European Radiocommunications Committee (ERC)
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COMPATIBILITY STUDY BETWEEN MOBILE SATELLITE SERVICE IN THE 1610-1626.5 MHz BAND AND RADIO ASTRONOMY SERVICE IN THE 1610.6-1613.8 MHz BAND

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1. INTRODUCTION

WARC-92 (RR 731 E) 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 Radio Astronomy service and MSS.

The band 1610.6-1613.8 MHz is used by radio astronomers to observe the spectral line of the hydroxyl molecule near 1612 MHz, which is considered to be among the most important lines below 275 GHz. The radioastronomy service is protected by footnote 733E stating that "harmful interference shall not be caused to stations of the radioastronomy service using the band 1610.6-1613.8 MHz by stations of the radiodetermination service and mobile-satellite services (RR 2904 applies)". 15 stations of radioastronomy are likely to use this band in Europe and, consequently, require protection from MSS (see annex 1).

Characteristics for MSS are not fully determined for the moment. Both TDMA and CDMA access techniques and both GSO and non GSO satellites are considered in 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 Iridium project intends to use secondary status downlink allocation in the band 1616 MHz to 1626.5 MHz.

2. IN BAND INTERFERENCE FROM MES TO STATIONS OF RADIOASTRONOMY

see annex 2 for detailed explanations

<u>2.1. In-band interference (1610.6-1613.8 MHz) for one user considering different propagation models</u>

The aim of this section is to assess the required separation distances between a radio astronomy observatory and a Mobile Earth Station.

ITU-R Recommendation 769 gives the maximum level of interference at a radio astronomy observatory (-262 dBW/Hz in 20 kHz).

Separation distances are calculated assuming interference for 10% of the time. This percentage is stemming from UIT-R report 696 and is also recommended in the draft recommendation of Study Group 7 about "the protection of the Radio Astronomy service in the frequency bands shared with other services".

Unless specified, the MES antenna height has been assumed as 1.5 m and the radio observatory antenna height as 30 m.

An internationally agreed propagation model for interference prediction exists in ITU-R 452-5. This involves several propagation mechanisms. For a time percentage of 10% and distances greater than approximately 100 km, the tropospheric scatter mechanism is dominant. For shorter distances, diffraction dominates. It is therefore judged that these models should determine the required separation distances. However, as there are also other models in use, separation distances for two other models are included for comparison. It can be noted that required separation distances vary considerably, depending on the propagation model.

The following 4 propagation models are used (see annex 2, sections 1 and 2 for explanations) :

- spherical diffraction, using ITU-R Recommendation 526;

- extrapolation of Okumura’s model;

- EPM 73 model (EPM for Empirical Propagation Model);

- tropospheric scatter using ITU-R Recommendation 452-5, with 0° or 1° additional elevation angles. Calculations have also been computed assuming an antenna height of 15 m to simulate a MES on a ship.

Required separation distances are given in the following table for 5 representative MSS systems:

		GLOBALSTAR	**ODYSSEY**	**IRIDIUM**	**INMARSAT CDMA**	**INMARSAT TDMA**
Required path loss (dB)		**198.8**	**194.3**	**212.9**	**201.0**	**218.0**
Spherical diffraction		98 km	91 km	118 km	101 km	126 km
Extrapolation ofOkumura's model		226 km	187 km	413 km	247 km	513 km
EPM 73		169 km	130 km	379 km	191 km	509 km
Tropospheric scatter 1.5 m antenna height	0°	196 km	160 km	328 km	215 km	380 km
	1°	119 km	90 km	232 km	135 km	280 km
Tropospheric scatter 15 m antenna height	0°	203 km	165 km	335 km	222 km	388 km
	1°	124 km	95 km	239 km	140 km	287 km

It should be noted that the higher required path loss for TDMA systems is balanced by a lower probability of finding a MES transmitting in the RAS receiving bandwidth. Moreover, footnote 731E states that a MES should produce an EIRP lower than -15 dB(W/4kHz) in part of the band used by systems operating in accordance with the provisions of RR 732 and -3 dB(W/4kHz) in any other part of the band.

2.2. In-band interference for a density of users

In this section, a density of 0.004 users per square miles (0.001545 users per square kilometre) during peak loading hours is taken into account, based on commercial market surveys. This figure is obviously not valid for a MES on a ship and, consequently, this case has not been computed.

