RECOMMENDATION ITU-R SA.1236*

FREQUENCY SHARING BETWEEN SPACE RESEARCH SERVICE EXTRA-VEHICULAR ACTIVITY (EVA) LINKS AND FIXED AND MOBILE SERVICE LINKS IN THE 410-420 MHz BAND

(Question ITU-R 212/7)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that the fixed and mobile services operate and plan to operate a variety of systems in the 410-420 MHz band;

b) that the space research service plans to operate extra-vehicular activity (EVA) links in the 410-420 MHz band for space-to-space communications within 5 km of an orbiting, manned space vehicle;

c) that protection of the fixed and mobile services can be achieved by suitable power flux-density (PFD) limits on extra-vehicular activity emissions;

d) that the interference environment for the space research service in the 410-420 MHz band may often be a contributing factor in determining the maximum operational distance of EVA systems;

e) that Annex 1 contains one approach to evaluate protection for fixed and mobile services and also to predict the radio frequency environment for EVA systems,

recommends

1 that in the frequency band 410-420 MHz the maximum power flux-density, under assumed free-space propagation conditions, at the surface of the Earth produced by emissions from EVAs in a low-Earth orbit, for all conditions and methods of modulation, should not exceed:

-153	$\text{dB(W/m}^2)$	for	$0° \leq \theta \leq 5°$
$-153 + 0.077(\theta - 5)$	$\text{dB(W/m}^2)$	for	$5° < \theta \leq 70°$
-148	$\text{dB(W/m}^2)$	for	$70° < \theta \leq 90°$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal) and the reference bandwidth is 4 kHz;

2 that EVA systems be designed to optimize operational distances and be operated to take maximum advantage of operational techniques such as frequency diversity and activity scheduling to mitigate possible interference effects.

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* This Recommendation should be brought to the attention of Radiocommunication Working Parties 8A and 9D.

ANNEX 1

Frequency sharing between space research service EVA links and fixed and mobile service links in the 410-420 MHz band

1 Introduction

At the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92), a secondary allocation was made to the space research service in the 410-420 MHz band for space-to-space operations. These operations, limited to 5 km from an orbiting manned space vehicle, are to permit EVA communications between astronauts and between astronauts and primary or base space vehicles. As permanent space facilities are developed in the future, the needs and requirements for EVA will also increase in order to support many of the planned and envisioned space activities. This is particularly true when considering the construction, maintenance, and operation of space facilities.

This Annex serves as an update to the work done at ex-CCIR, 1991. It shows the EVA communication requirements in the 410-420 MHz band and identifies typical communication characteristics for the fixed and mobile services in the band. The Annex investigates the interference from the space research EVA systems to the fixed and mobile service systems in terms of power flux-densities incident at the surface of the Earth. A representative fixed service system and a representative mobile service system are used in evaluating interference to the space research EVA links.

2 Space research service objectives and requirements

The primary purpose for the space research space-to-space links in the 410-420 MHz band is to provide high quality communications links for astronauts who have exited a space vehicle and are engaged in extra-vehicular activity. These links serve to provide the following three necessary communications requirements:

– a direct means of voice communication between astronauts engaged in EVA operations,

– a direct means of voice communication between an astronaut and the primary space vehicle,

– a direct means of data communication from an astronaut to the primary space vehicle.

Astronauts communicate via an EVA mobility unit (EMU) attached to the astronaut’s life support suit. Although communications may be required infrequently, the need for establishing the link must be available at any time. A maximum of four astronauts will be able to communicate simultaneously with the primary space vehicle.

Typical orbital altitudes for EVA activities range from 333 to 460 km with inclination angles of up to 60°. Maximum operational distance for communications between astronauts is 500 m. For communications between an astronaut and primary space vehicle, the maximum operational distance is 1 000 m.

3 System description and characteristics

The required communications in this system results in the following three links:

– links between two (or more) astronauts (EMU-to-EMU),

– links from an astronaut to the base vehicle (EMU-to-base),

– links from the base vehicle to one (or more) astronauts (base-to-EMU).

Table 1 lists the communication characteristics and Table 2 shows the link equations for this system. Antenna radiation pattern diagrams for the EMU antenna and the base vehicle antenna are given in Figs. 1 and 2.

