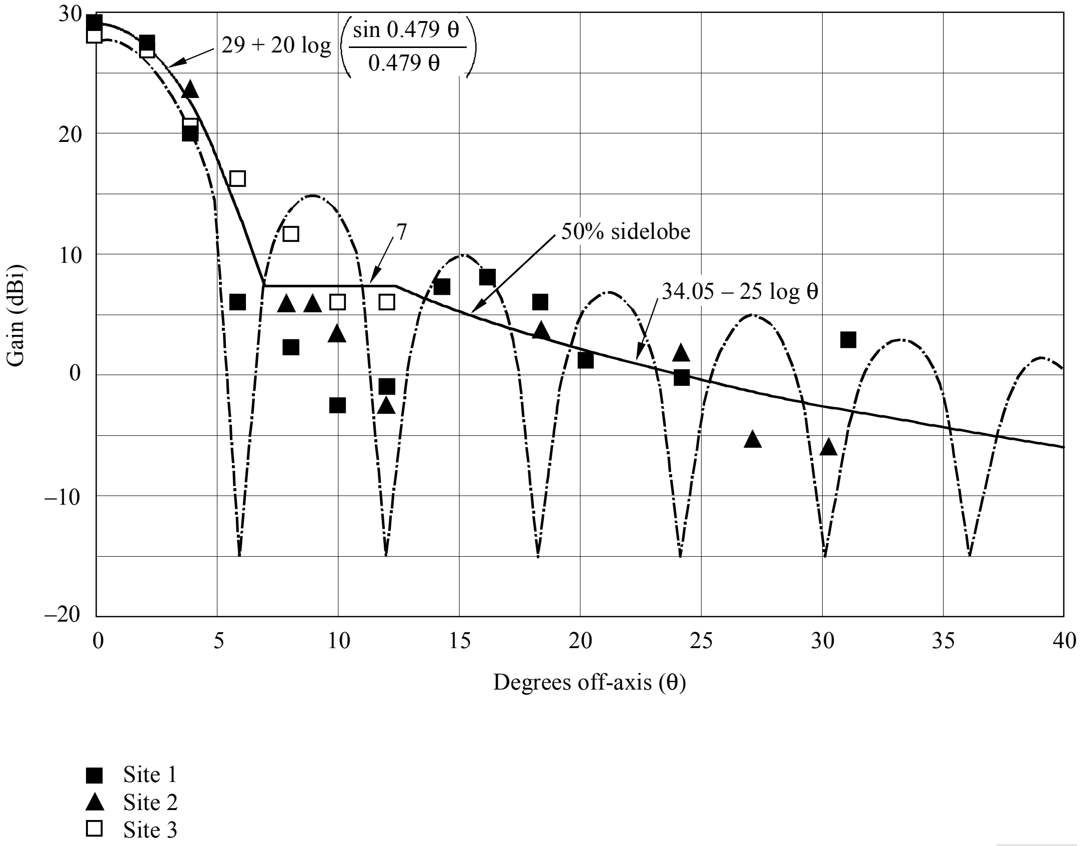

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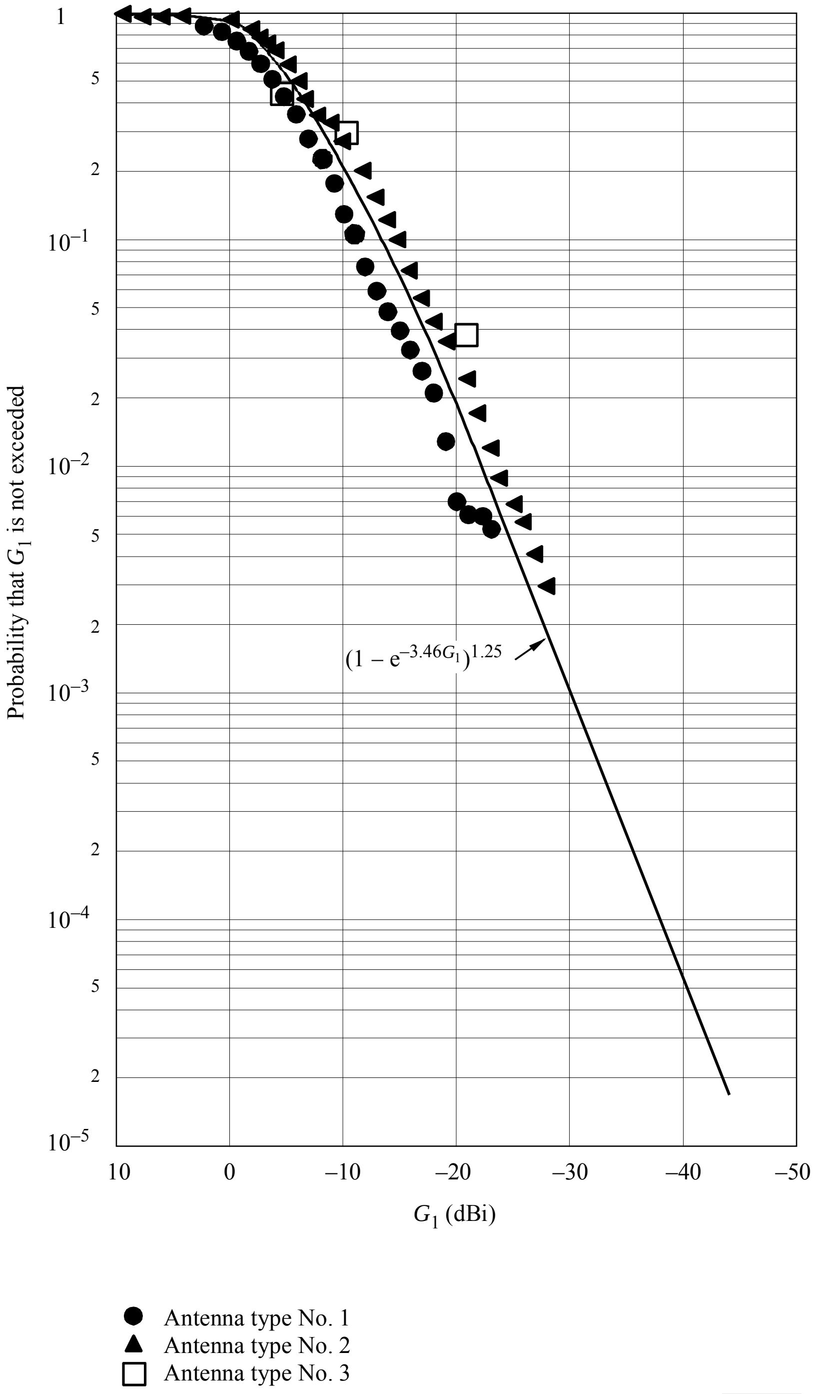
FIGURE 2

