REPORT ITU-R RS.2095

Sharing of the 36-37 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive)

(2007)

TABLE OF CONTENTS

Page

1 Introduction 2

2 EESS (passive) 2

  2.1 Applications 2

  2.2 Passive sensor parameters 2

  2.3 Interference criteria 4

3 Fixed and mobile service parameters 5

  3.1 Fixed service (FS) 5

  3.2 Mobile service (MS) 6

4 Simulation studies 7

  4.1 General simulation methodology 7

  4.2 Simulation study number 1 7

  4.3 Simulation study number 2 9

  4.4 Simulation study number 3 11

    4.4.1 P-P FS systems 11

    4.4.2 P-MP FS systems 15

  4.5 Simulation study number 4 17

  4.6 Summary of sharing study results 20

    4.6.1 Sharing between the FS and the EESS (passive) 20

    4.6.2 Sharing between the MS and the EESS (passive) 22

5 Mitigation techniques 22

  5.1 EESS (passive) 22

  5.2 FS 24

  5.3 MS 26

6 Summary and conclusions 26

7 Supporting documents 27

1 Introduction

The purpose of this report is to summarize the result of the studies on sharing the 36-37 GHz band by the fixed and mobile services and the Earth exploration-satellite service (EESS) (passive)

2 EESS (passive)

2.1 Applications

The band 36-37 GHz is of primary interest to measure rain, snow, ocean ice and water vapour. This band is also called a window. This band is essential for the precise knowledge of the hydrological cycle or global water circulation.

For the measurement of surface parameters, some radiometric window channels must be selected to determine the corresponding expected parameters for the ocean or land surfaces.

For ocean surfaces, the main parameters that are measured over the ocean surfaces are: salinity, wind speed, liquid clouds, water vapour and sea surface temperature. Liquid clouds are obtained via measurements at 36 GHz. Five frequencies (6, 10, 18, 24 and 36 GHz) are necessary for determining the above main parameters.

For land surfaces, the problem is more complex due to high temporal and spatial variability of surface characteristics (from snow/ice covered areas to deserts and tropical rain forests). Over this kind of surface, the retrieved parameters are: vegetation biomass, cloud liquid water, integrated water vapour, soil moisture and surface roughness. The use of the 36 GHz allows the retrieval of the contents of the cloud liquid vapour and of the snow covered areas. It has been shown that this band is the most suitable band for snow detection and has been used for the last 20 years for climatological studies of snow, sea ice, soil moisture, microwave vegetation index and land surface temperature. Measurements at 36 GHz have shown the capability to derive the snow water equivalent. The use of spaceborne remote sensing techniques offers a way to complement and extend conventional ground based measurements of snow to regional and global scales. There is a continuing need to determine the snow water equivalent and its variability over large areas for climatological and hydrological applications. In addition to the snow water equivalent, it is also possible to derive from spaceborne microwave remote sensing measurements, the snow depth based on the physics of the microwave radiation.

The 36-37 GHz band measurements also provide auxiliary parameters for other remote sensing instruments. Spaceborne radar altimeters are currently operated on a global basis above ocean and land surfaces, with important applications in oceanography and climatology. In order to remove refraction effects due to the atmosphere, the utilization of highly accurate altimetric data require that they are complemented with a set of auxiliary passive measurements around 18.7, 23.8 and 36.5 GHz. In that case, the goal of the 36 GHz band measurements is to compute the tropospheric delay in order to enhance the accuracy of the data retrieved through the altimeters.

It is to be noted that all the above usages are fully operational.

2.2 Passive sensor parameters

Table 1 summarizes the parameters of conical scanning passive sensors that are or will be operating in the 36-37 GHz band as illustrated in Fig. 1.