TABLE 1

EVA system characteristics

Frequency (MHz)	415	
Modulation	TDMA/CPFSK	
Burst data rate (kbit/s)	695	
Bandwidth (kHz)	800	
Required bit error rate	1×10^{-5}	
Required E_b/N_0 (dB)	12.6	
	EMU	Base vehicle
Transmitter parameters:		
Transmitter power (dBW)	−6.0	−6.0
Transmitter line losses (dB)	−0.2	−7.0
Maximum antenna gain (dBi)	1.5	3.0
Minimum antenna gain (dBi)	−10.0	−6.0
Antenna polarization	Linear	Circular
Maximum e.i.r.p. (dBW)	−4.7	−10.0
Receiver parameters:		
Maximum antenna gain (dBi)	1.5	3.0
Minimum antenna gain (dBi)	−10.0	−6.0
Antenna cable loss (dB)	−0.2	−7.0
System noise temperature (K)	1 820	2 754

TABLE 2

EVA system link budgets

	EMU-to-EMU	EMU-to-base	Base-to-EMU
Transmitting System:			
Transmitter power (dBW)	−6.0	−6.0	−6.0
Transmitter line losses (dB)	−0.2	−0.2	−7.0
Minimum antenna gain (dBi)	−10.0	−10.0	−6.0
E.i.r.p. (dBW)	−16.2	−16.2	−19.0
Maximum distance (m)	500	1 000	1 000
Space loss (dB)	−78.8	−84.8	−84.8
Receiving System:			
Minimum antenna gain (dBi)	−10.0	−6.0	−10.0
Antenna cable losses (dB)	−0.2	−7.0	−0.2
Polarization loss (dB)	−3.0	−3.0	−3.0
Received power (dBW)	−108.2	−117.0	−117.0
System noise temperature (K)	1 820	2 754	1 820
Noise spectral density (dB(W/Hz))	−196.0	−194.2	−196.0
Bit rate bandwidth (dB(Hz))	58.4	58.4	58.4
Implementation loss (dB)	−3.0	−3.0	−3.0
Received E_b/N_0 (dB)	26.4	15.8	17.6
Required E_b/N_0 (dB)	12.6	12.6	12.6
Link margin (dB)	*13.8*	*3.2*	*5.0*

FIGURE 1

EMU antenna pattern

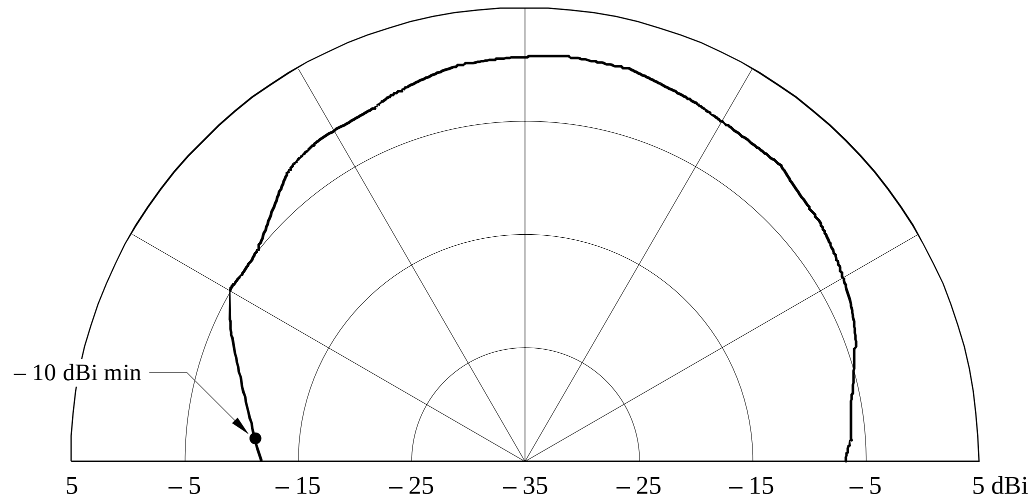

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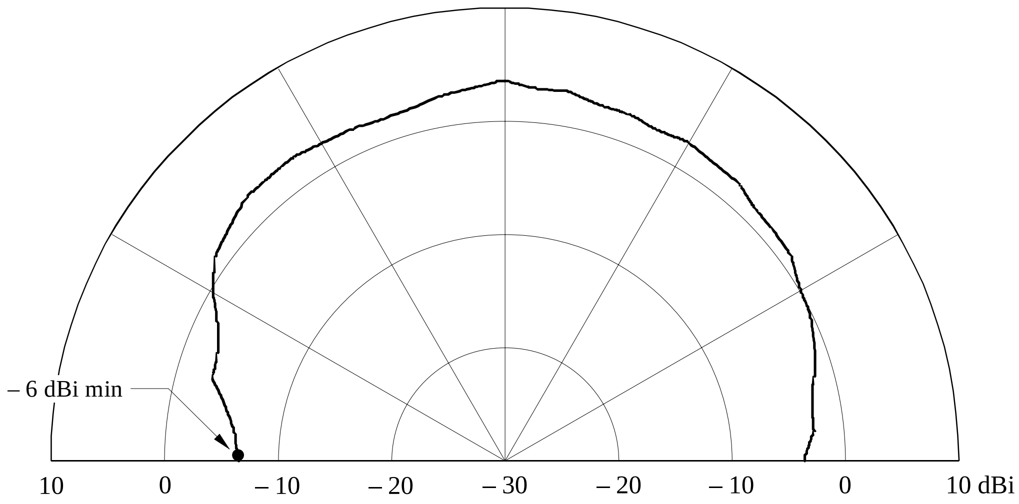
FIGURE 2

