REPORT ITU-R M.2124*

Interference calculations to assess sharing between the mobile-satellite service and space research (passive) service in the band 1 668-1 668.4 MHz

(2007)

1 Introduction

Under WRC-07 Agenda item 1.7, Resolution 744 (WRC-03) requests studies into sharing between the mobile satellite service and space research (passive) service in the band 1 668-1 668.4 MHz. Two relevant space-VLBI (Very Long Baseline Interferometry) systems have been identified. The HALCA system began operation in 1997 and ceased operation in 2005. A proposed system, Radioastron, is planned for this band and characteristics have been made available.

The band 1 668-1 668.4 MHz is allocated for MSS (Earth-to-space) but is unlikely to be useable in the North America, where alternative fixed and mobile uses are planned. This and other restrictions which are likely in other parts of the world mean that this band is unlikely to be used by non-GSO MSS systems. Therefore this Report assesses the interference received by the HALCA and Radioastron systems from GSO MSS networks only.

2 Calculations of interference from MESs to space VLBI receivers

2.1 Characteristics of space VLBI satellites

The Radioastron satellite is planned to operate in an elliptical orbit, which is allowed to drift in inclination. There is also some variation in apogee and perigee height, however the representative values are: apogee height = 364 000 km, perigee height = 10 000 km, eccentricity = 0.9153, inclination 0 to 80°. The HALCA system operated in an elliptical orbit at a fixed inclination of 30°. Other key parameters are: height of apogee = 21 000 km, height of perigee = 560 km, eccentricity = 0.5956.

The HALCA receiver consisted of two channels of 16 MHz which could be tuned within the range 1 600-1 730 MHz. The receiver therefore had some ability to avoid frequencies where high interference could be anticipated. The Radioastron system on the other hand is planned to operate with a fixed receiver bandwidth.

A space VLBI satellite employs a large reflector antenna. The gain characteristics of such antennas are discussed in § 2.3.

2.2 Interference criterion

The threshold pfd levels for VLBI observations. These pfd levels are based on a criterion of interference equal to 1% of the receiver system noise.

Both the proposed Radioastron system and the HALCA system have receiver temperatures of about 70 K. In a bandwidth of 400 kHz, this equates to an interference threshold of –174 dBW.

* This Report should be brought to the attention of Radiocommunication Working Parties 7B and 7D.

Current technology for spaceborne receivers would allow a system noise temperature of about 30-40 K. Furthermore, it is also envisaged that in the future lower system noise temperatures may be achievable. By about 2010, values of about 20 K can be expected. In a bandwidth of 400 kHz, this equates to an interference threshold of –179.6 dBW. However, as can be seen from the results, the orbital characteristics of the satellite may have a more significant impact on the S-VLBI protection requirements.

Recommendation ITU-R RA.1513 recommends that interference from a network may cause a radio astronomy data loss of up to 2%. Therefore the criterion used is based on 1% of the receiver system noise ($I/N = -20$ dB) which may be exceeded by a single network for no more than 2% of the time. Recommendation ITU-R RA.1513 also recommends that data loss of up to 5% may be permitted from all networks and hence a second criterion is used based on 1% of the receiver system noise ($I/N = -20$ dB) which may be exceeded by all networks for no more than 5% of the time.

2.3 Characteristics of space radio telescope on-board antennas

The HALCA system used a large reflector antenna (8 m) and the Radioastron system also proposes to use a large reflector antenna (about 10 m diameter). The difference between the gain of the main antenna beam and far side- and back-lobes is about 40 dB and more for these antennas. But at the same time the D/λ value of these antennas is less than 100, taking into account the operating frequency range (1 668 MHz). Additionally, it should be noted that because of the design features of the Radioastron spaceborne antenna (deployable umbrella-type antenna) there is limited scope to significantly suppress the side- and back-lobes.

The angle between the direction to the observed space radio source and nadir (direction to the Earth centre) depends on the Sun position, the orbital location of the spacecraft and the direction to the earth control station (radio channel of delivering information). It can be assumed that this angle always exceeds 90°. Unfortunately, the antenna patterns of the HALCA and Radioastron satellites, that characterizes the sensitivity to the radiation from the far side- or back-lobes, was not measured. Moreover it should be mentioned that measurement of these levels is very difficult problem from the technical point of view, first of all because the level and arrangement of the antenna side- and back-lobes very largely depend on locations of other spacecraft components. It should also be noted that, due to distribution of interference sources and the satellite movement, the gain representative of the average gain in the direction of earth is required.

The subsections below provide two alternative approaches by which it is proposed that the appropriate value of the antenna gain be determined.

The Radioastron system will operate with both LHC and RHC polarization and hence no polarisation discrimination between the space-VLBI system and MSS systems can be assumed.

