European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY STUDY BETWEEN MOBILE SATELLITE SERVICE IN THE 1610-1626.5 MHz BAND AND FIXED SERVICE OPERATING UNDER RR730

Brussels, June 1994

CONTENTS

COMPATIBILITY STUDY BETWEEN MOBILE SATELLITE SERVICE IN THE 1610-1626.5 MHz BAND AND FIXED SERVICE OPERATING UNDER RR730

1. INTRODUCTION

WARC-92 (RR 731E) allocated the band 1610-1626.5 MHz on a primary basis to the Mobile Satellite Service (MSS) in the earth-to-space direction (uplink) and the band 1613.8-1626.5 MHz on a secondary basis to the MSS in the space to earth direction (downlink). This report presents the results of the study concerning the sharing between Fixed Service and MSS.

RR730 gives primary allocation to Fixed Service in the following CEPT countries : Germany, Austria, Bulgaria, Spain, France, Hungary, Poland, Romania, Czech Republic and Slovakia. RR731E states that MSS stations shall not cause interference or claim protection from stations operating under RR730. Spain and France have been added to this footnote during WARC92. France has not planned any introduction of systems for the moment. All other countries are expected to withdraw equipment before MSS operations in 1996.

Characteristics for MSS are not fully determined at the moment. Both TDMA and CDMA access techniques and both GSO and non GSO satellites are considered in the calculations, with technical data already available. MSS systems are referred to by name for ease of identification.

According to RR731E, the MES maximum EIRP should be -15dBW/4kHz when sharing with systems operating under RR732 and -3dBW/4 kHz elsewhere.

For the time being, only the Iridium project intends to use a secondary status downlink allocation in the band 1616 MHz to 1626.5 MHz.

2. INTERFERENCE FROM MES TO FIXED SERVICE

According to Germany and their experience from sharing between Inmarsat C and the fixed service, interference has sometimes occurred above 1626.5 MHz but the tactical RR systems, owing to their freedom in frequency selection, are able to deal with this interference.

To give the order of magnitude of the interference, a very short calculation has been made in annex 1 and gives the following required separation distances :

Main lobe : 33 km (CDMA) to 66 km (TDMA)
Side lobe : 22 km (CDMA) to 46 km (TDMA)
Back lobe : 12 km (CDMA) to 30 km (TDMA)

However, considering the low number of radio relays operating simultaneously in the 1610-1626.5 MHz band, the likelihood of interference could be low when the MSS starts to develop.

3. INTERFERENCE FROM FIXED SERVICE TO MSS SATELLITES

Calculations carried out in this section have been made before knowing that German Radio Relays will be withdrawn before 1996. Thus, interference scenario considered was between a MSS satellite and a particular MES located close to Germany. It is likely that similar results would be obtained with other European countries operating Fixed Service according to RR730.

Interference effects from the Fixed Service into MSS satellite receivers have been studied for example for GSO and Non-GSO/ICO systems. Since the information on the number of simultaneous co-channel transmitting FS stations could not be gathered, a single FS station was assumed to be transmitting co-channel with a particular mobile earth station.

For a Non-GSO/ICO system, the worst case scenario of a spot beam covering both the FS and the MES location was chosen. The simulation consisted of calculating, at intervals of 10 minutes, the interference from the FS station into the satellite which is providing service to the MES at that moment. The selection strategy for the satellite was to choose the one with minimum elevation angle > 20 degrees. The elevation angle from the FS location to the selected satellite was generally greater than 0 degrees thus affording some FS antenna discrimination. The duration of the simulation was 24 hours. It was also assumed that there was no azimuth discrimination between the satellite and the FS station.

For the GSO case a system with four orbital locations visible to Germany was assumed.

The results obtained for the GSO (TDMA) case show that at least one of the four satellites, which has low elevation angle towards Germany, will receive excessive interference in some of the spot beams covering the FS stations in Germany.

For the Non-GSO/ICO case the results show that the interference to the MSS uplink carrier from a given MES (operating in Germany) could exceed the protection criteria for 33 % of the time.