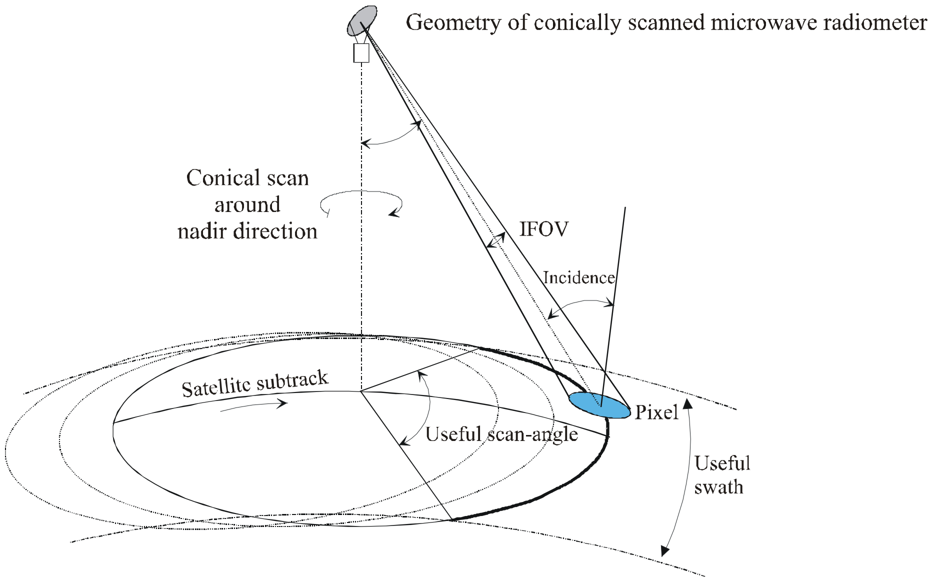
TABLE 1

Passive sensor parameters

Type of sensor	**MADRAS**	**AMSR-E**	**CMIS**
Channel bandwidth (GHz)	1	1	1
Pixel size across track (diameter of the pixel) (km)	38	7.8	12
Incidence angle i at footprint centre (degrees)	52.3	55	55.7°
Offset angle to the nadir or half cone angle α (degrees)	44.5	47.5	47
Polarization	H	H,V	H,V
Altitude of the satellite (km)	817	705	833
Maximum antenna gain (dBi)	45	53	55
Reflector diameter (m)	0.65	1.6	2.2
Half power antenna beamwidth θ_{3dB} (degrees)	1.8	0.4	0.52
Useful swath (km)	1 607	1 450	1 782
Antenna pattern	Fig. 2	Fig. 3	N/A

FIGURE 1

Geometry of conical scan passive microwave radiometers



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The antennas of passive sensors are modelled according to the following figures.

FIGURE 2

MADRAS antenna gain pattern at 36 GHz

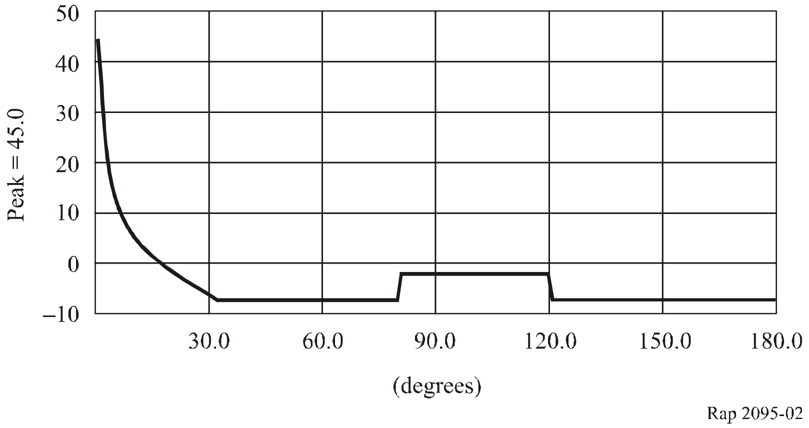
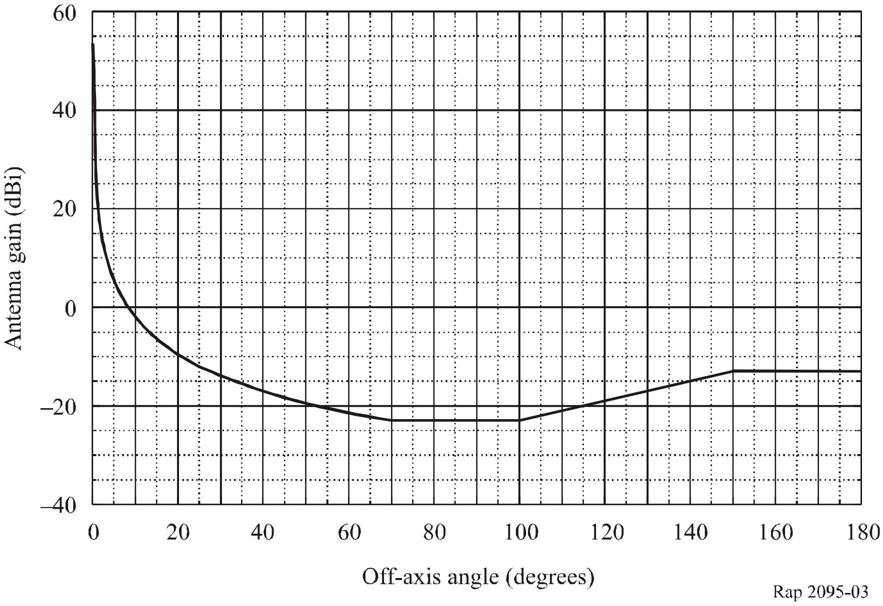