2.3.1 Approach 1 – Examination of ITU-R Recommendations

The field test measurements of the onboard Radioastron antenna were made for verification of the main beam and determination of the gain value and location of the first side-lobe of it. Therefore the real measured Radioastron antenna far side- and back-lobes gain are not currently available.

The existing Recommendation ITU-R SA.509-2, showing analytical expressions for antenna radiation patterns of receiving stations of the radioastronomy service cannot be applied for side- and back-lobe Radioastron spaceborne antenna gain because the D/λ value of this antenna is less than 100. Recommendation ITU-R RA.1631 may not be applicable for antennas with such a small value of D/λ.

The analysis of existing Recommendations (ITU-R S.465, ITU-R S.580, ITU-R S.731, ITU-R F.699, ITU-R F.1245, ITU-R S.1428, ITU-R S.672, ITU-R S.1528) and Appendixes 7 and 8 of the Radio Regulations (RR) with analytical expressions for antenna radiation patterns (with D/λ

value less than 100) of different radio services shows that the level of the antenna back- and side-lobes is between 0 dBi and −11.7 dBi.

At this time, Recommendations ITU-R S.672-4 and ITU-R S.1528 which describe the satellite antenna radiation pattern in the fixed satellite service (GSO and non-GSO systems) can be used for preliminary calculations to assess sharing between the MSS and the space research service (passive) in the band 1 668-1 668.4 MHz. Based on the analytical expressions shown in these Recommendations, the best case back-lobe gain (φ more than 90°) of the Radioastron spaceborne receive antenna toward the Earth will be no less than 0 dBi.

Recommendation ITU-R S.672-4 is intended as a design objective for the antennas of GSO FSS satellites. For angles in the range 90º-180º, the sidelobe level is given by:

L_B: $15 + L_N + 0.25\ G_m + 5 \log z$ dBi or 0 dBi whichever is higher.

Taking the example of the Radioastron antenna parameter values, L_N = –18 dB, G_m = 42 dBi and z = 1. This leads to a value of L_B = 7.5 dBi.

Recommendation ITU-R S.1528 is intended for non-GSO FSS systems below 30 GHz. It recommends that, where possible, a measured pattern be used and alternatively, that patterns given by one of a number of equations are used. Taking the equations given in *recommends* 1.1 as an example, the gain for angles in the range 90-180º is given by the same equation as for Recommendation ITU-R S.672:

L_B: $15 + L_N + 0.25\ G_m + 5 \log z$ dBi or 0 dBi whichever is higher.

For the Radioastron antenna parameter values, this naturally leads to the same value: 7.5 dBi.

However, neither of these recommendations are appropriate to the case in hand, for several reasons:

– Both recommendations apply to FSS satellites, where large unfurlable antennas of about 10 m diameter are unheard of.
– Recommendation ITU-R S.672 applies to GSO satellites and Recommendation ITU-R S.1528 applies to non-GSO satellites with multiple-beam antennas. Neither is appropriate for non-GSO systems with single beam antennas which would be appropriate in this case.
– Both recommendations are for peak envelope rather than average gain patterns.

Furthermore, for any directional antenna, the average gain of the side lobes must be less than 0 dBi and this is clearly not the case for an antenna for which the minimum gain value is 7.5 dBi. Hence the values given by these recommendations cannot be appropriate for this case.

While there are no ITU-R Recommendations explicitly related to the case in hand, one can identify other recommendations which point towards the possibility of much lower values. It is particularly relevant to examine recommendations which address the average antenna pattern.

For example:

– in Recommendation ITU-R S.1428, in the case of D/λ = 55, the average sidelobe gain value for angles in the range 80°-120° is –4 dBi and for angles in the range 120°-180° is −9 dBi.
– in Recommendation ITU-R RA.1631, the average antenna gain for angles in the range 80°-120° is –7 dBi and for angles in the range 120°-180° is −12 dBi.
– in Recommendation ITU-R F.1245, in the case of D/λ = 55, the sidelobe value beyond 48º is –11.7 dBi.

Hence examples of Recommendations aimed at average antenna gain values suggest a value in the range −4 to −11.7 dBi.

It should be taken into consideration that the Radioastron system suggests observations of space radio sources in wide ranges of angles relative at the Earth.

Based on the aggregate above-mentioned information it has been proposed to use the value −5 dBi for the average gain of the side- and back-lobes of the space-VLBI on-board antenna pattern in the sharing studies between MSS (E-s) and SRS (passive), in the absence of other information.

2.3.2 Approach 2 − Spherical integration

While it would be useful to have actual measured antenna patterns of the satellite antenna, it is also possible to take a more theoretical approach.

