ERC REPORT 28

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

COMPATIBILITY STUDY BETWEEN MSS IN THE 1610-1626.5 MHz BAND AND SWEDISH RADARS

Brussels, June 1994

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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 Swedish radars and MSS.

In Sweden, an Aeronautical Radio Navigation system is operating at the frequency 1614 MHz. The system consists of high power radar station. It should be noted that according to the RR731E, MSS shall not cause harmful interference to, or claim protection from, stations in the Aeronautical Radio Navigation Service.

Characteristics for MSS are not fully determined at the moment. Both TDMA and CDMA access techniques 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 SWEDISH RADARS

According to Swedish authorities, MES stations operating according to RR 731E outside the Swedish border, will not cause interference to the Aeronautical Radio Navigation (ARN) service. Interference from MES within the Swedish border shall be solved on a national basis.

3. INTERFERENCE FROM SWEDISH RADARS TO MSS SATELLITES

Calculations have shown that the radar stations will cause interference to the CDMA or TDMA MSS systems. In both cases, the maximum interference level is exceeded by approximately 50 dB. It is therefore necessary to know in detail how the different MSS systems can co-exist with intermittent interference. However, some calculations showed that :

- If a spot beam is covering Sweden, a worst case Bit Error Ratio of around 20% for TDMA systems and 1% for CDMA systems could occur on the uplink.

- If a spot beam is covering an area outside Sweden, an unacceptable BER could also occur unless sufficient satellite antenna discrimination is provided.

The MSS systems can not claim protection from the ARN system. Hence, it follows that mobile satellite systems have to be designed in such a way that they can co-exist with interference from ARN. The MSS operators have received detailed technical information about the ARN systems and further studies on this point should be undertaken by the MSS operators in cooperation with the Swedish Administration.

The calculations are attached in Annex 1.

4. INTERFERENCE FROM DOWNLINK MSS TO SWEDISH RADARS

According to Swedish authorities, MSS downlink transmissions are not expected to interfere with radars.

5. CONCLUSION

Interference from MES and MSS satellites to Swedish radars will be solved on a national basis. On the other hand, Swedish radars are likely to interfere with MSS satellites in the band occupied by the radars, even for beams outside Sweden.

ANNEX 1

INTERFERENCE FROM SWEDISH RADARS TO MSS SATELLITES

1. INTRODUCTION

In Sweden, an Aeronautical Radio Navigation system is operating at the frequency 1614 MHz. The system consists of high power radar earth stations, that will be operating well beyond the year 2000. The aim with this annex is to identify the problem between MSS and ARN, since the solution to the problem is very dependent on the system concerned. It includes examples of both CDMA and TDMA systems.

2. TDMA

IRIDIUM is used as an example of a TDMA MSS system.

2.1 Interference criteria

The IRIDIUM system provides dynamic control of the transmitted power. The transmitters are operating only at the power levels necessary to satisfy the communication link bit error requirements. The maximum power that the subscriber terminal will be required to transmit is that needed to overcome the effect of vegetative shadowing. 6.3% noise is allocated for interference. A bandwidth of 40 kHz and a total system temperature for the satellite receiver of 500 K, give a maximum allowable interference level of -168 dBW. The calculations will not take into account noise contribution from other systems.

2.2 Calculation of the peak interference power

According to CCIR report 972, the peak interference power can be calculated as follows:

$$I = EIRP(ARN) + G_r - L_b - FDR + \eta_i - \eta_o \qquad (1)$$

Where:

G_r = satellite receiving antenna gain

L_b = free space loss

FDR = the frequency dependent rejection, which is a measure of the rejection produced by the receiver selectivity curve on an unwanted transmitter emission spectra;

η_i = average power of the interfering waveform at the receiver input - peak power of the interfering waveform at the receiver input;

η_o = average power of the receiver response waveform produced by the interferer - peak power of the receiver response waveform produced by the interferer.

$$\eta_i = 10\log(\tau \cdot PRF) \qquad (2)$$

$$\eta_o = 10\log(PRF/B_r) \qquad B_r\tau \leq 1,\ |\Delta f| \geq 0 \qquad (3)$$

$$\eta_o = 10\log(\tau \cdot PRF) \qquad B_r\tau > 1,\ |\Delta f| \leq B_r/2 \qquad (4)$$

In our case, this gives $\eta_i - \eta_o = 10\log(\tau B_r) = 10\log(0.6\mu s \cdot 40 kHz) = -16$ dB.

The FDR can be devided into two terms, the on-tune rejection (OTR) and the off-frequency rejection (OFR), the additional rejection which results from off-tuning interferer and receiver.

The value of FDR is taken from the measured power spectrum. The OTR is 20 dB and the OFR can be found in Table 6.1.