FIGURE 3

AMSR-E antenna gain pattern at 36 GHz



2.3 Interference criteria

Recommendation ITU-R RS.1029 – Interference criteria for satellite passive remote sensing recommends permissible interference levels and reference bandwidths for use in any interference assessment or sharing studies. The permissible interference levels for the 36-37 GHz band are –156 dBW in a reference bandwidth of 100 MHz for current passive sensors, and –166 dBW in a reference bandwidth of 100 MHz for future passive sensors that are more sensitive than the currently operational passive sensors. The first number is indicated for sharing conditions circa 2003; while the second number is for scientific requirements that are technically achievable by sensors in the next 5-10 years. Recommendation ITU-R RS.1029 also specifies that these interference levels should not be exceeded for more than 0.1% of sensor viewing area, described as a measurement area of a square on the Earth of 10 000 000 km^2 unless otherwise justified.

3 Fixed and mobile service parameters

3.1 Fixed service (FS)

FS systems in this band can generally be characterized as either point-to-point (P-P) or point-to-multipoint (P-MP) systems.

Table 2 summarizes the parameters of P-P system that could operate in the 36-37 GHz that were considered in these studies.

TABLE 2

P-P FS station parameters

Parameter	FS-1	FS-2
Modulation type		O – QPSK
Distance between stations (one hop length) (km)	Around 2	From 0.5 to 20 Point-to-point
Channel capacity (Mbit/s)		2.048; 8.448; 34.368
Receiver sensitivity (BER up to 10^{-6}) (dBW)		Up to –117
Transmitter power (dBW)	–18.24 dBW/30 MHz (= 15 mW/30 MHz)	–13 to –7
Antenna gain (dBi)	37	39-42
Antenna diameter (m)		0.4-0.5
Antenna type		Parabolic
Antenna pattern		Rec. ITU-R F.1245
Max. feeder loss (dB)		0.5
Frequency grid		Rec. ITU-R F.749

Table 3 summarizes the parameters of one possible type of terrestrial P-MP station that could operate in the 36-37 GHz.

TABLE 3

P-MP FS station parameters

Parameter	Central (hub) station	Customer terminal station
Modulation	QPSK	
Access method	Time division multiplex (TDM)	
Bandwidth/carrier (MHz)	28	28
Antenna type	Sectoral antenna	Dish
Antenna gain (dBi)	17	39
Antenna beamwidth (degrees)	45	1.4
Number of active carriers/sector	4	4
Number of sectors	8	–

TABLE 3 (*end*)

Parameter	Central (hub) station	Customer terminal station
Path length (km)	0.1 – 6	
Maximum transmit power per carrier (dBW)	–5	–10
Receiving system line loss (dB)	0	0

3.2 Mobile service (MS)

Technical characteristics of systems in the MS operating in the band 36-37 GHz are shown in Table 4. As for the antenna pattern, Recommendation ITU-R F.1245 – Mathematical model of average radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 to about 70 GHz is used in the simulation.

MS-1 and MS-2 systems are used mainly for video transmission in nomadic applications. Their corresponding activity factor is 3%.

In European countries, the band 36-37 GHz is allocated to the MS and the FS for the usage of government applications. Due to the specific operation, the MS-3 system which is used for government point-to-point links can be considered as MS systems due to their portable usage. It is noted that the characteristics of such MS stations are very similar to the FS station characteristics assumed in the dynamic simulations, so that the conclusions of the FS studies are generally assumed to be applicable to the MS.

TABLE 4

Mobile service station parameters

Parameter	MS-1	MS-2	MS-3
Antenna input power	–7 dBW/17 MHz (= 0.2W/17 MHz)	–3 dBW/17 MHz (= 0.5W/17 MHz)	–10 dBW (max) –15 dBW (typical)
Antenna gain (dBi)	37	37	44 (typical)
Antenna diameter (m)	0.3	0.3	0.3
Antenna type	Parabolic/Cassegrain	Parabolic	Parabolic
Feeder loss (dB)	0	0	0
Polarization	H/V	H	H/V
3 dB beam width (degrees)	2	2	1

NOTE 1 – Elevation angles are not specified because of its nomadic usage. This means that the transmitting antenna has a possibility to point any elevation and azimuth angles. However, the antenna is fixed during its operation.