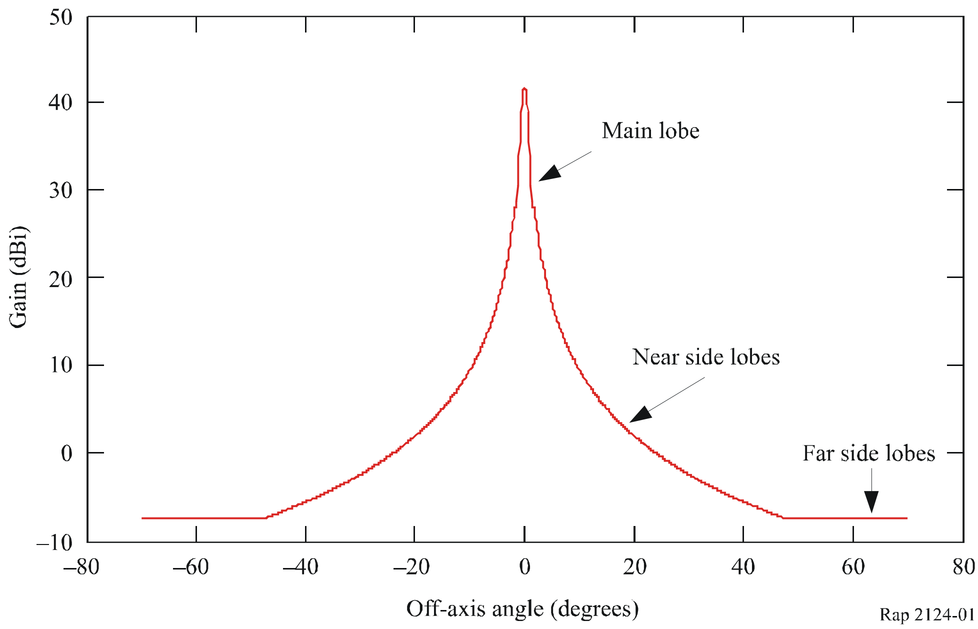
Taking the Radioastron system as an example, the antenna diameter is about 10 m. The peak antenna gain is 42 dBi and the antenna beamwidth is about 1.4°.

Reflector antenna gain patterns generally follow a common shape, illustrated in Fig. 1:

– the main lobe follows a parabolic equation;
– the near side lobes follow a constant −25 log θ pattern;
– the far side lobes are relatively constant.

FIGURE 1

Typical antenna pattern envelope



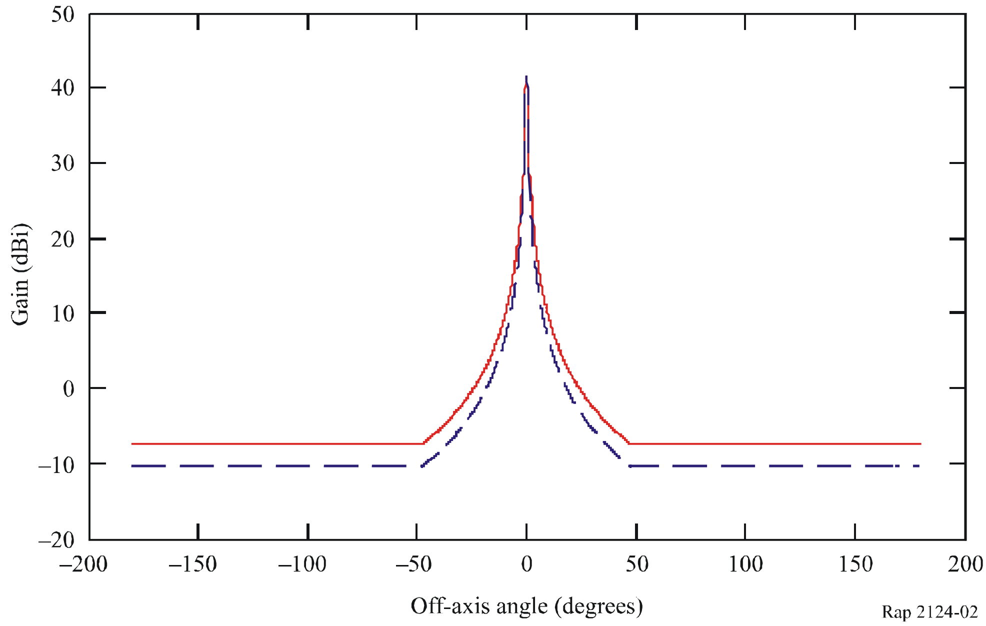
The curve in Fig. 1 is based on the equations given in Recommendation ITU-R F.699. Similar equations are used to represent reflector antennas in other recommendations for space and terrestrial applications.