Δf (MHz)	1	2	5	10
OFR (dB)	3.5	11	17	22

Δf is the frequency separation from 1614 MHz.

Table 6.1. OFR

Note: Report 972 includes reference to CCIR report 654. According to that report, OTR should be calculated by $20\log(B_t/B_r)$ for radar pulses. However, in formula 1, this has been taken into account by the calculations of $\eta_i - \eta_o$. Consequently, in formula 1, OTR should be calculated by $10\log(B_t/B_r)$.

The EIRP of the radar at different elevation angles is given in Table 6.2.

Elevation	10°	11.9°	18.8°	21.4°	34.2°	70°	90°
EIRP (dBW)	57	57	57	54	45	35	27

Table 6.2. Radar EIRP

The probability that more than one pulse hits the receiver at the same time has not been included in the calculations. The satellite receiving antenna gain (G_r) depends on the elevation angle and can be found in the IRIDIUM system overview (see Table 6.3). This antenna gain is valid for beams directed at Sweden.

Elevation	10°	11.9°	18.8°	21.4°	34.2°
G_r (dBi)	22.3	22.0	19.8	17.5	12.8
L_b (dB)	163.8	163.3	161.5	160.9	158.4
G_r-L_b (dB)	-141.5	-141.3	-141.7	-143.4	-145.6

Table 6.3. IRIDIUM antenna data

For Δf = 0, the interference level (I) at different elevation angles, can be found in Table 6.4.

Elevation	10°	11.9°	18.8°	21.4°	34.2°
I (dBW)	-120.5	-120.3	-120.7	-125.4	-136.6
Margin (dB)	-47.5	-47.7	-47.3	-42.6	-31.4

Table 6.4 Margin

The antenna rotation rate is 36°/s, but for low elevation angles the radar will cause interference in all directions, since the backlobe will only give an attenuation of approximately 40 dB. It should be noted that this backlobe attenuation is only obtained for low elevation angles. For elevation angles approaching 90°, the margin in the main lobe will be higher, but the advantage of scanning is lost.

The margin can be improved by using frequencies separated from 1614 MHz and the interference may then be intermittent due to the scanning effect. The margin would also be improved for spot beams directed at areas outside Sweden, due to possible satellite antenna discrimination.

If the interference is acceptable or not, depends on how the system can co-exist with this kind of interference. Automatic repeat request is used to request retransmission of missing datapackets. If this will occur very often due to radar pulses, the traffic capacity could be reduced to an unacceptable level.

The calculations have only taken into account one radar station but there are approximately 30 radar stations in operation. Some of them have a lower EIRP than used in these calculations.

2.3 Assessment of BER

To assess the BER, we first have to see what the interfering pulses look like in the satellite receiver. A pulse is 0.6 µs wide. This pulse will be widened in the receiver filter to approximately 2/(40 kHz) = 50 µs. A pulse train of four pulses within 10 µs will thus be transformed into a single interfering pulse with a width of approximately 60 µs. The pulse trains are repeated every 2.5 ms.

2.3.1 Case 1 : the radar is causing interference in all directions

Two different cases can be distinguished. One case is when the margin is so low that the radar is causing interference in all directions. The binomial distribution can be used to assess the probability of one or more radars causing interference.

p = P[a radar is interfering] = 60/2500 = 0.024;
$q = 1-p = 0.976$;

Assuming that 20 radars are operating simultaneously

p_n = P[n radars interfering] = $p^n q^{(20-n)} 20!/(n!(20-n)!)$.

$p_0 = 0.615$; $p_1 = 0.303$; $p_2 = 0.071$.

The probability of interference is thus $1 - p_0 = 0.385$. A more detailed investigation is needed to assess the BER accurately. An estimated worst case value could be 0.385*0.5 = 0.19. This is assuming that the interfering signal is not causing blocking of the satellite receiver.

2.3.2 Case 2 : improvement of the margin, antenna discrimination

The second case occurs if the margin can be improved. For low elevation angles, the radar antenna discrimination would then be sufficient to keep the interfering signal below the threshold outside of a certain beamwidth. The antenna pattern for 25° elevation is used in the following calculations. This pattern is representative for elevation angles up to 25°. The discrimination for higher angles is gradually reduced up to 90° elevation where, of course, there is no discrimination. The improvement necessary to apply the calculations below can be derived by comparing with the results of section 2.2. It should be noted that no means to achieve this improvement have so far been identified, apart from using frequencies separated from 1614 MHz.

If the margin can be improved to -30 dB, the interference would be restricted to a 10° beamwidth. The binomial distribution is now used to calculate the probability of one or more radars being within interference range.

p = P[a radar within int. range] = 10/360 = 0.028;
$q = 1-p = 0.972$.

p_n = P[n radars within int. range] = $p^n q^{(20-n)} 20!/(n!(20-n)!)$.