NOTE 2 – MS-1: More than 30 transmitting stations are in operation and it is foreseen that the number of the stations will not increase rapidly in some administrations. MS-2: More than one transmitting station is in operation and it is foreseen that the number of the stations will not increase rapidly in some administrations.

4 Simulation studies

4.1 General simulation methodology

These sharing studies employ dynamic model simulations with the results required by Recommendation ITU-R RS.1029 concerning the percentage of the area over a 10 million km^2 measurement area that exceed the permissible interference power level. These dynamic model simulations develop cumulative distribution functions (CDFs) of received interference levels on the basis of such measurement areas so that such interference statistics can be directly compared with the specified interference criteria.

4.2 Simulation study number 1

This simulation assumes a deployment of 200 P-P FS stations evenly spread over an area defined by 40° N latitude, 0° longitude, 60° N latitude, and 20° E longitude. The transmitter power is –10 dBW and the antenna gain is 41 dBi, corresponding to an e.i.r.p. of 31 dBW. The propagation model includes atmospheric attenuations and the time increment for simulation is 2 s. The simulation results are given in Fig. 4 and Table 5 for the MADRAS passive sensor, in Fig. 5 and Table 6 for AMSR-E, and in Fig. 6 and Table 7 for CMIS.

FIGURE 4

Dynamic simulation for the MADRAS passive sensor

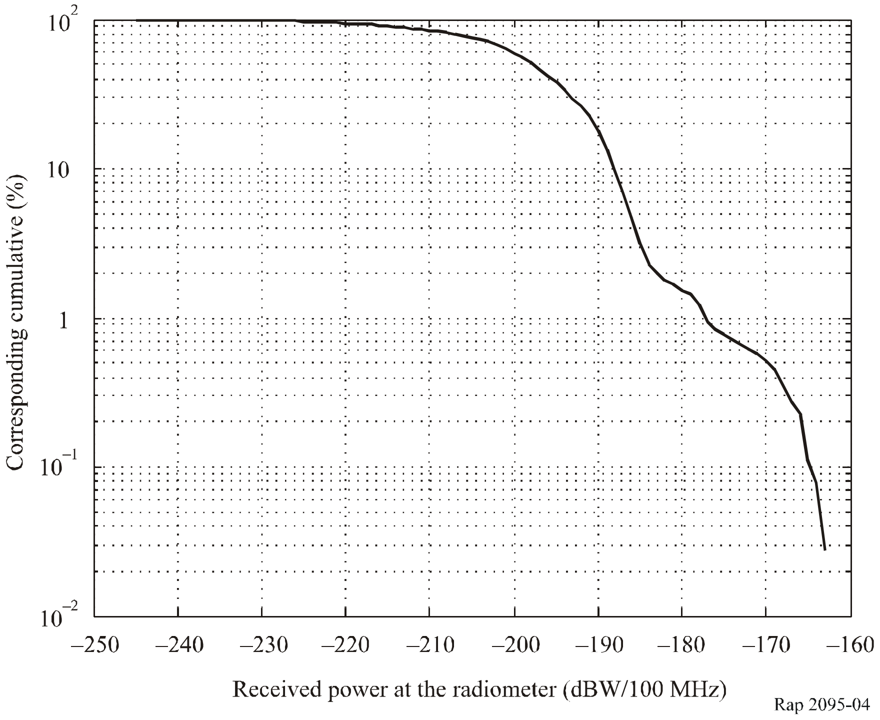


TABLE 5

Result of dynamic simulation corresponding to Fig. 4

Cumulative percentage (%)	1	0.2	0.1	0.02
Corresponding received power at the input of the radiometer in dBW for MADRAS for a 100 MHz bandwidth	–177	–167	–166	–163