For the studies in question, it is necessary to consider the interference received from a distribution of MESs. Hence it is appropriate to determine the average, rather than peak, gain in the direction of Earth. For any antenna, the average gain found by integrating throughout the sphere is 0 dBi. (If fact it is the directivity rather than the gain, but in practice the two values are very close). Hence, the desired antenna pattern, representative of the average side lobe level, should integrate to 0 dBi.

An integration of the pattern in Fig. 1 has been carried out and this has been found to result in the value 1.3 dB. The level of the near side lobe and far side lobe curve may therefore be lowered until the integral is equal to 0 dBi. By an iterative process, it was found that curves should be lowered by 3 dB to lead to an integral result of 0 dBi. The resulting pattern is shown in the dotted line in Fig. 2.

FIGURE 2

Typical and adjusted antenna patterns



The horizontal part of the curve, representative of the average far side lobe level is −10.5 dBi. Based on this approach it has been proposed to use the value −10 dBi for the average gain of the side- and back-lobes of the space-VLBI on-board antenna pattern in the sharing studies between MSS (E-s) and SRS (passive), in the absence of other information.

2.3.3 Conclusions regarding the satellite antenna

Actual measured antenna patterns for space-VLBI satellites would be required to accurately assess the average side lobes of the space-VLBI antenna. Until such patterns are available, it is necessary to assume a range of possible values. Based on the above analysis, values of −5 dBi and −10 dBi are considered.

2.4 Interference simulations

Computer simulations have been performed to model the interference received by a space-VLBI satellite receiver from an MSS network. Four representative MES types have been considered (Table 1). The Type A and Type B MESs are portable terminals, using directional antennas. The Type C and Type D MESs are hand-held terminals, using an omnidirectional antenna. The MES transmitter parameters are shown below. For MES Types A and B the MES antenna patterns are based on those given in Recommendation ITU-R M.1091 and shown in Fig. 3.

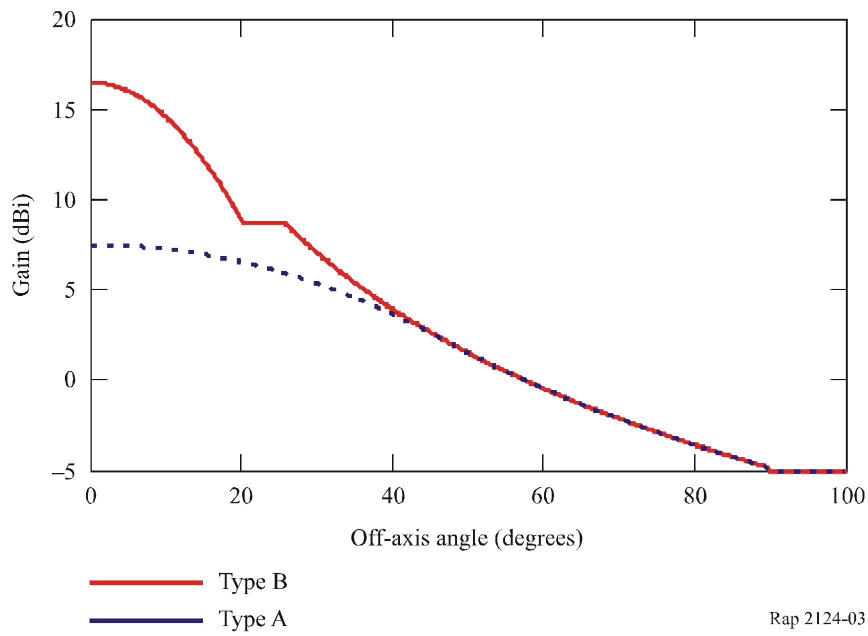
TABLE 1

Mobile earth station parameters

	Type A	Type B	Type C	Type D
Peak antenna gain (dBi)	7.5	16.5	0	3
Polarization	Circular	Circular	Circular	Circular
e.i.r.p. (dBW)	9	21	3.5	5
Channel bandwidth (kHz)	100	200	31.25	31.25
Maximum e.i.r.p. spectral density (dBW/4 kHz)	–4.0	5.0	–5.4	–3.9
Power spectral density delivered to the antenna (dBW/4 kHz)	–11.5	–11.5	–5.4	–6.9
Total power delivered to the antenna (dBW)	1.5	4.5	3.5	2

FIGURE 3

MES antenna patterns



It is necessary to model a distribution of MESs. Using the Inmarsat-4 characteristics, the satellite provides coverage to almost the entire visible earth surface with 228 spot beams. Frequencies are re-used on a 7-cell repeat basis, meaning each frequency may theoretically be used up to 32 times. It should be noted that, in practice, frequencies are not re-used to this extent due to the uneven geographical distribution of traffic. However, for the purpose of this analysis, the more conservative assumption has been retained. A fully loaded MSS satellite has been assumed (i.e. each cell is fully loaded with traffic).