Base vehicle antenna pattern



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4 Interference to fixed and mobile service links from space research service EVA links

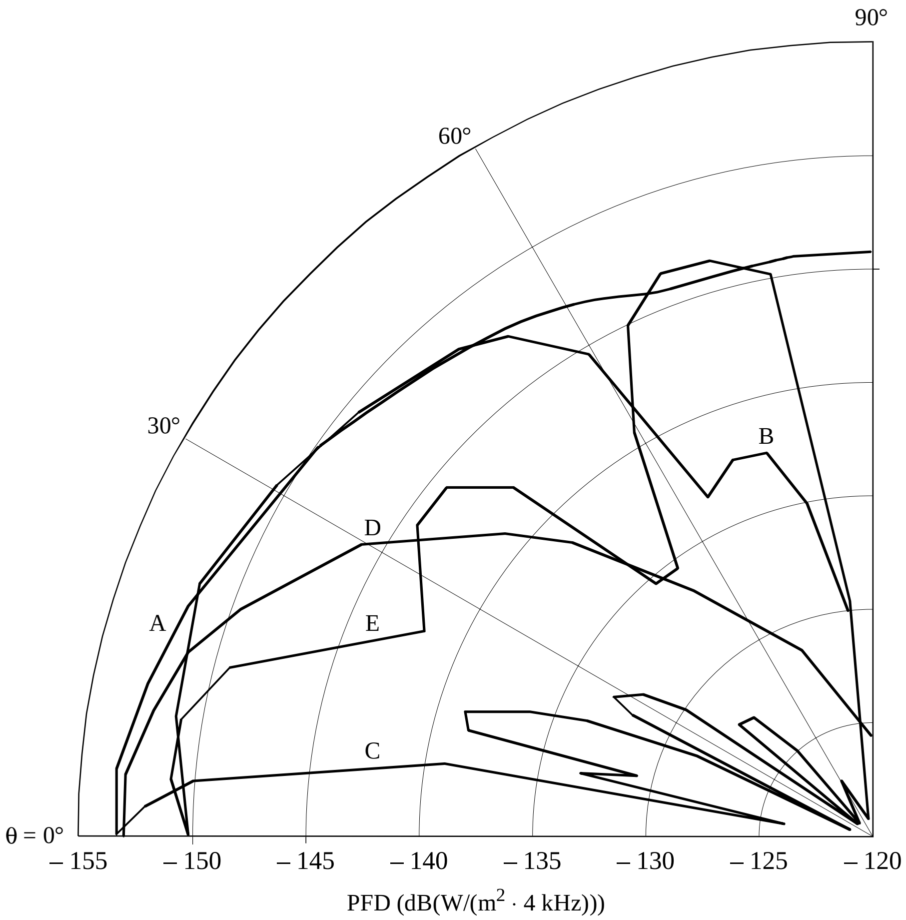
Report ITU-R 358, "Protection Ratios and Minimum Field Strengths Required in the Mobile Services", specifies that a degradation of the initial signal-to-noise ratio of 20 dB to a signal-to-(noise plus interference) ratio of 14 dB is an acceptable protection ratio. This 6 dB of degradation equates to a signal-to-interference ratio of 15.26 dB. This criterion was used to determine the allowed unwanted field strength and corresponding power flux-density values from EVA links to protect terrestrial mobile receiving stations. At a 0° elevation angle, an unwanted field strength of – 1.4 dB(μV/m) in a 16 kHz band, corresponding to a power flux-density of – 153.2 dB(W/(m^2 · 4 kHz)) was determined for a base station. For a mobile station, an unwanted field strength of +1.6 dB(μV/m) in a 16 kHz band, corresponding to a power flux-density of – 150.2 dB(W/(m^2 · 4 kHz)) was determined.

Curves B, C, D, and E of Fig. 3 show values of worst-case unwanted field strength (expressed in terms of power flux-densities incident at the mobile receiving station) as a function of the angle of elevation of the satellite, taking into account the change in receiving antenna gain with increasing elevation angles. An interfering field strength less than (to the left of) the values given by the curves would meet the criteria.

Curve A of Fig. 3 shows the power flux-density limits developed by the ex-CCIR, 1991. As can be seen from the figure, the interfering field strength meets the criteria at most points, and is marginal for the worst-case elevation angles.