FIGURE 5

Dynamic simulation for the AMSR-E passive sensor

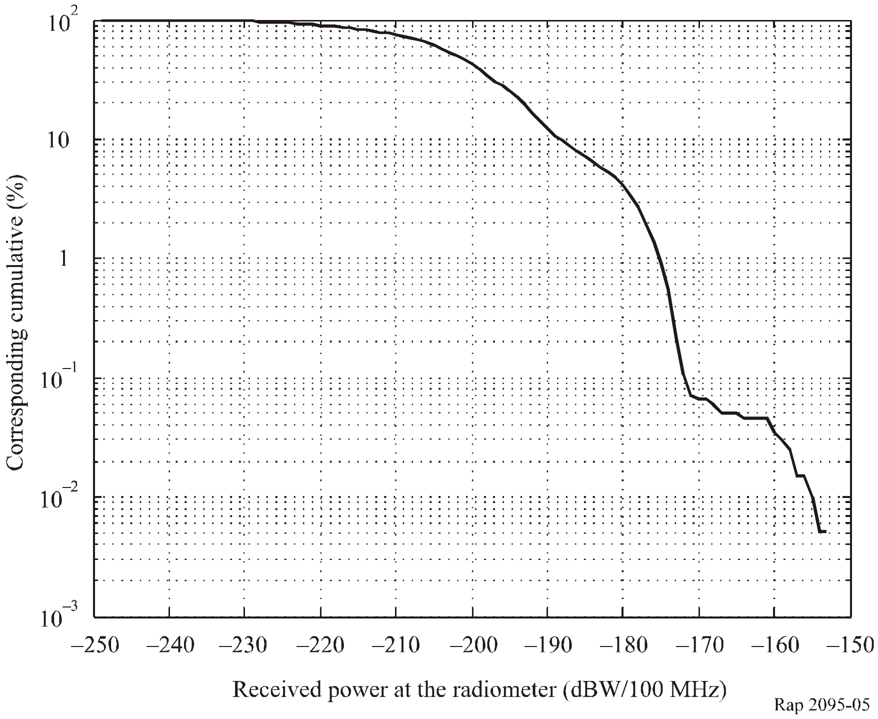


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TABLE 6

Result of dynamic simulation corresponding to Fig. 5

Cumulative percentage (%)	10	1	0.1	0.05
Corresponding received power at the input of the radiometer in dBW for AMSR-E	–188	–175	–172	–156

FIGURE 6

Dynamic simulation for the CMIS passive sensor: 200 P-P stations in operation

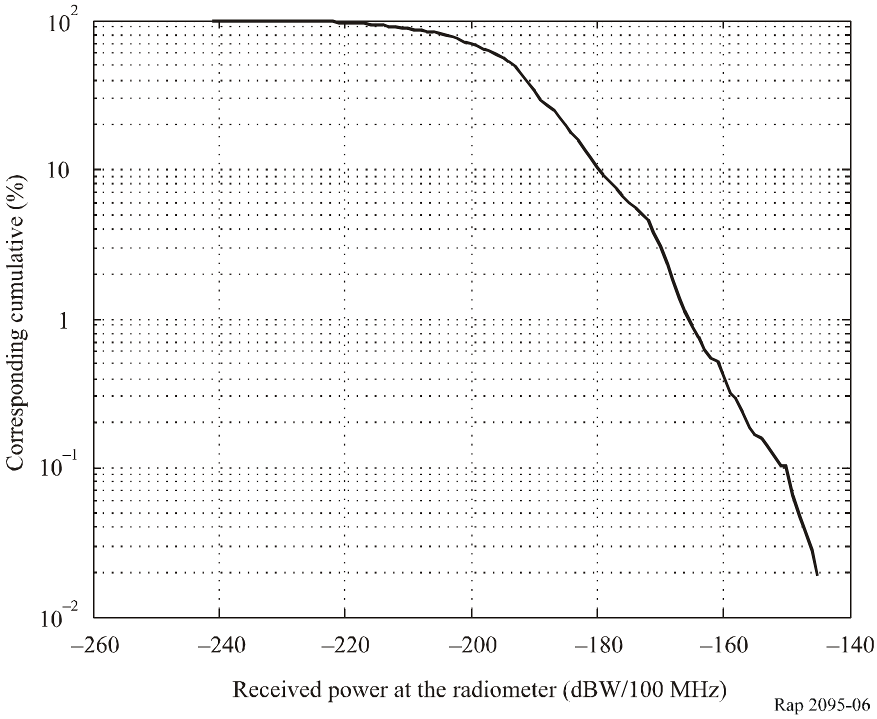


TABLE 7

Result of dynamic simulation corresponding to Fig. 6

Cumulative percentage (%)	10	2	1	0.1	0.02
Corresponding received power at the input of the radiometer in dBW for CMIS	–180	–166	–165	–152	–145

4.3 Simulation study number 2

This simulation is designed to develop a relationship between FS station deployment density and the EESS (passive) interference level. The simulation was conducted for the AMSR-E passive sensor, and each FS station was assumed to have a –11 dBW transmitter power and to employ a 40.5 dBi antenna whose side-lobe conform to the reference antenna pattern given in Recommendation ITU-R F.1245 for a 3 dB beamwidth of 1.5°.