Airborne telemetry transmitting antenna gains, G_1



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2.2 Interference from geostationary satellites

2.2.1 Time-gain function of interference

If it is assumed that the telemetry antenna may be pointed at any point on its hemisphere of visibility, the cumulative probability, P_2, that a satellite at geostationary altitude is within a radius of θ, as viewed from the telemetry receiving station, is:

$$P_2 = (1 - \cos\theta) \qquad \text{for} \quad 0 \leq \theta \leq \pi/2 \tag{3}$$

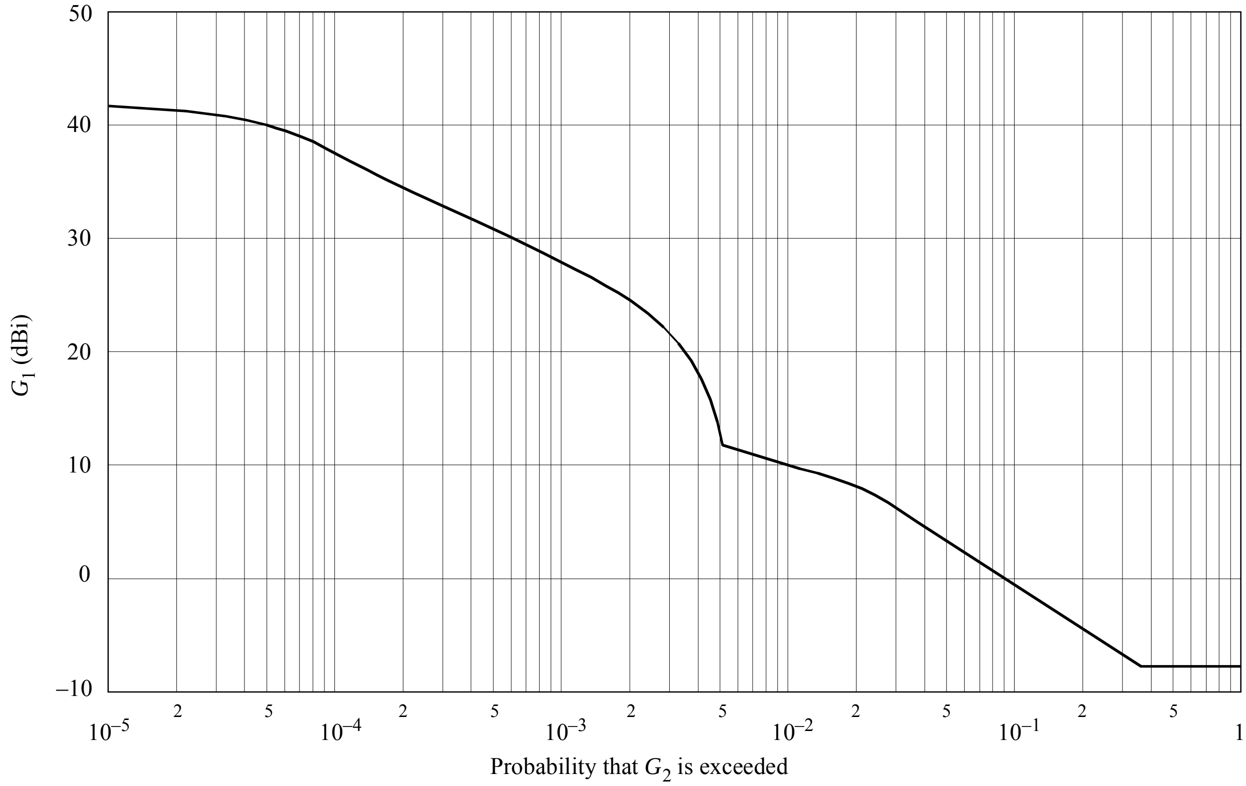
The θ in equation (1) is the same as in equation (3). Thus, by combining equations (1) with (3), functions can be developed which relate the probability (portion of time) that the telemetry receiving antenna gain, G, toward the satellite is equal to or greater than a given value, G_2, as shown in Fig. 3.

The received I/N and the interference power, I, are proportional to the functions shown in Fig. 3.