FIGURE 3

Power flux-density (PFD) incident at mobile receiving station



Curves A: highest PFD produced at the Earth's surface by EVA links (333 km orbital altitude)

B: maximum PFD to meet Report ITU-R M.358 criteria, 5 dBi base station antenna

C: maximum PFD to meet Report ITU-R M.358 criteria, 12 dBi base station antenna

D: maximum PFD to meet Report ITU-R M.358 criteria, 1/4 wave vehicle antenna

E: maximum PFD to meet Report ITU-R M.358 criteria, 5 dBi vehicle antenna

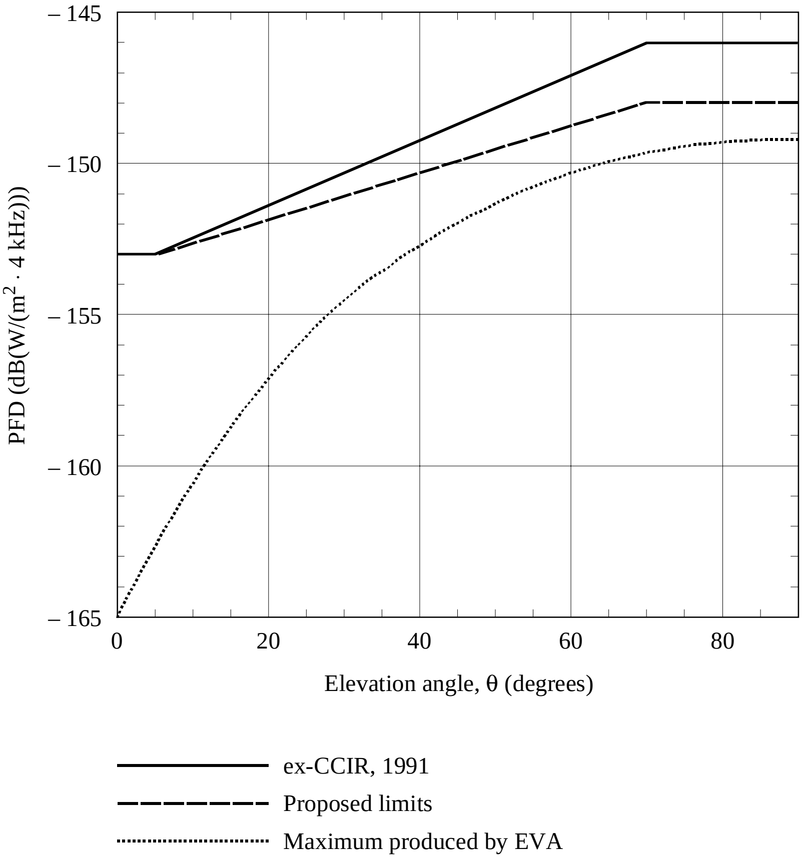
1236-03

The sharing situation between EVA transmitters and terrestrial fixed systems is similar to that involving mobile base stations using 12 dBi antennas. Typical fixed systems have 25 W transmitters and use 10 dBi gain antennas with maximum gains pointed towards the horizon.

The current technology allows for more restriction on the EVA system thus allowing for more protection for the fixed and mobile services in the band. Figure 4 shows the recommended limits agreed to by the ex-CCIR, 1991, the proposed new recommended limits, and the maximum power flux-density incident at the surface of the Earth produced by the EVA system.

FIGURE 4

Recommended power flux-density (PFD) limits



ex-CCIR, 1991 recommended PFD limits:

– 153 dB(W/m^2) in any 4 kHz band $0° \leq \theta \leq 5°$

– 153 + 0.108 (θ – 5) dB(W/m^2) in any 4 kHz band $5° < \theta \leq 70°$

– 146 dB(W/m^2) in any 4 kHz band $70° < \theta \leq 90°$

New proposed PFD limits:

– 153 dB(W/m^2) in any 4 kHz band $0° \leq \theta \leq 5°$

– 153 + 0.077(θ – 5) dB(W/m^2) in any 4 kHz band $5° < \theta \leq 70°$

– 148 dB(W/m^2) in any 4 kHz band $70° < \theta \leq 90°$

1236-04

5 Interference to space research service EVA links from fixed and mobile service stations

In considering interference to EVA links, two assumptions are required regarding the development of a set of representative transmission characteristics and a worldwide distribution of mobile service stations. An explanation of these assumptions is given below:

– *Characteristics of representative mobile emitters*

Characteristics of mobile systems in the 410 to 420 MHz band were based on data from the International Frequency List (IFL) and usage in the United States of America. Characteristics of typical base and mobile stations are as follows:

	Base	Mobile
Power (W)	100.0	100.0
Power (dBW)	20.0	20.0
Maximum gain (dB)	12.0 or 5.0	5.0
Bandwidth (kHz)	16.0	16.0

In some parts of the world, lower powers may be typically used. Figure 5 shows four antenna patterns typically used in the mobile service: a 12 dBi base station antenna, a 5 dBi base station antenna, a quarter-wave dipole vehicle antenna, and a 5 dBi vehicle antenna. For this analysis, the population of mobile transmissions is assumed to be made up of the following mix of antennas, using the transmitter power levels given above.

25% are base stations, using the 12 dBi base station antenna pattern (see Fig. 5a))

25% are base stations, using the 5 dBi base station antenna pattern (see Fig. 5b))

25% are mobile stations, using the quarter-wave dipole antenna pattern (see Fig. 5c))

25% are mobile stations, using the 5 dBi mobile station antenna pattern (see Fig. 5d))

Line losses, although assumed to be zero in this analysis, would typically reduce the e.i.r.p. by 3 dB.