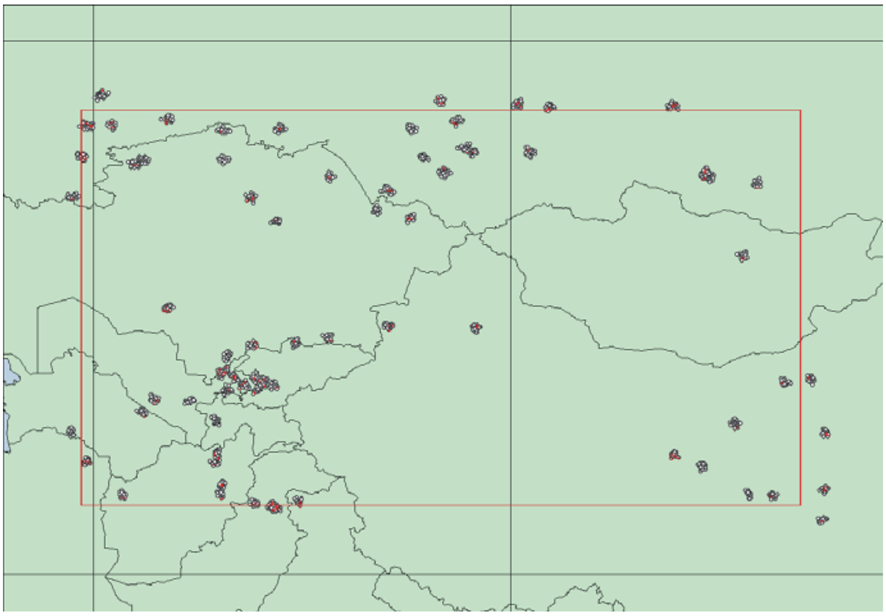
In this simulation model, a large range of FS station deployment densities was achieved by assuming that between 1 and 20 two-way FS links were randomly distributed around 74 cities in and around the 10^7 km^2 passive sensor measurement area illustrated in Fig. 7. Of the 74 cities in the simulation area in central Asia illustrated in Fig. 10, 66 were located within the 10^7 km^2 passive sensor measurement area itself. The FS station density, N_{FS}, within this area is calculated as:

$$N_{FS} = 2 \text{ (stations/link) x FS (links/city) x 66 (cities)}$$

where FS is the number of FS links/city assumed for the particular interference CDF.

FIGURE 7

Central Asia measurement area



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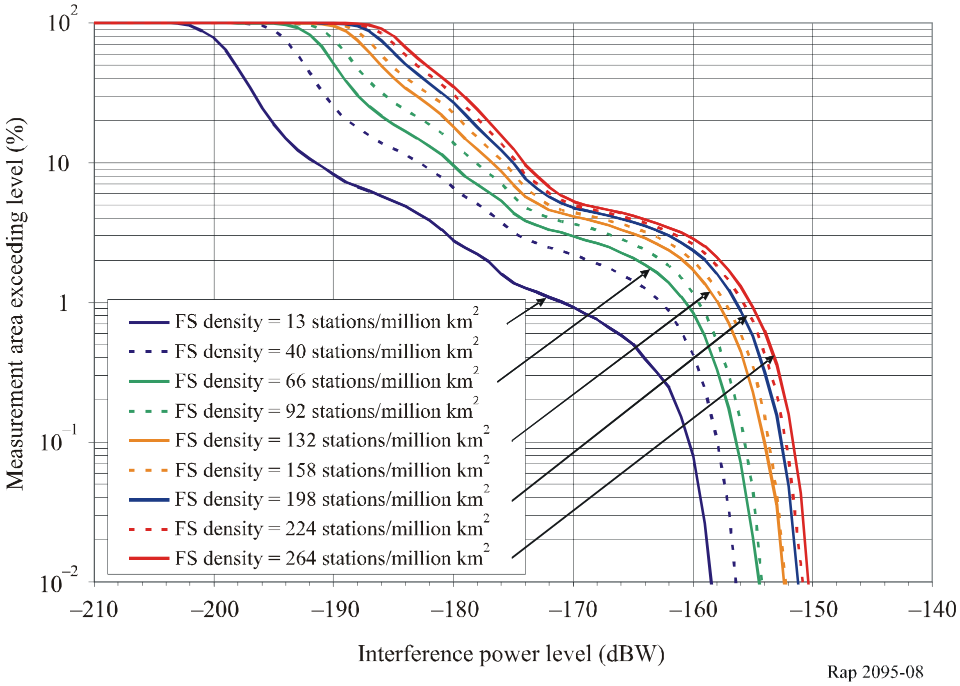
The resulting interference CDF for this simulation include calculations only for time steps for which the passive sensor beam intersected the Earth's surface within the measurement area and are displayed in Fig. 8.