However, it is important to notice that a small improvement in the protection criteria threshold (e.g. 3 dB) would reduce considerably the percentage time of excess interference. Consideration of statistical factors associated with azimuthal pointing differences (extra FS antenna discrimination) and the probability of co-channel operation between the FS and the MES would also help to ameliorate the interference effects. For CDMA MSS systems, consideration of their processing gain would also help lessen the interference effects.

The calculations for the example cases are presented in annex 2 for the ICO case and in annex 3 for the GSO case.

4. INTERFERENCE FROM DOWNLINK MSS TO FIXED SERVICE

Calculations have been carried out and show that the difference between the maximum PFD for protection of the FS in Germany (given by RR2557, article 28) and the calculated PFD produced by the published satellite systems HIBLEO and HIBLEO-2 (e.g. Iridium) is in the range of 34 to 47 dB. These calculated results and the current RR specifications show that the frequency sharing of FS systems and MSS systems in the 1613.8 - 1626.5 MHz band would be quite difficult for future operation of the MSS downlink.

see annex 4 for detailed calculations

Further studies should be undertaken by the MSS operators in cooperation with Administration of countries which will operate FS under RR730 after 1996, including the interference potential from FS transmitter into the MES receiver (e.g. MSS hand-held).

5. CONCLUSION

Interference from MES to radio relays, when it occurs, will be solved on a national basis. There is also a potential risk that radio relays will interfere with MSS satellites.

Interference from secondary MSS downlink emissions in this band are likely not to be tolerable.

ANNEX 1

INTERFERENCE FROM MES TO GERMAN RADIO RELAYS

1. TECHNICAL DATA ON TYPICAL GERMAN TACTICAL RADIO RELAY SYSTEM

One typical German Radio Relay system has the following characteristics :

Frequency band : 1400-1660
Output power : up to 1.2 W
Noise figure : 8 dB max.
IF bandwidth : 600 kHz
Antenna gain : 19.5-22 dB
Side lobe attenuation : 9 dB min.
Front to rear ratio : 18 dB min.

Other tactical Radio Relays used in this band have some very similar characteristics. However, their antenna sidelobe and backlobe attenuation are better. Hence, following calculations have to be understood as a worst case.

2. CO-CHANNEL INTERFERENCE FROM MSS TO FS

It is possible to assess interference distance from various MSS systems to German fixed service. Only co-channel interference case will be studied, considering a mobile in the antenna mainlobe, sidelobe or backlobe.

In calculations, we considered the CCIR interference criteria of a maximum 1 dB increasing of noise. This gives a noise to interference ratio of 6 dB. Multiple interferers scenarios would lead to some highest values but will not be considered for these rough calculations.

Various MES power from CDMA or TDMA multiple access, LEO, ICO or GSO space segment configurations have been computed.

Interfering distances have been deduced from Okumura curves at 1500 MHz for open area, with a mobile height of 1.5 m and a base height (RR height) of 30 m.

Calculations are presented on the following page

3. RESULTS

First, it should be noted that the space segment configuration (GSO, ICO, LEO) has no effect on the interference distance. On the other hand, TDMA multiple access, having an higher power in the RR bandwidth, gives some more harmful interference than CDMA multiple access.

Even with a better sidelobe and backlobe discrimination, interference would occur in all directions. Hence, the likelihood of interference could increase very quickly with the development of MSS in Germany. Precise figures on interference probability would require more information on the use of these military tactical radio relays.

system	*GLOBALSTAR*	*ODYSSEY*	*IRIDIUM*	*INMARSAT*	*INMARSAT*	*INMARSAT*
multiple access	CDMA	CDMA	TDMA	TDMA	CDMA	TDMA
space segment	LEO	ICO	LEO	GSO	ICO	ICO
MES EIRP (dBW)	-2.2	-0.5	6	8	-1	8
MES bandwidth (kHz)	1250	5300	40	20	1000	20
MES EIRP (dBW) in 600 kHz	-5	-10	6	8	-3	8
RR receiver noise (dBW)	-138	-138	-138	-138	-138	-138
RR N/I (dB)	6	6	6	6	6	6
RR Max. interference level (dBW)	-144	-144	-144	-144	-144	-144
RR antenna gain (dBi)						
Mainlobe	22	22	22	22	22	22
Sidelobe	13	13	13	13	13	13
Backlobe	2	2	2	2	2	2
required path loss (dB)						
Mainlobe	161	156	172	174	163	174
Sidelobe	152	147	163	165	154	165
Backlobe	141	136	152	154	143	154
Interference distance (km)						
Mainlobe	38	33	60	66	43	66
Sidelobe	27	22	43	46	30	46
Backlobe	16	12	27	30	18	30