– *The number and distribution of simultaneous emitters*

The extent to which the 410-420 MHz band is used throughout the world by the mobile services can only be roughly estimated since there is no international requirement to register all the systems in the band. For the purpose of this analysis, it was therefore necessary to assume some sort of a worldwide distribution of these systems. This distribution was based on the following considerations:

– The identification of the 479 largest cities in the world. These are shown in Fig. 6.

– Mobile systems will be used mainly in and around these large cities.

– Based on United States statistics, one terrestrial station per 6 224 people is assumed for the most populated cities in the world.

– For areas outside large cities: for every country where the number of telephones per capita exceeded 1% of the United States rate (from a 1990 World Almanac), the country was divided into approximately 100 km squares. Each of these squares represents the location of 33 terrestrial stations. The locations of these rural areas are shown in Fig. 7.

– It is assumed that each mobile station operates with a 20% duty cycle.

FIGURE 5

Mobile system antenna patterns

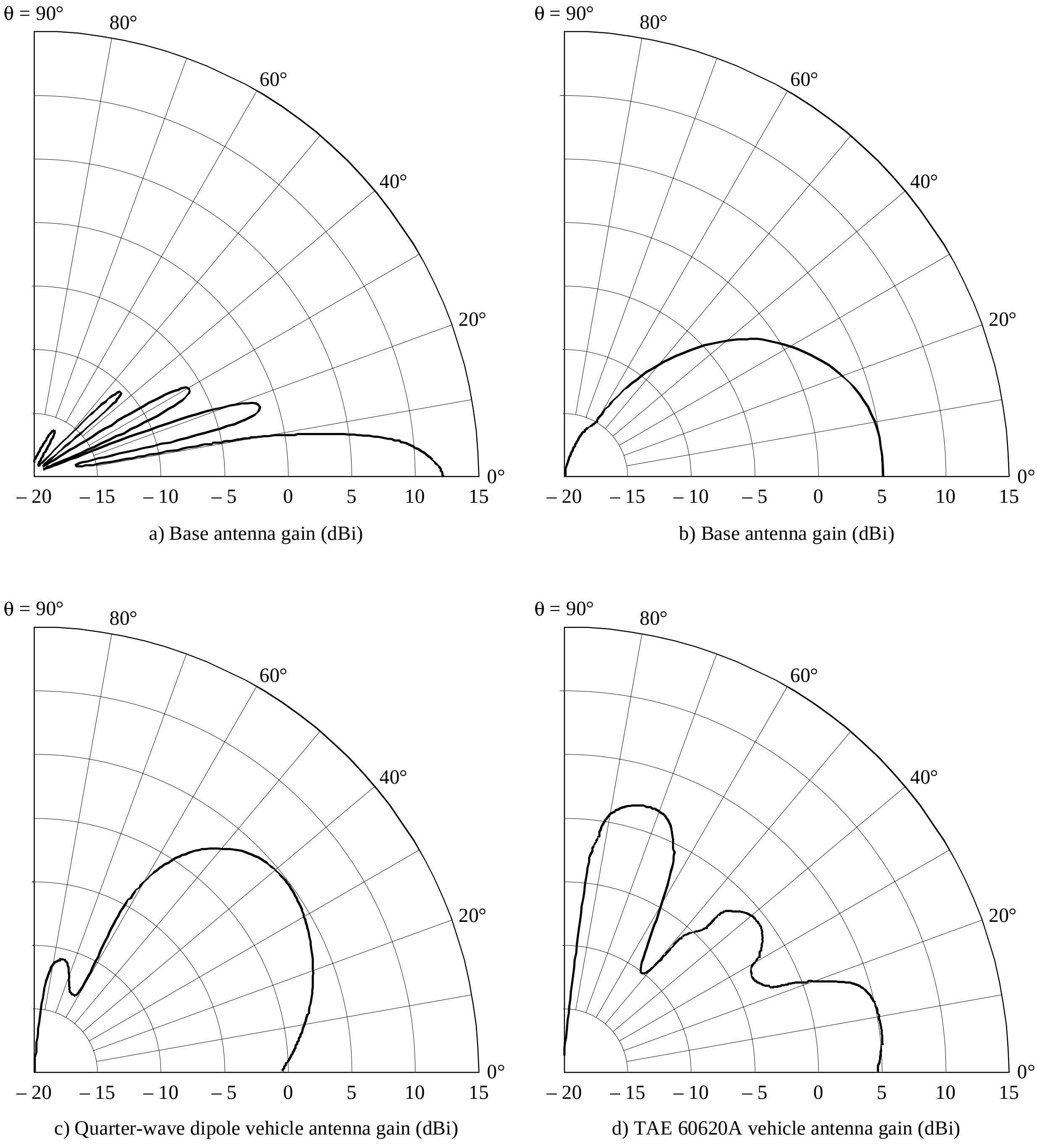


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FIGURE 6

Most populated cities in the world

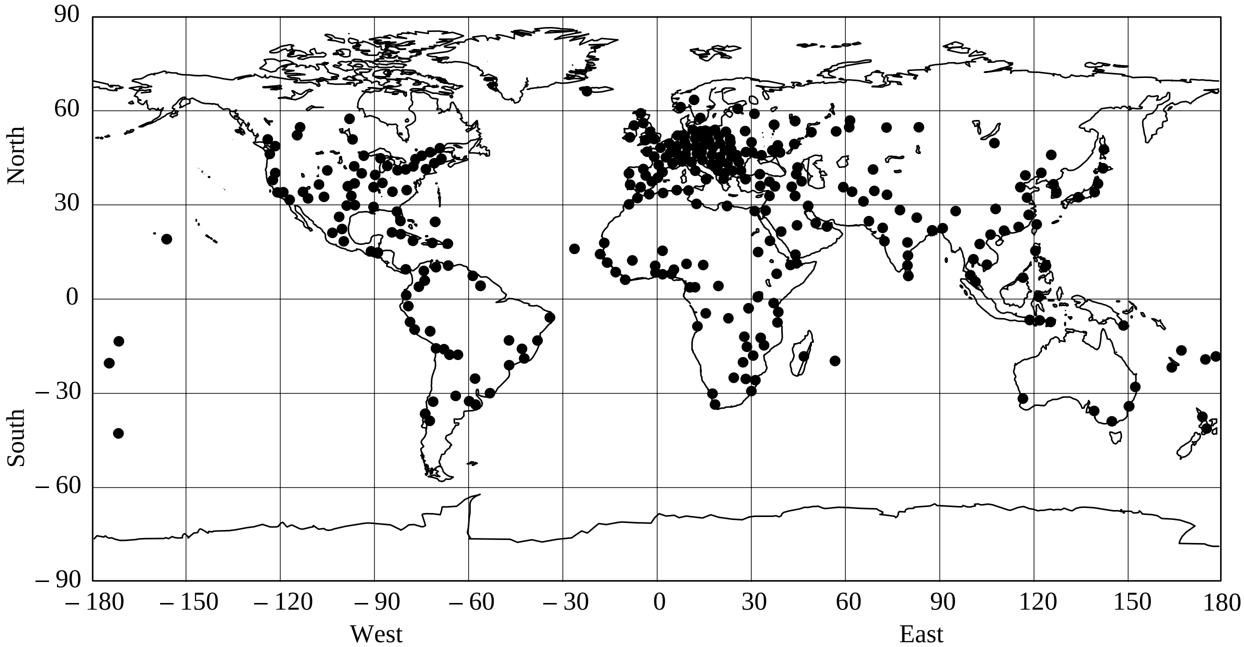

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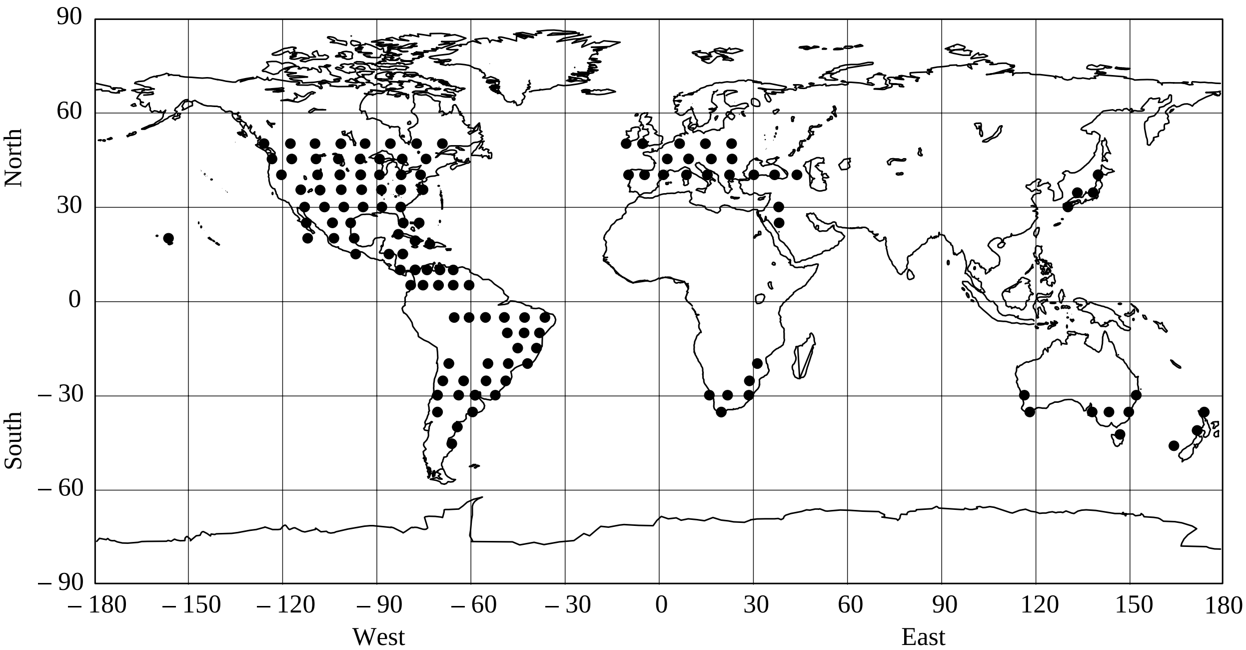
FIGURE 7