FIGURE 8

Interference CDFs from dynamic simulations



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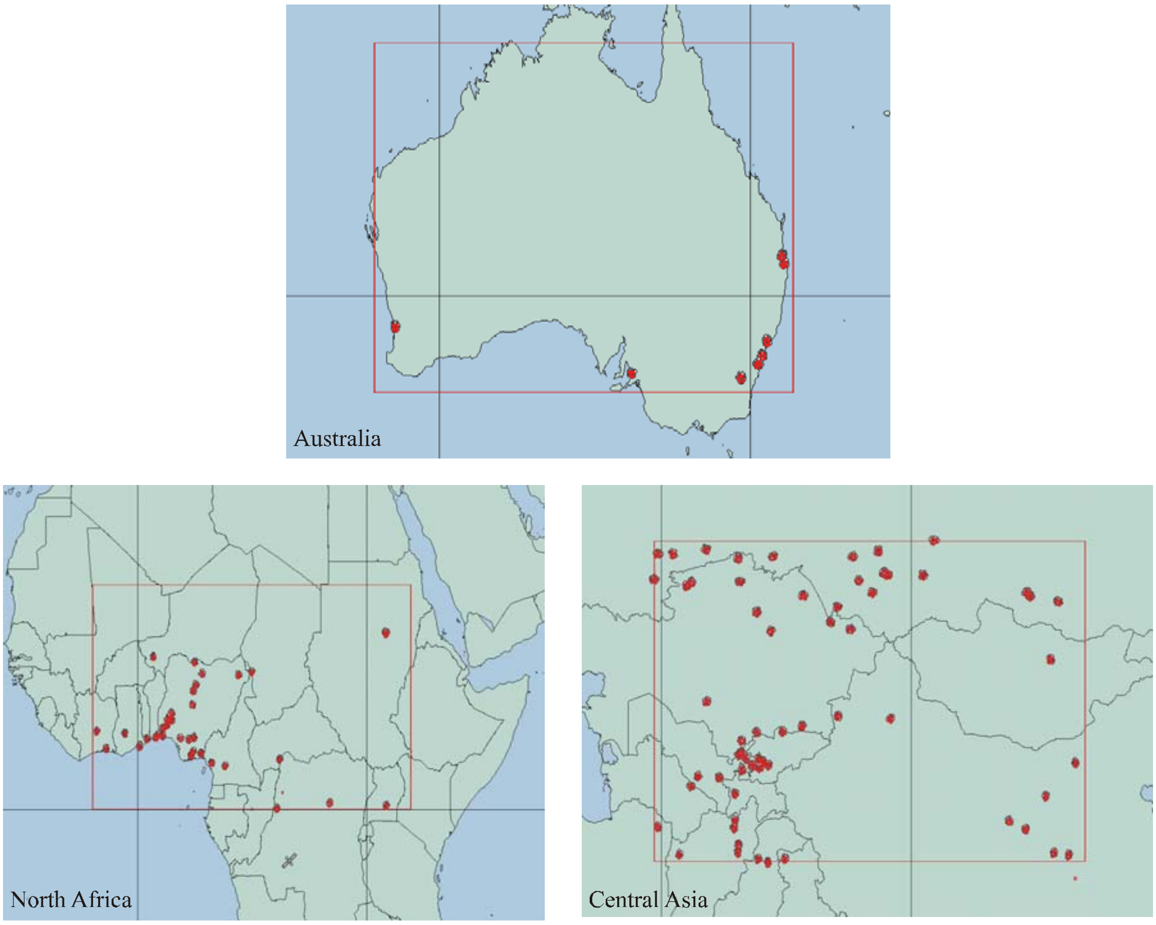
4.4 Simulation study number 3

This study addressed both P-P and P-MP FS systems. These simulations included in this study were conducted to develop interference CDF over the three different passive sensor 10 000 000 km^2 measurement areas illustrated in Fig. 9, each with different FS deployment densities, for comparison with Recommendations ITU-R RS.1029, which specifies permissible interference criteria for passive sensors in this band in terms of percentage of a 10 million km^2 measurement area over which the specified interference level is exceeded. The FS station density for each of these areas is based on the assumption of a single frequency use of the channel plan described in Annex 2 to Recommendation ITU-R F.749 – Radio-frequency channel arrangements for radio-relay systems in the 38 GHz band within each city. Interference into the passive stations is evaluated under free space propagation conditions, plus an additional loss of 0.32 dB for atmospheric (gaseous) absorption from Recommendation ITU-R P.676 – Attenuation by atmospheric gases for the Earth-to-space path.