ANNEX 2

INTERFERENCE TO ICO/MSS SYSTEMS FROM GERMAN FS SYSTEMS

1. INTRODUCTION

This annex analyses the interference which would be caused to ICO/MSS systems from co-primary FS systems in 1.6 GHz operating in Germany in accordance with RR 730 until 1996.

2. SYSTEM PARAMETERS

The ICO/MSS system parameters, similar to that being considered for Inmarsat's future hand-held system, are given in sub-annex 1. The system consists of 10 satellites in two intermediate circular orbits at 10,355 Kms inclined at 47.5 degrees.

The salient parameters of German FS systems are given in Sub-annex 2.

3. METHODOLOGY

Line of sight FS systems typically operate parallel to horizon and hence at 0 degree elevation angle. So if from a given terrestrial location the elevation angle to the ICO satellite would be 0 degree, and the satellite azimuth would coincide with the FS antenna azimuthal pointing, then the ICO satellite would receive a direct interference hit from the FS transmitter. For any off axis (elevation or azimuth) angles to the satellite the interference effects will be less.

A representative extreme terrestrial location, of 54 N, 14 E, was chosen on the German territory for this case study. A FS station could be assumed to be located at this point.

Since the worst case would relate to a spot covering both the FS and the MES location a typical MES location of 40 N, 14 E has been chosen. The MSS system is designed to provide service for elevation angles > 20 degree. So at any given time instant it is assumed that out of the visible satellites only the one with minimum elevation angle > 20 degree is providing service to the MES.

The analytical process consists of determining the satellite with which the MES is operating. Then, determining the elevation angle from the FS location to that particular satellite at that time instant. Then determining the off axis gain of FS antenna from Sub-annex 2 and the instantaneous slant range loss and hence compute the (C/I) at the input to the satellite receiver.

A protection criteria of a (C/I) of 17.0 dB has been used to determine whether the interference is excessive or not.

4. RESULTS

The results are given in Sub-annex 3. As can be seen the interference into a given MES uplink carrier exceeds the 17 dB criteria for 33 % of the day.

The following points are important for the conclusion and should be kept in mind :

* the analysis has considered interference from only one FS transmitter.

* no azimuthal pointing difference has been assumed for the FS antenna and the ICO satellite direction. Only one FS trend line corresponding to the azimuth of the Sub-annex 3 would actually result in these interference levels - all other azimuthal directions should afford further discrimination - and, as a matter of fact, the MES will communicate alternatively with a satellite in different orbital planes, leading to some azimuthal discrimination during part of the time.

* the FS tactical systems operating in Germany have a tuning range of 400 MHz. The possibility of excess interference into the MSS will occur only if the system in this worst case interference scenario is tuned in frequencies overlapping with the 1610-1626.5 MHz band.

* great part of the C/I values below 17 dB lie between 14 and 17dB. Therefore great part of the interference situations will have relatively small excess interference (< 3 dB).

5. CONCLUSION

In this case study the percentage of time when a given hand-held MES suffers excess interference was calculated as being 33 %. It was noticed that great part of the C/I values which are below the protection criteria of 17 dB lie between 14 and 17 dB. If the protection criteria is appropriately chosen within this range, then the percentage time for excess interference could be minimised. The probability of the azimuthal direction of the FS antenna pointing being the same as the azimuth angle to the ICO satellite coupled with the probability of the particular German FS system in consideration being tuned within 1610-1626.5 MHz reduces further the percentage of time when the MES will be interfered by the FS system.