In the case of geostationary satellite, the angle-of-arrival of interference at a telemetry receiving station is fixed. The only randomness involved is the telemetry receiving antenna pointing variations. Testing of airborne vehicles is often restricted to areas over water or uninhabited land in order to preclude danger to life or property in case of catastrophic failure of the vehicle being tested, thereby limiting the azimuth angles for these tests. There are also minimum limits on the azimuth and elevation pointing angle variations of the telemetry receiving antenna that are defined by the minimum air space in § 2.1.

FIGURE 3

Telemetry receiving antenna gain probability, G_2



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2.2.2 *C/I* analysis

Since equation (2) is proportional to C and the functions in Fig. 3 are proportional to I, the probability of C/I can be determined and is proportional to:

$$P((C/I) \geq (C/I)_c) \propto \left[(P_1(G' \leq G_1))/(P_2(G'' \leq G_2))\right] \tag{4}$$

where $(C/I)_c$ is a chosen value.

The square brackets indicate the joint, cumulative probability function. The C and I functions are independent since they result from independent sources. The indicated integrations were performed for various limited ranges of P_2 which, in turn, corresponds to limited steradian areas, S, when the satellite is within the minimum airspace defined in § 2.1. These integrations may be expressed as:

$$P_3(\Delta G \geq G_2/G_1) = \left[(P_2(G'' \geq G_2))/(P_1(G' \leq G_1))\right] \tag{5}$$

The (C/I) in equation (4) is normally expressed in relation to (C/N), and since loss of availability is the prime concern, it is expressed in relation to the threshold $(C/N)_T$ as follows:

$$(C/I) \geq (C/N)_T\,(P_4/P_3) \tag{6}$$

where

P_4: probability associated with $(C/N)_T$ and is set equal to $P(\Delta G)$

P_3: probability associated with (C/I).

The ratio (P_4/P_3) is analogous and numerically equal to (I/N) criteria. The allowable non-availability, P, is based on $C/(N+I)$ so that $P(\Delta G) = P - P_3$ which results in:

$$P(\Delta G) = P/(I/N + 1) \tag{7}$$

It is now necessary to relate ΔG to pfd. First, a pfd is determined when the telemetry antenna is directed toward the satellite:

$$pfd \leq \frac{k\,T\,B(I/N)}{(\lambda^2/4\pi)\,G_0} \qquad \text{W/(m}^2 \cdot B) \tag{8}$$

where:

k: Boltzmann's constant

T: noise temperature (K)

B: bandwidth (Hz)

$G_0 = 13\,183$ (41.2 dB).

This pfd is associated with a $(\Delta G)_m$ at a $P(\Delta G)$. At G_0, only C is variable and thus, C/I is given by equation (2). The $(\Delta G)_m$ function is closely approximated by:

$$(\Delta G)_m = 45\,000/P(\Delta G)^{1.25} \tag{9}$$

The pfd from equation (8) can be increased by $(\Delta G)_m/(\Delta G)$. Thus:

$$pfd \leq \frac{k\,T\,B(I/N)}{G_0(\lambda^2/4\pi)} \times \frac{(\Delta G)_m}{(\Delta G)} \qquad P(\Delta G)_m = P(\Delta G) \qquad \text{W/(m}^2 \cdot B) \tag{10}$$

2.2.3 Impact on telemetry link design

Analyses show that the value of P, the telemetry link non-availability, does not significantly affect the pfd values. The pfd values are primarily determined by the value of (I/N). The impact on the telemetry link measured in terms of the decrease in usable range, R, for a given P, as a function of (I/N) can be determined from equation (7), since $R^2 \propto 1/(N + \text{I})$ for a fixed transmitter power. The decreased usable range as a function of (I/N) is shown in Fig. 4. The impact on telemetry link design becomes severe for (I/N) values greater than one (0 dB) because the link must be designed to overcome interference rather than internal noise. The maximum practical value is considered to be approximately 0.5 (–3 dB) with smaller values desired.

2.2.4 Interference allowances

Based on the factors given in § 2.2.3, the following aggregate allowances appear appropriate for this case. The total noise is the sum of internal noise, N_I, plus interference from satellites, I_S, plus interference from terrestrial sources, I_T. The aggregate permissible interference from satellites and terrestrial sources are:

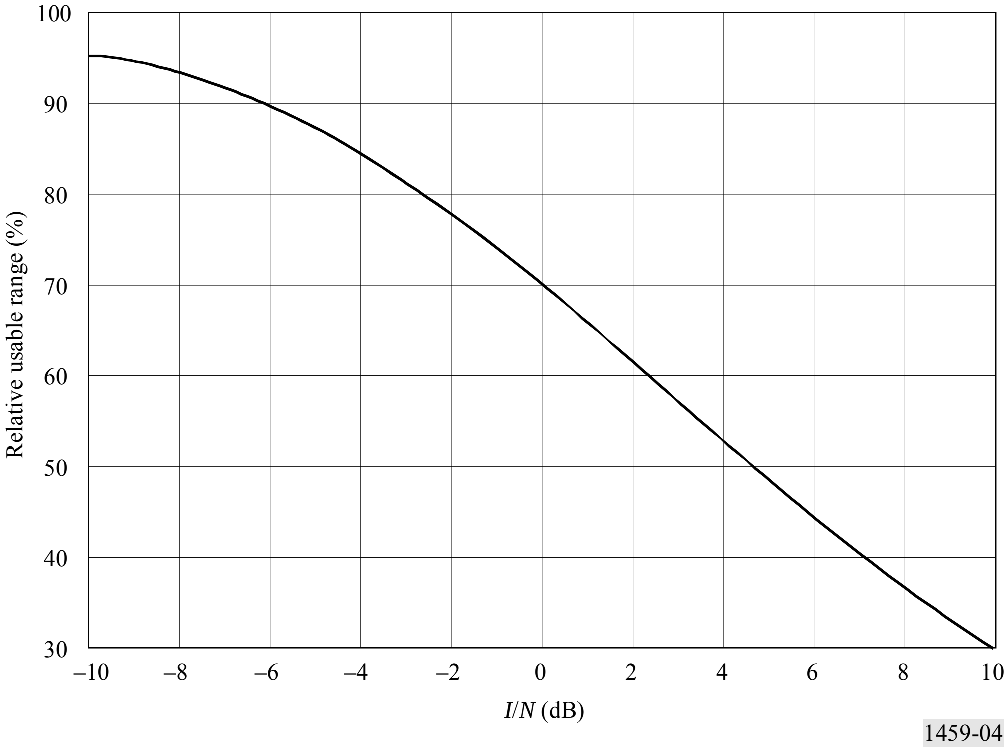
$$I_S = 0.25\,(N_I + I_S + I_T) \tag{11}$$