Rural areas used in the interference model



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Using the distribution model described above, the interfering power level produced at orbital altitudes of 333 km and 460 km and an inclination of 60° was calculated for every point on the orbit. Interference was calculated as the power level in dB(W/MHz) that would be received by an isotropic antenna. The highest interference level obtained was –91.7 dB(W/MHz) incident at the satellite at an altitude of 333 km. Figure 8 shows the interference level versus percentage of time for the simulations. The received interference levels were the greatest over the United States of America and Europe. A map depicting the locations on the EVA orbit where the interference level was the greatest is shown in Fig. 9.

FIGURE 8

Interference level incident at the EVA system orbit versus time

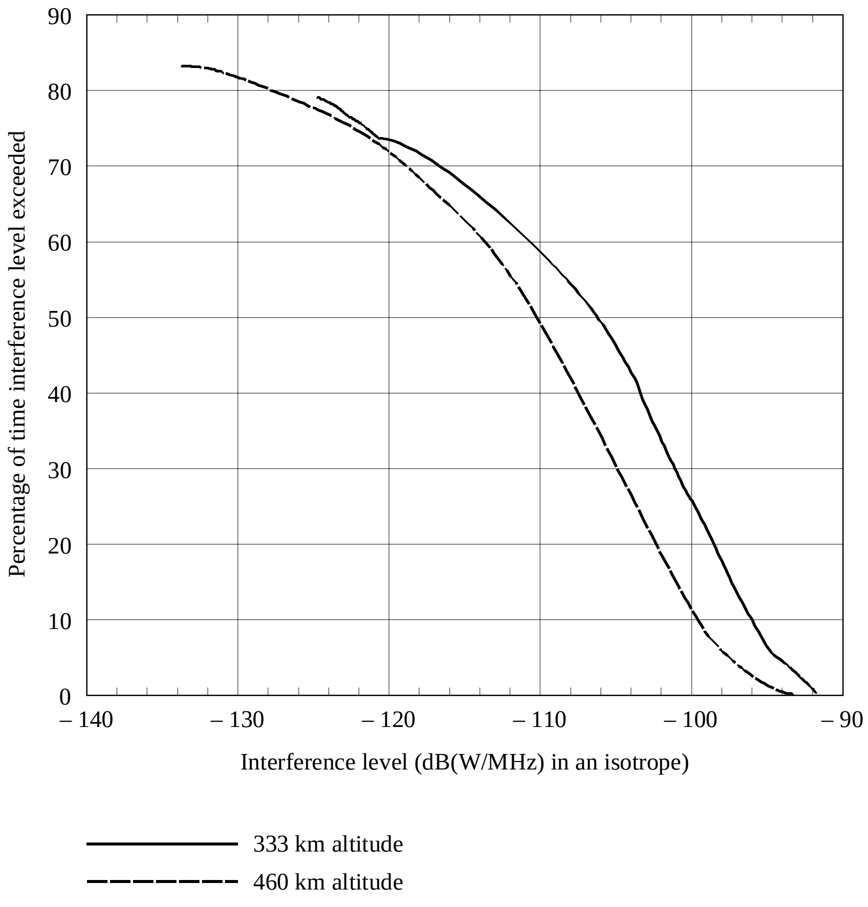

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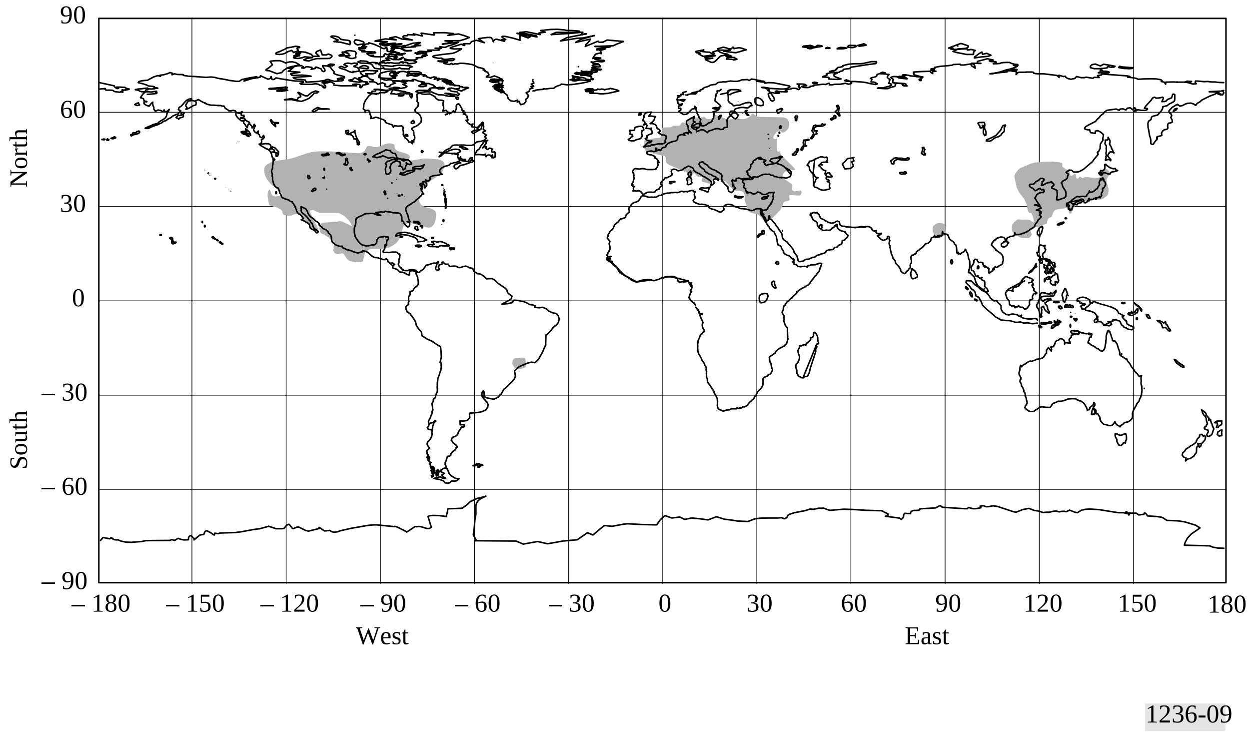
FIGURE 9

Areas on the EVA system orbit where the most interference was received



5.1 Achievable operational distance

A number of assumptions were made in analysing the effect of interference on the EVA receivers:

– The EVA link with the smallest link margin (from Table 2) was used in analysing the interference to the EVA system. This link is the EMU transmitting to the base vehicle.

– The −91.7 dB(W/MHz) interference level was assumed to have the same effect on the base vehicle receivers as random noise.