ITU-R Rep 1126 describes the way to calculate separation distances between the radio astronomy observatory and the mobile services : the interfering signal received at a Radio astronomy observatory is assumed to be the sum of the contributions of users located in concentric rings 10 km large around the observatory. Given the distances considered, only tropospheric scatter model is used.

In order to calculate final separation distances for interference for approximately 10% of the time, path losses for the first three rings are calculated assuming interference 10% of the time and for 50% for the other rings.

For CDMA systems, calculations are made on 50 rings (500 km more than the required separation distance).

For TDMA systems, calculations are stopped when the maximum number of users for one channel and one spot beam is reached (8 users for the INMARSAT system, 4 users for the IRIDIUM system), without exceeding 50 rings.

See annex 2 section 3 for detailed explanations.

Required separation distances for a land MES (antenna height 1.5 m) are given in the following tables:

	GLOBALSTAR	**ODYSSEY**	**IRIDIUM**	**INMARSAT CDMA**	**INMARSAT TDMA**
0° elevation angle	266 km	285 km	257 km	279 km	279 km
1° elevation angle	158 km	176 km	150 km	171 km	171 km

Using a density of users and taking the probability of interference in the radio astronomy band into account leads to more homogenous required separation distances between TDMA and CDMA systems.

However, calculated values are in some cases (e.g. TDMA systems) lower than when considering a single user. The reason is that in the above calculations, users are assumed to be uniformely distributed. This means for instance that the average number of users in the first ring is very much less than one. Calculations carried out with a single user assume that there is one user at the edge of the coordination area, regardless of the probability of such an event.

However, the assumption of an uniform distribution of users is not sufficiently reliable and, consequently, the provisional separation distance should be based on the methodology (single user or density of users) which gives the greatest separation distance.

3. MAXIMUM REQUIRED OUT-OF-BAND EMISSION IN ORDER TO AVOID INTERFERENCE FROM A MOBILE 1 KM AWAY FROM A RADIO ASTRONOMY OBSERVATORY.

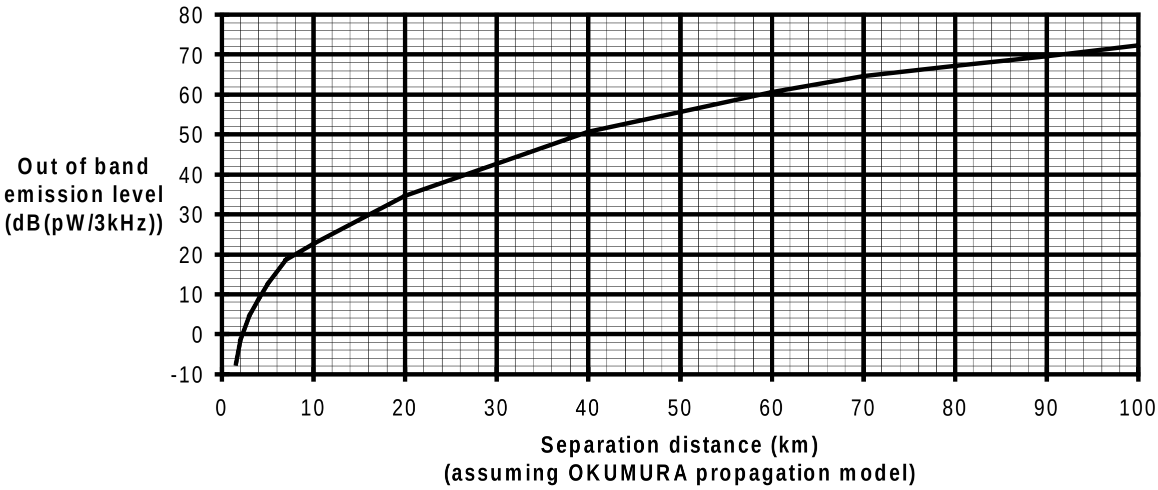
In this section, a mobile terminal channel is assumed to operate next to a radio astronomy observation (1610.6 - 1613.8 MHz). The aim of the following calculations is to evaluate the maximum out-of-band emissions from the operating MES to prevent interferences to the radio astronomy service.

For this calculation, the MES is assumed to be not closer than 1 km from the radio astronomy observatory (this assumption is based on the size of a radio astronomy site).

Using a free space propagation model, the maximum acceptable out-of-band emissions from the MES in any radioastronomy channel is then -129 dB(W/4kHz)

i.e. -10 dB(pW/3kHz).