$p_0 = 0.567$; $p_1 = 0.326$; $p_2 = 0.089$; $p_3 = 0.015$; $p_4 = 0.002$;
$p_{5+} = 0.001$.

Since a radar is interfering for 2.4% of the time it is within interference range, the total percentage of time that interference occurs is, assuming that interfering pulses from different radars do not overlap,

$T\% = \Sigma p_n * n * 2.4 = 1.4\%$.

Similarly to above, the worst case BER is estimated to 0.007.

Based on the calculations in section 2.2, it seems unlikely that the margin can be kept above -30 dB for IRIDIUM. However, for elevation angles around 25°, -40 dB seems to be a fairly realistic figure. The radar antenna discrimination would then keep the interfering signal below the threshold outside of a 120° beamwidth. Repeating the same calculations as above for this value gives T% = 16%, and a BER of 0.08.

3. CDMA

Globalstar and Odyssey have been chosen as two examples of CDMA systems.

3.1 Technical parameters for the MSS systems

The relevant parameters are given in Table 6.5.

	Globalstar	Odyssey
Inclination	52°	55°
Altitude	1407 km	10354 km
Baseband bitrate, R	4.8 kBPS	4.8 kBPS
Processing gain, G_p	24.2 dB	30.4 dB 2)
Minimum E_b/N_0	4.8 dB	4.5 dB
M_i 1)	4.4 dB	10.9 dB
Mobile EIRP	-2.2 dBW	-0.5 dBW
Allocated bandwidth per carrier BW_{RF}	1.25 MHz	5.3 MHz

1) M_i is the acceptable ratio between the interfering and the wanted signal.

$(N+I)/C = G_p - E_b/N_0 - L_{sys}$,

where
- L_{sys} is the system implementation losses in the receiver, a typical value is 3 dB,
- N includes noise and intra-system interference,
- I is the inter-system interference.

If 6.3 % of the interference allowance is allocated to inter-system interference, then

$M_i = I/C = (N+I)/C - 12$ dB

2) The processing gain can be estimated by the equation

$G_p = 10\log(BW_{RF}/R)$.

In the case of Odyssey, this would give G_p=30.4 dB. An FCC report gives the value 35.4 dB. In the report, it is also stated that a change of RF bandwidth is contemplated for Odyssey from 5.5 to 16.5 MHz. It seems likely that the processing gain 35.4 dB should be associated with this new bandwidth. For this reason, the value 30.4 dB is assumed for these calculations.

Table 6.5. Technical parameters for MSS systems

3.2 The peak interference power

The probability that more than one pulse hits the receiver is not included in the calculations.

The peak interference power is according to formula 1:

$I_{Globalstar} = 57+G_r-L_b-10\log(3.5M/1.25M)+10\log(0.6\mu\cdot 1.25M) = 51.3 \text{ dBW} + G_r - L_b$

$I_{Odyssey} = 57+G_r-L_b+10\log(\tau\cdot PRF)-10\log(\tau\cdot PRF) = 57 \text{ dBW} + G_r - L_b$

3.3 Interference levels

No information about the satellite antenna gain has been available, so in the calculations (G_r-L_b) has been assumed to be the same for the radar and the mobile. This gives the results in Table 6.6.

	C - I (dB)	Margin (dB)
Globalstar	-53.5	-49.1
Odyssey	-57.5	-46.6

Table 6.6. Margin for CDMA systems

Since the attenuation in the backlobe of the radar antenna is approximately 40 dB, the radar may cause interference in all directions. If we assume a shadow margin of approximately 10 dB, power control becomes crucial.

Whether sharing is possible is dependent on how the system concerned can co-exist with intermittent interference. To be able to draw any conclusion about that, it is necessary to know for example how many chips will be perturbed by the pulses and if that is acceptable, if the decoding will improve the BER to an acceptable level and if the false alarm rate caused by the radars is acceptable.

The calculations have taken into account only one radar station, but there are approximately 30 radar stations in operation. Some of them have a lower EIRP that used in these calculations.

3.4 Assessment of BER

Similar calculations to those in 2.3 can be made for CDMA systems. Only the example of Odyssey is treated here. With a receiving bandwidth of 5.3 MHz, the pulses are virtually unaffected. Thus,

$p = P[\text{a radar is interfering}] = 4*0.6\mu s/2.5ms = 0.00096,$
$q = 1 - p = 0.99904,$
$p_0 = 0.981.$

The probability of interference is, with twenty radars operating, $1 - p_0 = 0.019$, and the estimated worst case BER is 0.0095.

4. CONCLUSION

The radar system will exceed the maximum allowable interference level. Whether sharing is possible or not is dependent on how different systems can co-exist with intermittent interference and the limit for how much the satellite transponder can be degraded. This depends for example on the signalling, decoder and acceptable false alarm rate.