For the purpose of simulation the following assumptions have been made:

– *The variant 1*: the Type A MES only will operate in the frequency band 1 668-1 668.4 MHz. Hence there are 128 Type A MESs.

– *The variant 2*: Half of the bandwidth is dedicated to the Type A MES and the other half is dedicated to the Type B MES. Hence, within the 400 kHz bandwidth, there are 64 Type A MESs and 32 Type B MESs.

– *The variant 3*: the Type B MES only will operate in the frequency band 1 668-1 668.4 MHz. Hence there are 64 Type B MESs.

– *The variant 4*: hand-held terminals (Type C or Type D MES) only will operate in the frequency band 1 668-1 668.4 MHz. With a maximum of twelve channels within the 400 kHz bandwidth. For the type C terminals, there are assumed to be 384 hand-held terminals, based on the maximum re-use factor of 32. For the type D terminals, there are assumed to be 240 hand-held terminals, based on the maximum re-use factor of 20. These different assumptions reflect the fact that the system in which the Type D terminals operate has a maximum re-use factor of 20.

These variants assumed that the MSS system operates at 100% of its capacity for 100% time, which is an extremely conservative assumption. In practice, the theoretical maximum frequency re-use is not obtained due the variations in the geographical distribution of traffic. Secondly, it is unrealistic to assume that all operating terminals transmit simultaneously due to the temporal distribution of traffic (e.g. relatively little use at night). Thirdly, all MESs are assumed to transmit at maximum power, whereas power control is usually used to reduce MES e.i.r.p. where possible. Under normal operation, a terminal would operate at power or e.i.r.p. levels close to the minimum values and would increase power only to compensate for any shadowing or fading that might occur during transmission. Thus effectively only a small percentage of the total MESs would operate at maximum power or e.i.r.p. at any given time. For example the nominal operational e.i.r.p. for Type (D) terminal is –1.4 dBW compared to a maximum e.i.r.p. of 5 dBW.

Therefore additional simulations were carried out to model 50% of theoretical capacity for terminal Types A to C, and 40% for terminal Type D. The lower figure for the Type D terminals is based on an assumption of 40% for the voice activity factor for the MSS system in which the Type D terminal operates. These simulations were termed as variant 1a, variant 2a, variant 3a and variant 4a.

Figures 4 and 5 show the geographic distribution of the MESs used in the computer simulation. Figure 4 shows the MES locations for scenario 1 for which a single MSS network is assumed. In this scenario, the interference exceeded for 2% of the time is determined and compared to the criterion applicable to a single network. For scenario 2, simulations are also run with three geostationary MSS satellites to enable the aggregate interference to be compared to the interference criterion of −174 dBW which may be exceeded by up to 5% time. The three satellites are spaced by 120º from one another. In the areas where the beams overlap, MESs have been removed to meet the requirement for adequate spacing between co-frequency beams. In total, there are 84 MES locations and several MESs are assumed to operate at each location. Figure 5 shows the locations.

In the simulations, average antenna gain values of −5 and −10 dBi towards Earth, G_s, have been assumed. It was also assumed that the S-VLBI satellites operate continuously over the entire orbit, including while close to perigee.