$$I_T = 0.10\,(N_I + I_S + I_T) \tag{12}$$

From this, the aggregate allowable I/N from satellites is 0.3846 or –4.15 dB, and from terrestrial sources is 0.1538 or –8.13 dB. Since pfd is not particularly sensitive to P, a mid-range value of P of 0.005 is selected for numerical evaluation which results in a $P(\Delta G)$ of 0.003611 from equation (7).

FIGURE 4

Decrease in usable range versus *I*/*N*



2.2.5 Minimum *S* versus angle of arrival, α

The minimum value of *S* can be determined from the minimum radius of a circle in which aircraft testing is normally accomplished (see Fig. 5). *S* as a function of α is determined as follows. The elevation angle of arrival is:

$$\alpha = \tan^{-1}\left(\frac{h}{d} - \frac{d}{2r}\right) \qquad \text{rad} \tag{13}$$

The incremental angle of arrival, Δα, along the telemetry antenna pointing azimuth is:

$$\Delta\alpha = \tan^{-1}\left(\frac{h}{d-a} - \frac{d-a}{2r}\right) - \tan^{-1}\left(\frac{h}{d+a} - \frac{d+a}{2r}\right) \qquad \text{for } d \geq a \qquad \text{rad} \tag{14a}$$

$$\Delta\alpha = \tan^{-1}\left(\frac{d+a}{h}\right) - \tan^{-1}\left(\frac{d-a}{h}\right) \qquad \text{for } d < a \qquad \text{rad} \tag{14b}$$

The angle tangent to the azimuth, β, is:

$$\beta = 2\tan^{-1}\left(\frac{a\cos\alpha}{d}\right) \qquad \text{rad} \tag{15}$$

From which *S* is:

$$S = \pi/4\,(\beta)\,(\Delta\alpha) \qquad \text{steradians} \tag{16}$$

where:

h: aircraft altitude = 20 km

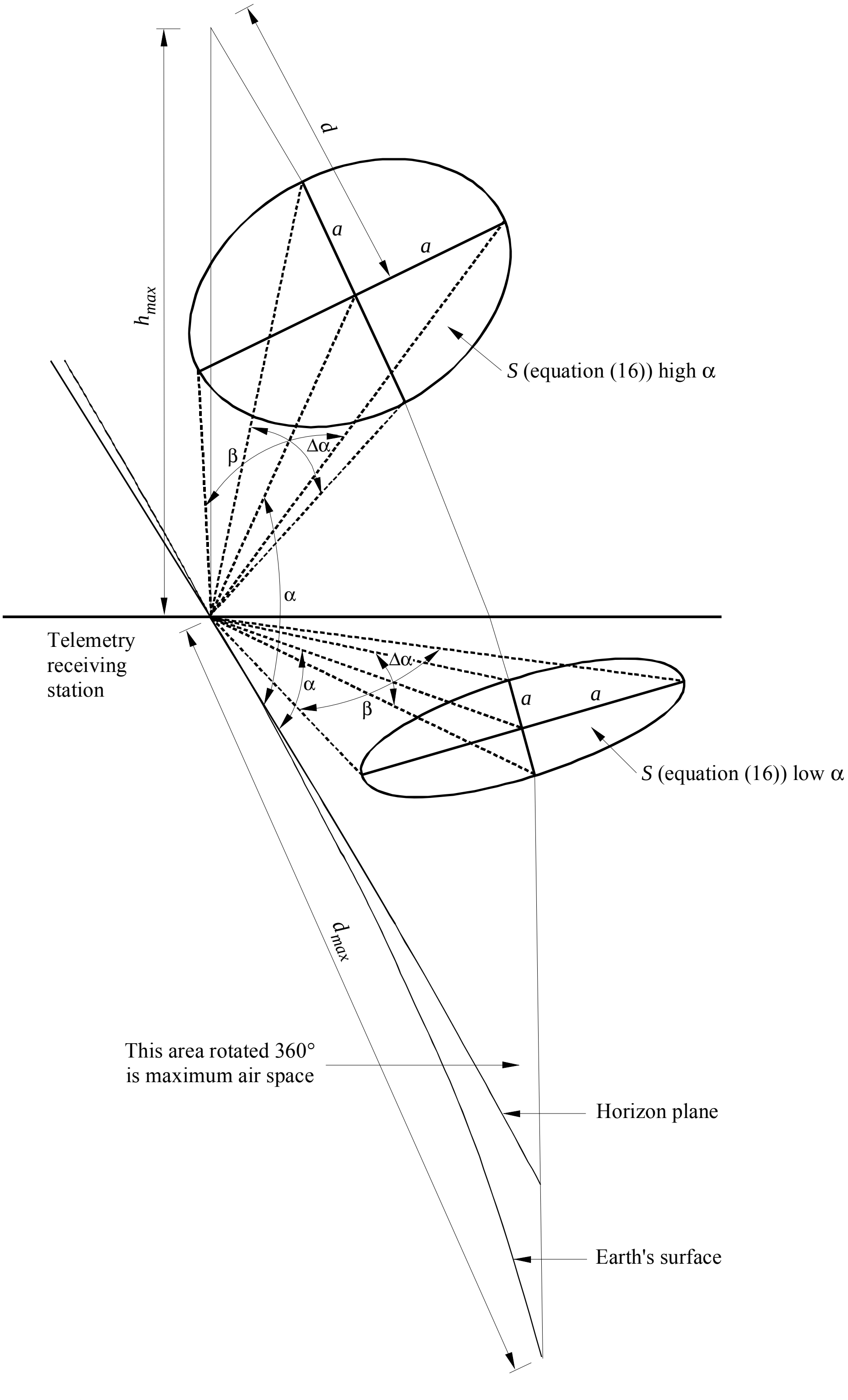
d: surface distance to aircraft = 320 km (maximum)