If out-of-band emissions in the band 1610.6-1613.8 MHz are higher than this value, the MES should not emit in a given area around the radio astronomy observatory. For the out-of-band level to be low enough, the required separation distance can be computed using the Okumura-Hata propagation model valid for a distance smaller than 100 km. The relation between out-of-band level and the separation distance is given in the figure below.



4. INTERFERENCE FROM DOWNLINK MSS

The only calculation which can be made is to give the maximum EIRP of the satellite in the 1610.6 - 1613.8 MHz band in order to protect the radio astronomy service. Calculations have been made just for the Iridium system, which would normally transmit in the band above 1616 MHz.

The maximum interfering signal coming from the MSS downlink must not exceed -262 dB(W/Hz) at the receiver of the radioastronomy observatory. Using a free space propagation model and a 0 dBi radio astronomy sidelobe antenna gain, this figure leads to a maximum average EIRP (in the adjacent radio astronomy 1610.6 - 1613.8 MHz band) of - 71.6 dB(W/4kHz) (IRIDIUM satellite height is 780 km). It is recognised that Iridium satellites could be seen in the main lobe of radio astronomy antenna for a very short time. This may be tolerated by the radio astronomy community.

When considering all 4 time slots used, IRIDIUM average EIRP is 21.5 dBW/40kHz. The above figure leads to a maximum EIRP at the satellite antenna (in the adjacent radio astronomy 1610.6 - 1613.8 MHz band) of -83 dBc.

5. OPERATIONAL SHARING TECHNIQUES

If coordination is to work, the mobile user must have some means of determining when a coordination zone has been entered, and some means of reducing the power flux density received at the radioastronomy observatory below the threshold for harmful interference. Two possible solutions have been discussed, although neither system has yet been demonstrated in practice.

In the first solution the mobile user carries position-determining equipment (e.g. GPS receiver) together with a regularly updated list of positions of those radio astronomy sites currently observing in the 1612 MHz band, and their required coordination zones. Emissions in the band 1610.6 - 1613.8 MHz are then inhibited whenever the mobile enters a coordination zone in accordance with section 2. A similar solution is not to allocate a channel in the radio astronomy band or in adjacent bands when the MES is in a spot beam which overlapps with the coordination area. Attention should be given to the accuracy of position-determining equipment (if worse than few kilometers).

In the second solution, the radio astronomy observatory has an omni-directional beacon transmitter. The beacon is activated only when radio astronomical measurements are being made, and the power level of the beacon is related to the size of the coordination zone required. Transmission from the mobile is inhibited in the band 1610.6 - 1613.8 MHz whenever the mobile user detects the beacon.

Two types of beacon have to be examined :

- beacon in a nearby frequency band : in this case propagation losses are the same between the beacon and the MES receiver as between the MES transmitter and the radio astronomy observatory. But this solution requires a receiver and a transmitter in a nearby frequency band in the MES terminal which is technically difficult.

- beacon operating in another frequency band than the MES : this case is technically easier but beacon path loss and MES path loss would be different. Therefore, assuming a propagation model for MES and a propagation model for the beacon, a coordination zone would have to be calculated in accordance with section 2.

Because of the disadvantages of the second solution discussed above, the first solution is considered to be more realistic at the moment.

6. CONCLUSION

A supplementary elevation angle of 1° above the horizon at radio astronomy observatories or at MES antennas is realistic in most cases (trees 10 m high located 500 m away from the MES or hills 180 m high located 10 km away from the radio astronomy site) for a MES on land. No supplementary elevation angle should be taken into account for MESs on ships.

For a MES on land, calculation should be made with a single user and a density of users, using tropospheric scatter 1°. Provisional separation distances should be based on the largest separation distance. For a MES on a ship, calculation should be only made assuming a single user and tropospheric scatter 0°.

The following separation distances are found :

	GLOBALSTAR	**ODYSSEY**	**IRIDIUM**	**INMARSAT CDMA**	**INMARSAT TDMA**
Land MES	158 km	176 km	232 km	171 km	280 km
MES on a ship	203 km	165 km	335 km	222 km	388 km

Then it can be seen that maximum required separation distances range from 176 km for a CDMA MES to 280 km for a TDMA MES when operating on land. For a MES on a ship, distances range from 222 km for a CDMA MES to 388 km for a TDMA MES. If coordination is to work, the MES should carry position-determining equipment and the list of positions of radio astronomy sites and separation distances should be regularly updated.