FIGURE 4

MES locations − Scenario 1

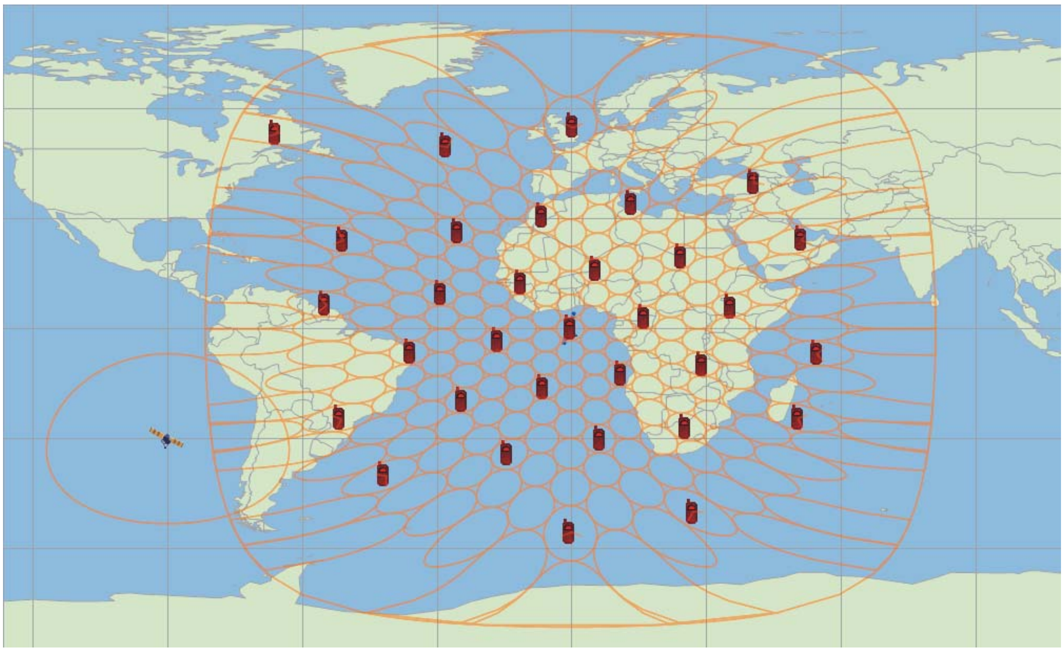


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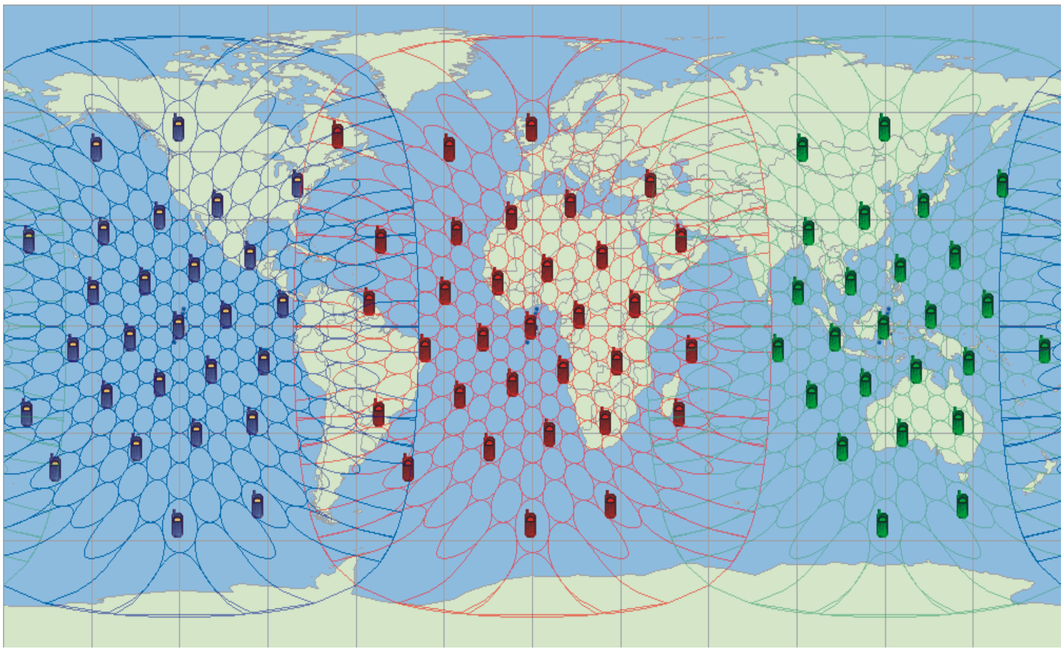
FIGURE 5

MES locations − Scenario 2



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3 Results

For each simulation, the cumulative distribution of interference was determined and the level of interference exceeded for either 2% or 5% time as appropriate was determined.

3.1 Results for the Radioastron system

For the Radioastron system, the inclination angle may drift between about 0° and 80° and hence example inclination angles of 0°, 30°, 40° and 80° have been considered. There is also some variation in the values of apogee and perigee height, although for the simulations a single representative set of values has been used: apogee height = 364 000 km, perigee height = 10 000 km, eccentricity = 0.9153. There is some sensitivity in the results to argument of perigee (ω) which is also subject to drift within the Radioastron orbit. Hence two values were considered: ω = 0° and ω = 90° and an average of the two resulting values is given below. The total simulated time interval was 284 days and the time step of simulation was 10 min. The results for the Radioastron system are shown in Tables 2 to 5.