r: radius of the Earth = 6 378 km

a: minimum radius of flight patterns = 20 km.

FIGURE 5

Geometry for *S* computations for geostationary satellites



β (equation (15))
Δα (equation (14))
α (equation (13))

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2.2.6 pfd versus angle of arrival

– pfd escalation due to *S*

  The permissible pfd increases with *S* which increases with angle of arrival, α. The pfd as a function of *S* can be calculated using equation (16), in conjunction with the ΔG versus *S* functions developed in § 2.2.5, for a $P(\Delta G) = 0.003611$ which, in turn, is used in equation (10). The minimum *S* is 0.001262 steradians.

– pfd escalation due to excess margin

  There will be some distance, d_0, between the telemetry receiving station and the airborne vehicle at which the desired availability is generally exceeded. Thus, excess margin is available which could be used to increase the allowable pfd. The value of d_0 can be determined by:

$$d_0 = \left\{ \frac{P\, G_a\, G_0}{1\,758\, k\, T\, B\, M\; f^2 (C/N)_T} \right\}^{0.5} \quad \text{km} \tag{17}$$

where:

P: aircraft power (W) = 4

G_a: aircraft median antenna gain = 0.2

G_0: telemetry receiving antenna gain = 800

M: availability margin required = 300

f: frequency (MHz) = 1 500

k: Boltzmann's constant

T: noise temperature (K) = 250

B: bandwidth (Hz) = 3×10^6

$(C/N)_T$: threshold value = 32.

The nominal values for each parameter as listed above are considered to be the most appropriate for determining d_0. The solution of equation (17) with these values result in a d_0 of 40 km.

The angle of arrival, α, is determined by the distance, *d* and the aircraft height, *h* and is:

$$\alpha = \text{arc sin}\,(h/d) \tag{18}$$

From equation (18), α as a function of *d*, for values of *d* between d_0 and *h* can be determined. The excess margin, M_e, which can be used to increase the pfd is:

$$M_e = (d_0/d)^2 \tag{19}$$

The maximum value of *h* is assumed to be 20 km. Using these values M_e as a function of α is computed. A nearly exact formulation of this function can be expressed as a pfd escalation factor, pfd_e, as follows:

$$pfd_e = 1 \qquad \text{for} \quad 0° \le \alpha \le 30° \tag{20a}$$

$$pfd_e = 1 + 0.066\,(\alpha - 30) \qquad \text{for} \quad 30° < \alpha \le 62.5° \tag{20b}$$

$$pfd_e = 4 \sin^2 \alpha \qquad \text{for} \quad 62.5° < \alpha \le 90° \tag{20c}$$

2.2.7 Multiple entries

When the value of *S* is very small, sidelobe and back lobe interference levels from similar satellites in the GSO will be insignificant as compared to the main lobe level. As *S* increases, the sidelobe and back lobe contributions become statistically significant and are accounted for on a per-satellite basis in § 2.2.1. Therefore, multiple entries are primarily related to the number of geostationary satellites within the limited steradian coverage of the telemetry antenna, *S*.

First, it is assumed that an area, S', is circular and that its diameter, δ, is aligned with the GSO, and second, it is assumed that there are N satellites equally spaced by an angle, Δ, each producing equal pfds at the telemetry antenna.

When δ is equal to Δ, two entries are possible but the probability is near 0. When δ is equal to 2Δ, the probability of two entries is near 1, while probability of three entries is near 0, and so forth. Thus, for a probability of about 0.5:

$$\delta = (N - 0.5)\,\Delta \qquad \delta \text{ and } \Delta\text{, degrees} \tag{21}$$

The area S' is:

$$S' = (\pi/4)\,\delta^2 \qquad \text{steradians} \qquad \delta\text{, rad} \tag{22}$$

From this model, N is closely approximated by:

$$N = 70(S')^{0.5}/\Delta \qquad \text{for} \quad \Delta^2/4\,900 \le S' \le 1.938 \tag{23}$$

Since $N \ge 1$, $S' \ge \Delta^2/4\,900$, and since the "maximum" minimum value of S from § 2.2.5 is 1.938, N in equation (23) is limited to this range. Thus, N is limited to the range; $1 \le N \le ((90/\Delta) + 0.5)$.