ANNEX 1 OF ANNEX 2

1. ICO satellite characteristics :

Orbit Height (H) : 10355 km

Orbit Inclination (I) : 47.5 degrees

Number of satellites per plane : 5

Number of planes: 2

Earth Parameters:

Earth Radius (R) = 6378 km

$\mu := 5.164 \cdot 10^{12}$

The Orbit Period T of the ICO satellite can be calculated from:

$$T := 2 \cdot \pi \cdot \sqrt{\frac{(R + H)^3}{\mu}}$$

T = 6 hours

Right ascension longitude = 0 degrees

Satellite antenna gain differential = 2 dB

2. Hand-held MES characteristics

EIRP = 1 dBW

Bandwidth (BWw) = 20 kHz

C/I required = 17 dB

ANNEX 2 OF ANNEX 2

The following German FS system parameters were considered in this case study:

FS system location : 54 N, 14 E

Maximum Gain = 22 dB

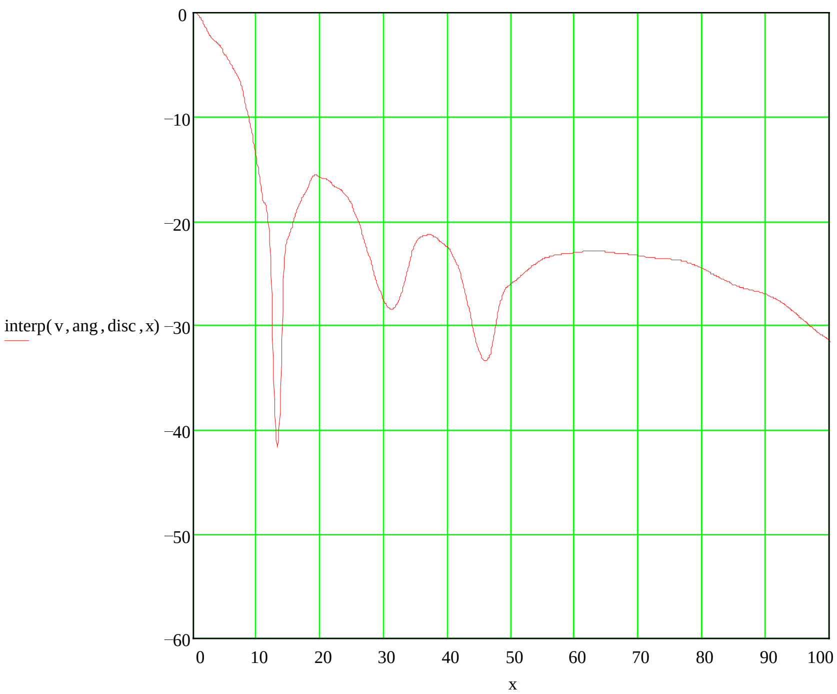
Power = 1.25 W = 1 dBW

BW = 600 kHz

Goff-axis = Maximum Gain + Antenna discrimination

The antenna discrimination can be obtained from figure 1

discrimination (dB)



off-axis angle (degrees)