TABLE 2

Orbital parameters and results for Radioastron (Scenario 1, MES variants 1, 2, 3 and 4)

MES variant	*i* (degrees)	*I* >2% time (dBW)	
		G_s = −5 dBi	G_s = −10 dBi
1	80	–176.4	–181.4
1	40	–174.1	–179.1
1	30	**–173.5**	–178.5
1	0	**–172.6**	–177.6
2	80	–176.2	–181.2
2	40	**–173.6**	–178.6
2	30	**–172.6**	–177.6
2	0	**–169.8**	–174.8
3	80	–175.3	–180.3
3	40	**–173.0**	–178.0
3	30	**–171.7**	–176.7
3	0	**–168.2**	**–173.2**
4 (Type C)/4 (Type D)	80	**–168.4/–168.6**	**–173.4/–173.6**
4 (Type C)/4 (Type D)	40	**–168.6/–169**	**–173.6/–174**
4 (Type C)/4 (Type D)	30	**–168.5/–168.9**	**–173.5/–173.9**
4 (Type C)/4 (Type D)	0	**–168.5/–168.8**	**–173.5/–173.8**

TABLE 3

Orbital parameters and results for Radioastron (Scenario 1, MES variants 1a, 2a, 3a and 4a)

MES variant	*i* (degrees)	*I* >2% time (dBW)	
		G_s = –5 dBi	G_s = −10 dBi
1a	80	–179.4	–184.4
1a	40	–177.1	–182.1
1a	30	–176.5	–181.5
1a	0	–175.6	–180.6
2a	80	–179.2	–184.2
2a	40	–176.6	–181.6
2a	30	–175.6	–180.6
2a	0	**–172.8**	–177.8
3a	80	–178.3	–183.3
3a	40	–176.0	–181.0
3a	30	–174.7	–179.7
3a	0	**–171.2**	–176.2
4a (Type C)/4a (Type D)	80	**–171.4/–172.4**	–176.4/–177.4
4a (Type C)/4a (Type D)	40	**–171.6/–172.8**	–176.6/–177.8
4a (Type C)/4a (Type D)	30	**–171.5/–172.7**	–176.5/–177.7
4a (Type C)/4a (Type D)	0	**–171.5/–172.5**	–176.5/–177.5

TABLE 4

Orbital parameters and results for Radioastron (Scenario 2*, MES variants 1, 2 and 3)

MES variant	*i* (degrees)	*I* >5% time (dBW)	
		G_s = –5 dBi	G_s = –10 dBi
1	80	–176.4	–181.4
1	40	**–173.7**	–178.7
1	30	**–173.0**	–178.0
1	0	**–171.9**	–176.9
2	80	–176.3	–181.3
2	40	**–173.1**	–178.1
2	30	**–172.1**	–177.1
2	0	**–169.1**	–174.1
3	80	–175.7	–180.7
3	40	**–172.7**	–177.7
3	30	**–171.3**	–176.3
3	0	**–168.6**	**–172.6**

* Simulations were not produced for variants 4 and 4a in the Scenario 2.

TABLE 5

Orbital parameters and results for Radioastron (Scenario 2*, MES variants 1a, 2a and 3a)

MES variant	*i* (degrees)	*I* >5% time (dBW)	
		G_s = –5 dBi	G_s = –10 dBi
1a	80	–179.4	–184.4
1a	40	–176.7	–181.7
1a	30	–176.0	–181.0
1a	0	–174.9	–179.9
2a	80	–179.3	–184.3
2a	40	–177.1	–181.1
2a	30	–175.1	–180.1
2a	0	**–172.1**	–177.1
3a	80	–178.7	–183.7
3a	40	–175.7	–180.7
3a	30	–174.3	–179.3
3a	0	**–171.6**	–175.6

* Simulations were not produced for variants 4 and 4a in the Scenario 2.

3.2 Results for the HALCA system

For the HALCA system, the orbital parameters are more precisely defined and it is necessary to model only a single set of orbital parameters (height of apogee = 21 000 km, height of perigee = 560 km, eccentricity = 0.5956, inclination = 30°). The simulation time was 26 days and 22.17 hours using 10 000 timesteps and it was assumed that the satellite operates continuously over the entire orbit. As for the Radioastron system, there is some sensitivity in the results with respect to argument of perigee (ω). Hence two values were considered: ω = 0° and ω = 90° and an average of the two resulting values is given below. For the HALCA system, the MES variants involving the Type A and Type B MESs only were considered. The results are shown in Tables 6 to 9.