The single entry escalation, pfd_{es}, is related to the aggregate pfd_{ea} by:

$$pfd_{es} = pfd_{ea}/N \tag{24}$$

2.3 Single entry pfd values

From the preceding analyses, values of single entry pfds may be developed. The pfd single entry values developed in the following sections are applicable for aeronautical mobile telemetry systems. Telemetry systems parameter values are as follows:

T: receiving station noise temperature = 250 K

B: referenced bandwidth = 4 kHz

λ: wavelength = 0.2 m

I/N: interference/noise = 0.3846

$P(\Delta G)$: probability of differential gain = 0.003611.

Using these values in conjunction with the ΔG versus S function, the excess margin and multiple entry factor for a Δ of 45°, results in the function shown in Fig. 6. As also shown in Fig. 6, the pfd versus angle of arrival is closely approximated by:

$$pfd \le -181.0 \qquad \text{dB(W/(m}^2 \cdot 4\text{ kHz))} \qquad \text{for} \quad 0° \le \alpha \le 4° \tag{25a}$$

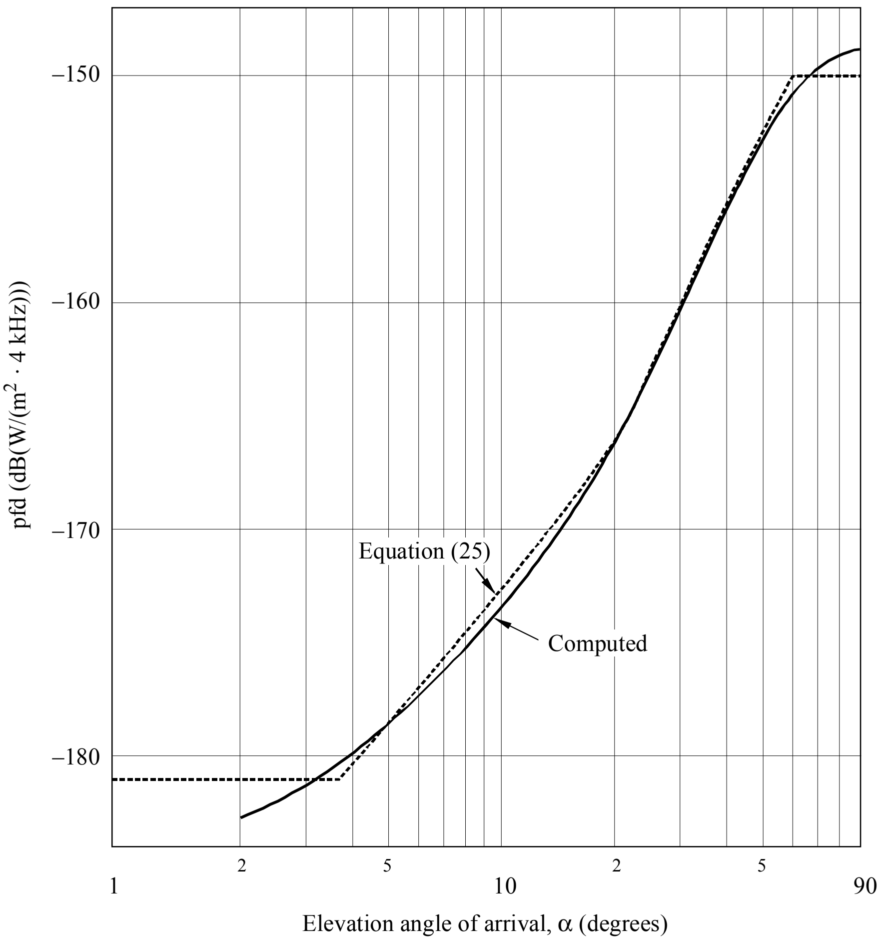
$$pfd \le -193.0 + 20 \log \alpha \qquad \text{dB(W/(m}^2 \cdot 4\text{ kHz))} \qquad \text{for} \quad 4° < \alpha \le 20° \tag{25b}$$

$$pfd \le -213.3 + 35.6 \log \alpha \qquad \text{dB(W/(m}^2 \cdot 4\text{ kHz))} \qquad \text{for} \quad 20° < \alpha \le 60° \tag{25c}$$

$$pfd \le -150 \qquad \text{dB(W/(m}^2 \cdot 4\text{ kHz))} \qquad \text{for} \quad 60° < \alpha \le 90° \tag{25d}$$

FIGURE 6

Single entry thresholds for aeronautical telemetry receiving stations due to interference from geostationary satellites



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ANNEX 2

Mitigation techniques

1 Mitigation techniques for telemetry systems in the aeronautical mobile service

The following mitigation techniques should be reviewed and used to the extent practical towards achieving successful sharing with the BSS (sound).

1.1 Frequency avoidance

If possible avoid the use of those portions of the affected frequency bands. In the case of isolated telemetry sites (no overlapping air space with any other site) with a light testing schedule, it may be possible to avoid use of portions of the bands allocated to BSS (sound). In the case where many site coverage overlaps occur and simultaneous testing occurs, frequency avoidance may not be possible.

1.2 Polarization discrimination

In situations where it is possible for telemetry systems in the aeronautical mobile service to use opposite polarizations than those employed by BSS (sound) systems then some polarization discrimination may be achievable during the worst-case interference scenario when the BSS (sound) transmit and the telemetry receive antenna boresights are in near alignment.