Figure 1 : FS antenna sidelobe patterr

ANNEX 3 OF ANNEX 2

1. FS SYSTEM ELEVATION ANGLE

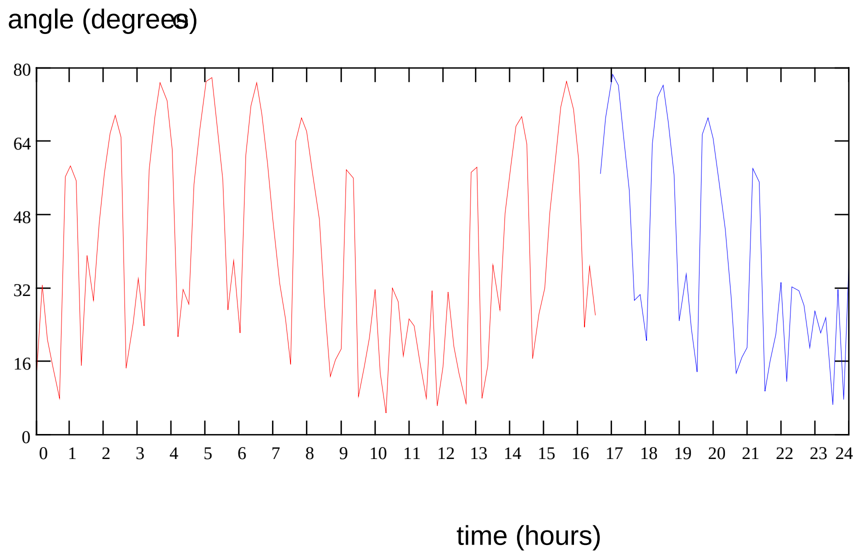


Figure 2 : Elevation angle from FS towards the ICO satellite

2. C/I CALCULATION

The Free Space Loss for a distance, d, can be calculated from:

$$FSL(d) := 32.4 + 20\cdot\log(d) + 20\cdot\log(1618)$$

The FS EIRP density can be calculated from:

Psd = Power/BW

Eirpsd = Psd + Gain off-axis

The slant range can be calculated as :

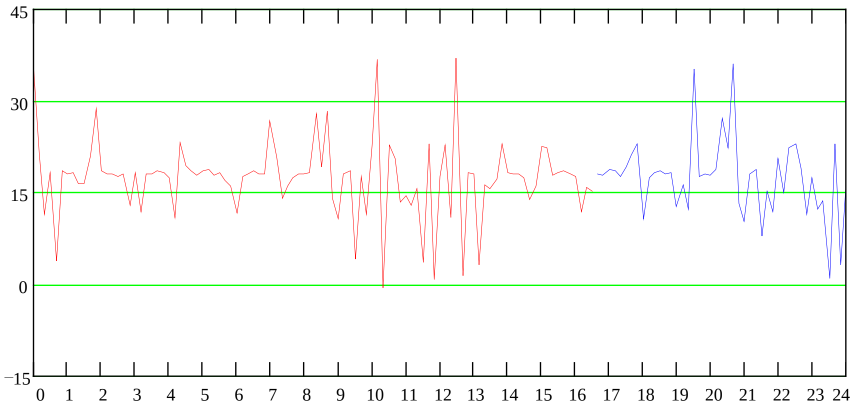
$$S_m := \left[(R+H)\cdot\frac{\sin\left[-\operatorname{asin}\left[\frac{R}{(R+H)}\cdot\sin\left(\frac{\pi}{2}+\Theta_m\cdot\frac{\pi}{180}\right)\right]+\frac{\pi}{2}-\Theta_m\cdot\frac{\pi}{180}\right]}{\sin\left(\frac{\pi}{2}+\Theta_m\cdot\frac{\pi}{180}\right)}\right]$$

The C/I values can be calculated from the following expression:

CI = (MESeirp - FSL (S)) - (Eirpsdfs + 10*log(BWw)) + FSL (s) + Sat gain diff

Figure 2 shows the C/I ratio as a function of time during a period of 24 hours.

C/I (dB)

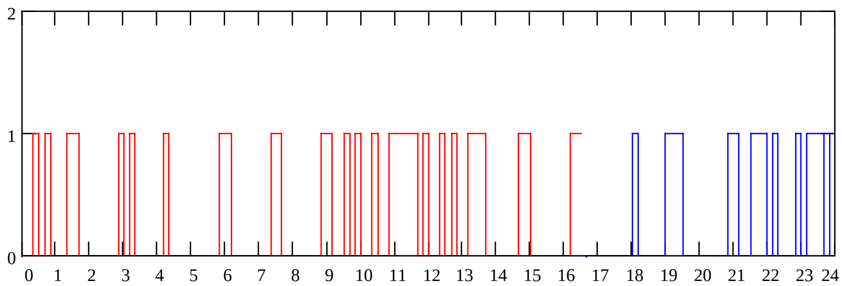


time (hours)

Figure 2 : Instantaneous C/I for interference from FS into ICO system

The following graph shows the periods of time when C/I < 17 dB:

C/I<17 = 1, C/I>17 = 0



time (hours)

Figure 3 : Time periods when C/I < 17

From figure 3 we can conclude that the interference into a given MES uplink carrier exceeds the 17dB total interference allowance for 33% of the time. It is important to observe in figure 2 that great part of the C/I values which are below 17dB lie between 14 and 17 dB. Thus , if the protection criteria is appropriately chosen in this range than the percentage time for excess interference could be minimized.