TABLE 6

Orbital parameters and result for HALCA (MES variants 1, 2 and 3)

MES variant	*I* >2% time (dBW)	
	G_s = –5 dBi	G_s = –10 dBi
1	**–151.7**	**–156.7**
2	**–150.2**	**–155.2**
3	**–149.1**	**–154.1**

TABLE 7

Orbital parameters and result for HALCA (MES variants 1a, 2a and 3a)

MES variant	*I* >2% time (dBW)	
	G_s = –5 dBi	G_s = –10 dBi
1a	**–154.7**	**–159.7**
2a	**–153.2**	**–158.2**
3a	**–152.1**	**–157.1**

TABLE 8

Orbital parameters and result for HALCA (Scenario 2, MES variants 1, 2 and 3)

MES variant	*I* >5% time (dBW)	
	G_s = –5 dBi	G_s = –10 dBi
1	**–151.4**	**–156.4**
2	**–149.7**	**–154.7**
3	**–148.7**	**–153.7**

TABLE 9

Orbital parameters and result for HALCA (Scenario 2, variants 1a, 2a and 3a)

MES variant	*I* >5% time (dBW)	
	G_s = –5 dBi	G_s = –10 dBi
1a	**–154.4**	**–159.4**
2a	**–153.7**	**–157.7**
3a	**–151.7**	**–156.7**

3.3 Further simulation results

The above-mentioned values show that the HALCA and Radioastron orbital parameters can be considered as limiting values for orbits of satellites in the SRS (passive), used for the S-VLBI radioastronomy observations. Therefore the decision on the possibility of co-existence of the MSS (E-s) and the SRS (passive) in the same frequency band based on the parameters of one or the other space-VLBI system can result in excessive restrictions on one of the concerned radiocommunication services, which contradicts the intent of Resolution 744 (WRC-03). Thus, the protection of satellite systems with orbits similar to HALCA can result in excessive restrictions on the MSS systems, while the protection of Radioastron alone can lead to the situation where the space-VLBI observations in lower orbits may be unfeasible.

Table 10 shows the interference levels at the space-VLBI receiver with noise temperature of 70 K for a system with orbit with apogee 150 000 km, based on e.i.r.p./power density –9 dB(W/4 kHz)/ –16.5 dB(W/4 kHz).

This MES e.i.r.p. / power density value would meet the protection criterion of –174.0 dB/400 kHz for such a space-VLBI system in the band 1 668-1 668.4 MHz and give the possibility of further development of VLBI satellite systems (with the apogee orbit of no less than 150 000 km).

TABLE 10

MES variant	h_p **(km)**	h_a **(km)**	**eccentricity,** e	i **(degrees)**	I **>2% time (dBW)**		
					G_s = –5/–10 dBi ω = 0°	G_s = –5/–10 dBi ω = 270°	G_s = –5/–10 dBi ω = average
1	10 000	150 000	0.81039	80	–177.9 / –182.9	**–172.0** / –177.0	–175.0 / –180.0
1	10 000	150 000	0.81039	40	**–172.8** / –177.8	**–169.7** / –174.7	**–171.3** / –176.3
1	10 000	150 000	0.81039	30	**–171.2** / –176.2	**–169.4** / –174.4	**–170.3** / –175.3
1	10 000	150 000	0.81039	0	**–169.0** / –174.0	**–169.0** / –174.0	**–169.0** / –174.0

Having regard to the difference in the amount of the transmitted traffic and activity of MESs during the day and night time, the interference level indicated in Table 10 can be reduced by 2-3 Db (valid for the SRS satellites (passive) with more than 2-day-orbital period).

3.4 Comparison of results for the different MES types

To compare the results for the three different MES types (Types A, B and hand-held), it is useful to take a single set of simulation results as a reference and to examine how each terminal compares to the criterion. For this purpose, the results for Scenario 1, 0° inclination, G_s = –5 dBi, MES variants 1a, 3a and 4a can be used, as contained in Table 3. This should not be taken as implying that these particular parameter values would necessarily apply in practice, as a range of values remains applicable to several of these parameters.

Table 11 shows the results and the extent to which MES powers would need to be adjusted to meet the criterion.

TABLE 11

Comparison of results for MES Types A, B and hand-held

	Type A	Type B	Hand-held	
			Type C	Type D
Margin with respect to criterion (for scenario 1, 0° inclination, $G_s = –5$ dBi)	1.6	–2.8	–2.5	–1.5
MES e.i.r.p. (dBW)	9	21	3.5	5
MES e.i.r.p. required to meet the criterion (dBW)	10.6	18.2	1.0	3.5
MES e.i.r.p. density (dBW/4 kHz)	–4.0	5.0	–5.4	–3.9
MES e.i.r.p. density required to meet the criterion (dB(W/4 kHz))	–2.4	2.2	–7.9	–5.4
MES power delivered to the antenna (dBW)	1.5	4.5	3.5	2.0
MES power delivered to the antenna to meet the criterion (dBW)	3.1	1.7	1.0	0.5
MES power density delivered to the antenna (dB(W/4 kHz))	–11.5	–11.5	–5.4	–6.9
Power density delivered to the antenna, required to meet the criterion (dB(W/4 kHz))	–9.9	–14.3	–7.9	–8.4