It should be noted that the propagation models used for the calculations do not take into account any terrain profile. Each radio astronomy site has its own terrain profile (forests etc.) which could be computed with an appropriate propagation model.

Moreover propagation measurements could be undertaken around each radio astronomy site to validate the order of magnitude of the required separation distances.

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ANNEX 1

Table 1. **European Radio Astronomy Sites operating in the bands 1610.6 - 1613.8 MHz and 1660.0 - 1670.0 MHz.**

Observatory	Location	Longitude (d m s)	Latitude (d m s)
Nancay	Nancay, France	02 12 00 E	47 23 00 N
Effelsberg	Effelsberg, Germany	06 53 00 E	50 31 32 N
Medicina	Bologna, Italy	11 38 43 E	44 31 14 N
Noto	Sicily, Italy	15 03 00 E	36 31 48 N
Dwingeloo	Netherlands	06 23 48 E	52 48 48 N
Westerbork	Netherlands	06 37 55 E	52 55 01 N
Madrid	Spain	04 12 00 E	40 16 12 N
Onsala	Sweden	11 55 39 E	57 23 47 N
Cambridge	England, U.K.	00 02 20 E	52 09 59 N
Darnhall	England, U.K.	02 32 03 W	53 09 22 N
Defford	England, U.K.	02 08 35 W	52 06 01 N
Jodrell Bank	England, U.K.	02 18 26 W	53 14 10 N
Knockin	England, U.K.	02 59 45 W	52 47 24 N
Pickmere	England, U.K.	02 26 38 W	53 17 18 N
Wardle	England, U.K.	02 35 46 W	53 06 45 N

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ANNEX 2

DETAILED CALCULATIONS

1. Assumptions :

Radioastronomy

Frequency band :	1610.6 - 1613.8 MHz
Antenna gain :	0 dBi
Maximum interfering signal :	-237 dB(W/m²/Hz) i.e. -262 dB(W/Hz)
Bandwidth :	20 kHz
Antenna height :	30 m

MES

Antenna height : 1.5 m (in the land)
15 m (on a boat)

For each system, path loss L is calculated considering the average EIRP from the MES :

$$L_{dB} = 262_{dBW/Hz} + \left[(EIRP_{dBW/4kHz} - 10 * \log(4000) \right]$$

	GLOBALSTAR	**ODYSSEY**	**IRIDIUM**	**INMARSAT CDMA**	**INMARSAT TDMA**
Technic of access	CDMA	CDMA	TDMA	CDMA	TDMA
Bandwidth BW (kHz)	1250	5300	40	980	20
Average EIRP (dBW/4kHz)	-27.1	-31.7	-13.0	-25.0	-8.0
Required path loss L (dB)	198.8	194.3	212.9	201.0	218.0

EIRP (dBW/4kHz) of TDMA systems is much more important than for CDMA systems, but bandwidths of emission are much lower (only 20 or 40 kHz regards to 1 to 1.5 MHz for CDMA systems).

Consequently, separation distances for TDMA systems are more important but the probability of a MES channel operating in the radio astronomy band is much lower than for CDMA systems.

2. Propagation models

5 different propagation models are computed. In order to be able to compare the results, separation distances are calculated assuming interferences during 10% of the time, which is considered as the most appropriate for Radio astronomy

- spherical diffraction (ITU-R Rec. 526) :
This model is used with k = 3, which corresponds to 10% of time of interference based on variation of k in Paris (k = 4/3 corresponds to 50% of time of interference).

- extrapolation of Okumura's model :
This extrapolation (given by the FCC) was carried out by simply plotting the linear part of the curve on semi-log graph paper and extending the straight line. This extrapolation is believed to be a conservative assumption (distance may be less important).
The model is used with the open area model (31 dB correction at 1600 MHz).
A corrective factor of 5.2 dB is added to the total attenuation to assess 10% of time of interference (Okumura's model gives the attenuation for 50% of the time). This correction factor is taken from ITU-R Rep 1007, considering Raleigh-distributed signal levels.

- EPM-73 model (EPM for Empirical Propagation Model) :
This simple empirical propagation model (IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-19, No 3 Aug 1977, pp 301-309) gives average propagation losses without knowing the relief.
As for Okumura's model, a corrective factor of 5.2 dB is added.