1.3 Modulation and bandwidth considerations

There are several types of modulations and bandwidths used in telemetry systems in the aeronautical mobile service with a general trend towards becoming all digital. Use of digital modulation will facilitate the use of FEC coding techniques that would provide a higher degree of immunity or coding gain against BSS (sound) interference. Also from the standpoint of the interfering BSS (sound) signal being digital, will exhibit noise-like interference into the telemetry signal.

pfds are currently specified in a 4 kHz bandwidth at these frequencies. When the interfered-with signal is analogue or digital, limiting the interference levels in such a narrow bandwidth may lead to overly protective criteria. The use of more appropriate averaging bandwidths for particular sharing situations can more accurately represent protection requirements. For this case a 400 kHz averaging bandwidth can be used.

1.4 Telemetry airborne transmit antenna diversity

An important parameter in telemetry systems in the aeronautical mobile service is the signal availability. Manoeuvres of the airborne test vehicle can result in severe fading of the telemetry receive signal which typically follows a Rayleigh distribution. In some cases it is feasible to employ multiple transmit antennas along the body of the test vehicle to provide transmitter antenna diversity which could result in significant reduction of signal fading.

1.5 Telemetry site diversity

Some telemetry test ranges in the aeronautical mobile service employ two or more receive antennas. If these antennas can be arranged to provide site/space diversity a significant reduction in Rayleigh signal fading would be achieved. Also properly spaced receive antennas may result in avoidance of boresight-to-boresight interference scenarios and boresight-to-sun scenarios further improving telemetry signal availability and improving sharing. Combining frequency and site diversity would further reduce the fading margins.

1.6 Aeronautical telemetry test range geometry

In most interfering situations boresight-to-boresight scenarios will result in worst-case interference. If the previously described countermeasures are not viable or sufficient, a flight path for the test vehicles may be selected so as to avoid the most critical azimuths corresponding to near boresight conjunction and the avoidance of lower elevation angles. The particular arrangement and degree of success achievable will depend on the mutual spatial position of the test range telemetry receive antenna and BSS (sound) interfering transmitter.

Perhaps the single most effective mitigation technique from the aeronautical mobile telemetry standpoint would be to avoid telemetry antenna main lobe conjunctions with geostationary satellites. This case has been analysed for the 1 452-1 525 MHz band and it is estimated that about 20 dB of additional protection could be achieved at very low angles of arrival to about 5 dB at near zenith. The extent to which this technique can be employed depends on the geometry of the test ranges and the flight patterns which are not known at this time.

1.7 Aeronautical telemetry receiver interference cancelling techniques

Active suppression of interference is regularly used in dual polarization FSS and fixed service radio systems and on many occasions where specific difficult sharing scenarios occur. Significant interference suppression may be achieved depending on the fading dynamics. Such techniques could be a means of ameliorating particular interference situations that occur.

1.8 General sharing assessment

Even under the most favourable geometric conditions with mitigation techniques, it is extremely unlikely that a successful sharing could be achieved under co-coverage, co-frequency conditions, considering that the required pfd for the BSS (sound) service is of up to –122 dB(W/($m^2 \cdot$ 4 kHz)).

However, under favourable geometric conditions and where BSS (sound) satellite antenna discrimination to the telemetry receiving antennas in the order of 30 dB can be achieved, there is a reasonable expectation of successful sharing for low-power systems, i.e. in the order of –138 dB(W/($m^2 \cdot$ 4 kHz)). However, this value is not typical for BSS (sound) systems.

2 Mitigation techniques to facilitate sharing with BSS (DSB) systems

2.1 BSS (sound) systems

It is normally presumed that new systems in the planning and early implementation stages have more flexibility in choosing operating parameters that will facilitate sharing with existing services. The following lists some possible mitigation techniques that could be considered applicable to the BSS (sound) service to alleviate sharing. Also the results of different ITU-R studies agree with the views stated below on the feasibility and applicability of these mitigation techniques.

2.2 Orbit location

The selection of orbital locations that minimizes exposure and spill-over into critical mobile aeronautical telemetry (MAT) sites is a possible mitigation technique. The ITU-R considers that it would be very difficult to select orbital locations to minimize exposure to the affected services. The BSS (sound) expects to offer a worldwide service, and the countries who use MAT systems are spaced around the world so that it is impossible not to illuminate one or more of them. Furthermore, in many instances there are constraints on the choice of orbital locations available to provide a viable BSS (sound) service. Therefore, the ITU-R does not believe that significant advantage can be gained from this technique.

2.3 Modulation and implementation

This involves the employment of efficient modulation and channel coding schemes, and utilization of path diversity techniques that minimize pfd requirements in achieving the desired level of system performance and availability.

The comments of the ITU-R on this mitigation technique is that it has been diligent in its search for efficient modulation and channel coding schemes. Indeed, the work discussed in ITU-R in recent years has been innovative and significant in its ability to enable spectrum efficient systems to be considered. It is not likely that any further improvements will lead to major reductions in the necessary pfds, and hence improvements in the sharing scenario.

2.4 Spectrum spreading

Employing spread spectrum techniques reduces the pfd by the inverse of the spread ratio (spread bandwidth/unspread bandwidth) and increases the interference immunity by the spread ratio.