ANNEX 3

INTERFERENCE TO GEO/MSS SYSTEMS FROM GERMAN FS SYSTEMS

(REVISION 1)

1. SYSTEM PARAMETERS

Four extreme geographical locations were chosen withinGermany as being FS locations in this case study. The selected coordinates were

Latitude	Longitude
$\gamma_e := \begin{bmatrix} 54 \\ 52 \\ 47 \\ 52 \end{bmatrix}$	$\phi_e := \begin{bmatrix} 14 \\ 7 \\ 10 \\ 15 \end{bmatrix}$

Convention :

North & East = positive
South & West = negative

The following GEO/MSS satellite locations, which are planned to be used by Inmarsat and are visible to Germany, were considered:

$$\phi_s := \begin{bmatrix} -55 \\ -15.5 \\ 20 \\ 64 \end{bmatrix}$$

The MES location has been chosen considering that the worst case would be a spot covering both the FS and MES location. The coordinate of the chosen location is:

$$\phi_h := 14$$

$$\gamma_h := 40$$

The differential longitude angle can be calculated by:

$$m := 0, 1 .. 3$$
$$n := 0, 1 .. 3$$

$$\Delta\phi_{m,n} := \left|\phi_{s_n} - \phi_{e_m}\right| \quad \text{degrees}$$

The Great Circle Angle (from the sub-satellite point to earth station) can be obtained from the following expression:

$$\beta_{m,n} := \operatorname{acos}\left(\cos\left(\Delta\phi_{m,n}\cdot\frac{\pi}{180}\right)\cdot\cos\left(\gamma_{e_m}\cdot\frac{\pi}{180}\right)\right) \quad \text{rad}$$

The Path Elevation Angle can be calculated from

$$\Theta_{m,n} := \operatorname{atan}\left(\frac{\cos(\beta_{m,n}) - 0.15127}{\sqrt{1 - \cos(\beta_{m,n})^2}}\right) \quad \text{rad}$$

2. C/I CALCULATION

The Free Space Loss for a distance, d, can be calculated from:

$$FSL(d) := 32.4 + 20\cdot\log(d) + 20\cdot\log(1618)$$

The slant range can be calculated from :

$$R := 6378 \quad \text{km}$$
$$H := 35786 \quad \text{km}$$

$$sr_{m,n} := \sqrt{R^2 + (R+H)^2 - 2\cdot R\cdot(R+H)\cdot\cos(\beta_{m,n})}$$

The FS eirp density can be calculated by :

$$E_{m,n} := \left(1 - 10\cdot\log\left(600\cdot 10^3\right)\right) + \operatorname{interp}\left(v, ang, disc, \Theta_{m,n}\cdot\frac{180}{\pi}\right) + 22$$

The C/I values can be calculated from the following expression:

CI = (MESeirp - FSL (SR))-(Eirpsdfs + 10*log(BWw)) + FSL (sr) + gain diff

$$CI_{m,n} := 1 - FSL(SR_n) - \left(E_{m,n} + 10\cdot\log\left(20\cdot 10^3\right)\right) + FSL(sr_{m,n}) + 2$$

The resulting C/I values in dB for each satellite in relation to all four FS locations are :

For GEO at 55 W ($CI_{m,0}$)	For GEO at 15.5 W ($CI_{m,1}$)	For GEO at 20 E ($CI_{m,2}$)	For GEO at 64 E ($CI_{m,3}$)
-3	10	20	34
2	17	22	10
2	23	16	24
-3	11	23	21

3. CONCLUSION

From the C/I results in this case study we can conclude that the GEO satellite located at 55 W will not be able to operate some of the spot beams which covers Germany FS stations considering a C/I criteria of 17 dB. Other spots from the satellite located at the 55 W location will have the benefit of additional satellite antenna discrimination. For the other GEO satellites, located closer to Germany and therefore with higher elevation angles from Germany to the satellites, it is less likely that interference will occur.