- tropospheric scatter (ITU-R Rec.452-5) :
This propagation model is of interest on long paths (typically longer than 100 km) and on supplementary horizon angles at the Radio astronomy observatory antenna.
Calculations are computed assuming 10% of time of interference.
Supplementary angles of 0° and 1° above the horizon are considered in the calculations. For example, a supplementary angle of 1° above the horizon is obtained with trees 10 m high located 500 m away from a MES or with hills 180 m high located about 10 km away from the radio astronomy site.
Calculations are computed assuming 1.5 m MES antenna height for hand portable or car mounted and with 15 m antenna height for MES on a boat.

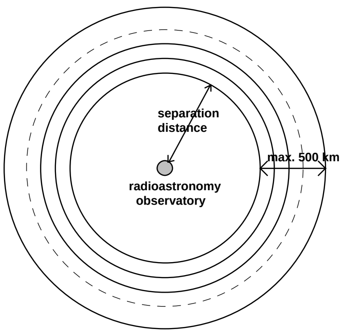
3. Coordination distance considering a density of 0.004 active users per square miles (peak loading hours in USA) using tropospheric scatter (ITU-R Rec.452-5)

Separation distances are calculated, using ITU-R Recommendation 452-5 propagation model (tropospheric scatter), with supplementary angles of 0° and 1° above the horizon.

The density of users is integrated in the calculation of the total interfering signal by summing (in power) the total power coming from concentric rings 10 km large around the radioastronomy observatory.

50 rings are taken into account in the calculation (which means that the contribution of operating MES located 500 km from the first ring is added).

But for TDMA systems, considering that the number of users is limited on one operating channel (8 users for INMARSAT systems and 4 users for IRIDIUM system), the calculation is stopped when this figure is exceeded.



The required separation distance is calculated for 10% of the time of interference.

But the real percentage of time of interference can not be exactly known with this way of calculating the final separation distance : even if path losses between each ring and the radio astronomy observatory are calculated for 10% of time of interference, the final separation distance is then given for a much lower percentage of time of interference (between 0 and 10% : problem of the sum of probabilities).

A good compromise is to have 10% of time of interference for the 3 first rings and 50% for the other rings.

If P_t (dBW/4kHz) is the average power emitted by the MES, the power received at the radioastronomy observatory and coming from the ring number i, Pr_i (dBW/4kHz) is then :

$$Pr_i = P_t - L(d_i, p_i) + 10 * \log(N_i)$$

where . d : required separation distance (km)
. di : distance between the MES and the radio astronomy observatory : $d_i = d + 10(i-1)$
. pi : required percentage of time of interference (10% or 50%)
. $L(d_i,p_i)$: propagation attenuation between the ring i and the radioastronomy observatory during p_i% of the time of interference.
. Ni : number of users in the ring number i : $N_i = \pi * \left[d_{i+1}^{\;2} - d_i^{\;2} \right] * \frac{0.004}{1.609^2} * \frac{BW}{16500}$
. BW : MES bandwidth (kHz)

The total interfering power at the radio astronomy site is then (dBW/4kHz) :

$$\text{Pr} = 10 * \log(\sum_{i=1}^{N_r} 10^{\frac{\text{Pr}_i}{10}})$$

with Nr : number of rings used for the simulations (Nr = 50 for CDMA systems, Nr ≤ 50 for TDMA systems)

4. Protection distance necessary between a mobile and radioastronomy observatories for different frequency offset

ETS 300 254 gives the maximum unwanted emissions generated by an operating MES in the 1626.5 - 1645 MHz :

Offset from the edge of the band (kHz)	**Maximum EIRP (dBpW/3kHz)**
0	117
100	104
200	84
> 700	74

For these frequency offsets, required isolation is still high and derived separation distances are larger than 100 km. Therefore, protection distances are calculated using tropospheric scatter propagation model (ITU-R Rec. 452-5) with supplementary elevation angles of 0° and 1°.

Required separation distances are given in the following table :

Frequency offset from the edge of the band (kHz)		0	100	200	> 700
Maximum required path loss		224.2	211.2	191.2	181.2
MES in a land	0°	446 km	311 km	136 km	73 km
	1°	341 km	217 km	73 km	33 km
MES on a boat	0°	454 km	318 km	142 km	77 km
	1°	349 km	224 km	77 km	35 km

For the cases where the calculated separation distance is less than 100 km, diffraction may be the dominant propagation mechanism, and the distances greater.

Thus, required separation distances for unwanted emissions are very important and may be more stringent than separation distances calculated in section 3.1. (MES operating in the radio astronomy band).

But it must be noticed that values for unwanted emissions of ETS 300 254 have not been calculated in order to protect adjacent services.