The ITU-R considers that spectrum spreading as a method of ameliorating sharing implies that there is sufficient spectrum allocated to the service to be able to spread the energy of the interfering signal over a larger bandwidth to provide a corresponding reduction in the pfd per unit of bandwidth, in this case per 4 kHz. Furthermore, in order to maximize this advantage, each interfering BSS (sound) service would need to utilize exclusive spectrum (i.e. no overlapping of the spread spectrum channels). Considering the relatively narrow-band of spectrum allocated to BSS (sound) by WARC-92, and further considering that this spectrum is shared with the broadcasting service (sound), spectrum spreading would not be a feasible mitigation technique to achieve sharing. This is illustrated by way of the following example:

The order of improvement in pfds to enable sharing appears to be greater than 30 dB. To achieve even 20 dB using spread spectrum techniques would, using normal pseudo-noise spreading systems, require a spreading gain of about 100, and hence use a spreading factor of 100. Given that the BSS band at 1.5 GHz is 40 MHz wide and we expect will, in time, be fully utilized, this would lead to a spectrum requirement for the BSS operation of 4 GHz if spread spectrum techniques were to be adopted.

2.5 Receiver performance

Maximization of the receiver figure of-merit, *G*/*T*, by employing low noise front ends and maximum gain antennas consistent with costs and the type of service being offered is a possible mitigation technique.

The ITU-R considers that RF device technology has now improved to the point that the low noise front end is not the limiting factor in setting the receiver noise budget. Typical receiver noise figures being considered range from 1-3 dB. As other sources of noise at the receiver, such as radiation from the ground, sky and surrounding objects, input filter losses, etc., contribute a significant portion of the overall receiver noise budget, we would therefore be suffering diminishing returns in considering reduction in receiver noise figure as a significant mitigation technique. Improving the gain of the antenna is feasible, and has been adopted in our attempts to realize cost-effective solutions. However, there is a limit to the amount that we can go in this direction when we consider that we are attempting to provide a service to mobile and portable receivers, and to offer a system which can be implemented at a price which can be afforded by all. Therefore, it would be difficult to achieve significant improvements in sharing by any possible improvements in the receiver *G*/*T*.

2.6 Satellite transmit antenna and coverage area

This mitigation technique consists of minimizing the satellite beam spill-over to the extent practical by utilizing beam shaping to conform as closely as practical to the intended service area.

The ITU-R considers that all proposals for BSS (sound) satellites pay careful attention to antenna engineering. The size of the antenna, and the need to minimize spill-over for efficient use of the BSS (sound) spectrum for our own purposes mean that beam shaping is already fully optimized. Also, while beam shaping will lead to more rapid roll-off of the close-in sidelobe levels (e.g. first sidelobe) thus facilitating sharing with services near the edge of the coverage area, such techniques do not improve the levels of the higher order sidelobes and hence will not improve sharing for systems located further from the edge of the coverage area which will tend to also correspond to lower elevation angles where the minimum pfd levels are required.

2.7 Highly-inclined elliptical orbit (HEO) BSS (sound) systems

For HEO systems, selection of orbital constellations that maximizes the elevation angles to affected MAT sites and making available Ephemeris (spatial and time information on the orbits) data to MAT operators are possible mitigation techniques.

The ITU-R considers that, given the large number of countries using fixed systems and the incomplete information about the location of these systems, it is not likely that any major improvement can be gained for HEO systems, other than those already achieved for the benefit of the broadcast service.

2.8 Frequency avoidance

This consists of selecting that part of the spectrum allotted to BSS (sound) least utilized by MAT systems when possible.

The ITU-R considers that this mitigation technique, while not representing in the true sense sharing, appears to be the only one which can be realistically exploited. The ITU-R realizes that, in the case of MATS, some of the band occupied by the MAT systems are safety of life systems. It would appear reasonable that, if at all possible, these elements of the MAT service occupy that part of the spectrum not occupied by BSS. It would make reasonable sense to require protection of this part of the service at the proposed levels.

The overall conclusions of the ITU-R on the above mitigation techniques to be applied to the BSS (sound) is that, except for the frequency avoidance technique, the sum of the improvements expected from the application of these mitigation techniques will not be nearly sufficient to ensure that successful sharing can be achieved. That being the case, the ITU-R considers that any improvements in sharing that may be achieved by the application of these and any other mitigation techniques would need to ensure that all administrations would have the capability of implementing the BSS (sound) service in the appropriate band allocated by WARC-92 and without the need for major constraints being placed on the level of service that can be provided.

3 Practical measures to permit inter-service sharing

When interference calculations are being made, worst-case scenarios are likely to be used, which could tend to lead to the conclusion that co-frequency or co-channel sharing by different services cannot occur. General technical parameters are used to establish appropriate sharing criteria. Those parameters may not reflect the actual proposed usage by administrations.

Where an administration wishes to establish a new system and appropriate sharing criteria have not been finalized, the measures outlined below should be considered to ensure that harmful interference is not caused to the existing service or to the proposed new service.

3.1 The affected administrations should identify specific areas, or installations, where such interference is likely to occur. It may then be possible to take specific action to adequately protect such areas or installations.

3.2 Initially, geographical separation will be a consideration, but as adjacent border areas will be most affected, this option may be limited.

3.3 When specific installations or sites have been identified as being affected, practical methods such as interference cancellers, special screening, and adaptive antenna systems may be implemented (see Recommendation ITU-R SM.856).

3.4 Modifications to existing channelling arrangements for systems in the fixed service may also need to be considered, provided this approach is consistent with economic advantage.

3.5 In the longer term, moves to the use of improved transmission techniques, such as spread spectrum (see Recommendation ITU-R SM.1055), coding techniques, automatic power control, and energy dispersal, may further facilitate inter-service sharing.