– Interference was assumed to enter the maximum gain region of the base vehicle receiving antenna.

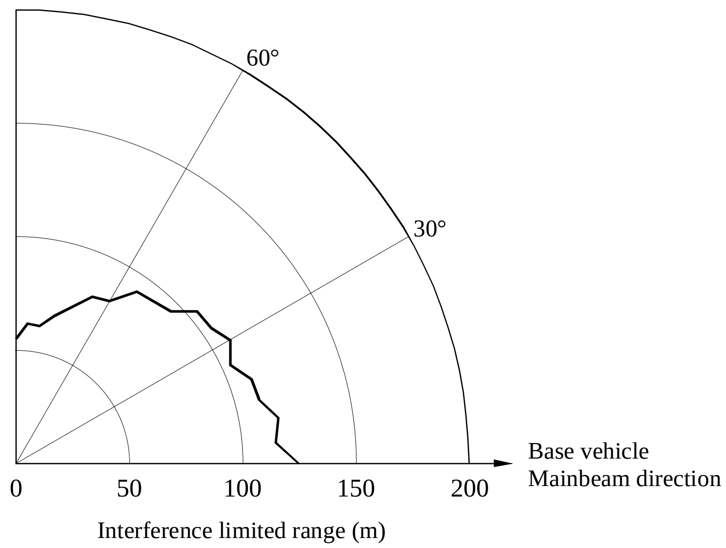
– The desired signal was assumed to enter the minimum gain region of the base vehicle antenna.

– No loss due to polarization mismatch between the mobile station and the receiving EVA base station was assumed.

The distance at which the link can be achieved can be obtained by adding the −91.7 dB(W/MHz) to the noise level in the link equation for the EMU-to-base link given in Table 2 and solving for the operational distance. This distance will vary around the base spacecraft as the gain of the base spacecraft antenna varies as shown in Fig. 2. This variation in distance as a function of direction effectively defines the service area around the base vehicle within which EVA communications can be accomplished. As seen in Fig. 10, distances from 55 m to 125 m can be achieved, depending upon direction from the base vehicle.

FIGURE 10

Achievable operational distance under worst conditions



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These distances would be greater in non-worst case scenarios, such as better than minimum antenna gain or non-zero line losses in the inclusion of polarization losses against interference. The distances will be greater than these minima for more than 99% of the time. If 3 dB line losses are included in the mobile emitters, the range of distances that can be achieved is improved by 41%. To further mitigate the effects of interference, multi-channel systems with the ability to receive on the least interfered with channel are planned.