All these results were obtained considering no azimuthal pointing difference for the FS antenı pointing and the GEO satellite direction from the FS (all other azimuthal directions should afford further discrimination). The probability of this situation to occur coupled with the probability of the FS system to be operated at frequencies which overlap with the MES frequency will reduce considerably the possibility of excess interference.

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ANNEX 4

COMPATIBILITY BETWEEN MSS DOWNLINK AND THE FS IN GERMANY IN THE BAND 1613.8 - 1626.5 MHz

1. INTRODUCTION

As a result of WARC-92, the 1613.8 - 1626.5 MHz band has become available for the MSS downlink on a secondary status. In Germany, this band allocated to FS (RR 730), will be used by tactical radio relay procedures laid down in RES 46 of WARC-92 (RR 731 F) until 1996. The German radio relay system is used as an example to illustrate interference from downlink MSS.

Section 2 of this document describes protection criteria for the FS. Sections 3 and 4 present the results of interference analyses based on the published data for MSS systems.

2. PROTECTION CRITERIA FOR THE FS IN GERMANY

The German tactical radio relay systems are protected with power flux density (PFD) limits at the Earth's surface, given by RR 2557 (Art. 28).

Coordination is required when the PFD, produced by the MSS downlink, exceeds the following values:

- 154 dBW/m²/4 kHz for angles of arrival between 0 and 5 degrees above the horizontal plane;

- 154 + 0.5 (δ - 5) dBW/m²/4 kHz for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane;

- 144 dBW/m²/4 kHz for angles of arrival between 25 and 90 degrees above the horizontal plane.

3. INTERFERENCE ANALYSIS FOR HIBLEO (USA)

The satellite network HIBLEO was published by IFRB circulars 2012 of 04.02.92 (AR 11/A/794) and 2024 of 28.04.92 (AR 11/A/810). HIBLEO is the US generic name of all mobile satellite systems.

Technical assumptions used for downlink calculation:

Height of space station	1300 km
Power density	- 34 dBW/Hz
Satellite antenna gain	25 dB
Frequency band	1613.8 - 1626.5 MHz

EIRP/4 kHz = - 34 dBW/Hz + 36 dB + 25 dB = 27 dBW/4 kHz

PFD = EIRP/4 kHz - 10 log (4π d²) = - 106,3 dBW/m²/4kHz

This PFD value exceeds the PFD threshold values, up to angles of arrival above the horizontal plane (section 2), between 37 dB and 47 dB.

4. INTERFERENCE ANALYSIS FOR HIBLEO-2 (USA)

The satellite network HIBLEO-2 was published by RB circular 2081 of 15.06.93 (RES 46/C/40), which describes a system with characteristics similar to Iridium.

Technical assumptions used for downlink calculation:

Height of space station	780 km
Power density	- 40.6 dBW/Hz
Satellite antenna gain	24.3 dB
Frequency band	1616 - 1626.5 MHz

EIRP/4 kHz = -40.6 dBW/Hz + 36 dB + 24.3 dB = 19.7 dBW/4 kHz

PFD = EIRP/4 kHz - 10 log(4π d^2) = - 109.1 dBW/m^2/4 kHz

This PFD value exceeds the PFD threshold values, up to angles of arrival above the horizontal plane (section 2), between 34 dB and 44 dB.

5. CONCLUSION

For angles of arrival between 0° and 5°, the excess of interference is ranging from 44 dB to 47 dB. For angles of arrival between 25° and 90°, this excess of interference is still ranging from 34 dB to 37 dB.

As a matter of fact, the following considerations should also be taken into account :

- actual antenna discrimination are better than those used for deriving the maximum PFD limits;
- due to the rapid movement of LEO satellites, interferences would be short-time;
- due to the frequency agility of the tactical FS system, there will be, in case of interference, the possibility to switch to a different band immediately.