FIGURE 9

FS deployment areas – City model



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4.4.1 P-P FS systems

Two types of FS deployment models were used in these simulation studies. It is commonly assumed that FS systems are predominantly deployed in urban and sub-urban areas, with few if any systems in rural areas. Therefore the first scenario is the "City Model" which distributes FS stations around urban cities within a given simulation area. However, some administrations indicate FS applications in the 36-37 GHz that may be distributed over wider areas, including rural area, including intermittent operations. For this reason a second scenario is identified as the “Random Model” which focuses on when the FS systems that are randomly distributed over the land area within the specified measurement area with a uniform probability distribution.

The P-P FS deployment densities are presented in Table 8 for the cases assumed in these simulations, based on the channel bandwidth.

TABLE 8

P-P FS deployment densities

Channel bandwidth (MHz)	112	56	28	14	7
FS stations/City	4	8	15	29	57
FS stations/Australia	32	64	120	232	456
FS stations/North Africa	148	296	555	1 073	2 109
FS stations/Central Asia	248	496	930	1 798	3 534

The P-P FS stations in these simulations were assumed to conform to the parameters for the FS-2 system, with a –10 dBW transmitter power and a 41 dBi antenna gain. For each deployment scenario, a simulation was run to produce the CDF over a simulation run of 16 days with a 200 m/s step size when the passive sensor was able to sample points within the measurement area. The CDFs of the interference from the FS systems into the AMSR-E passive sensor are presented in Figs. 10 through 13.

FIGURE 10

**P-P FS interference into AMSR-E
City and random models – 4 stations per city**

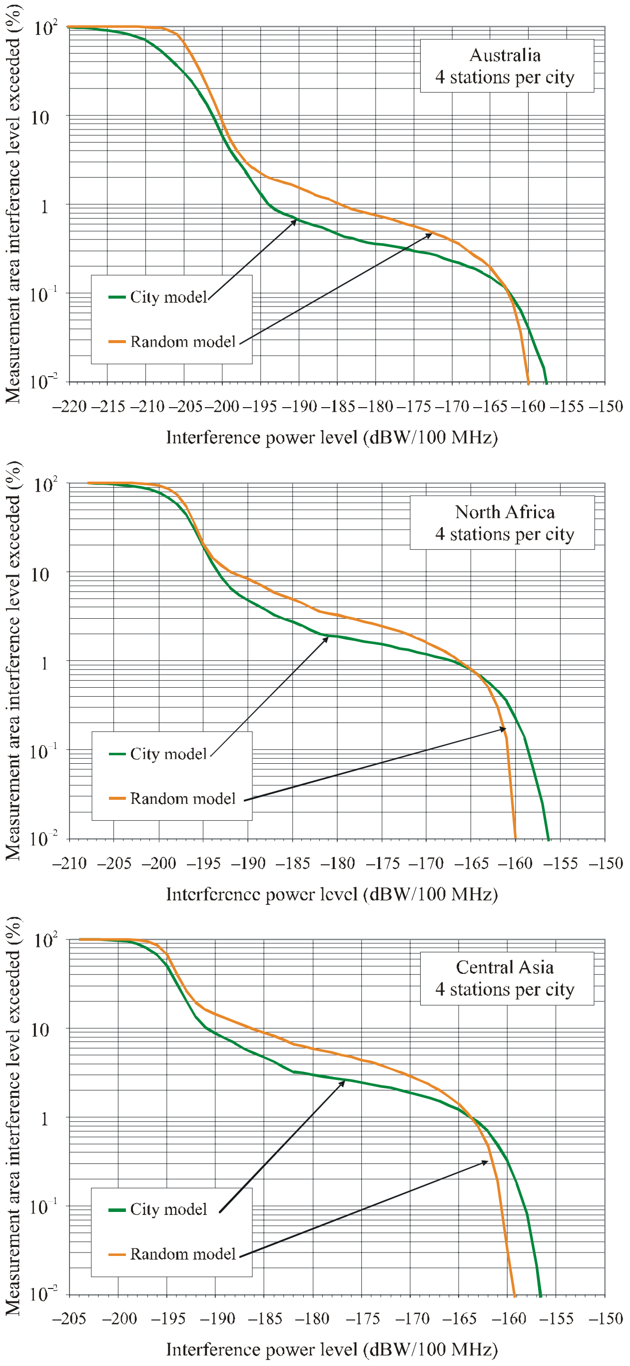

FIGURE 11

**P-P FS interference into AMSR-E
City and random models – 29 stations per city**

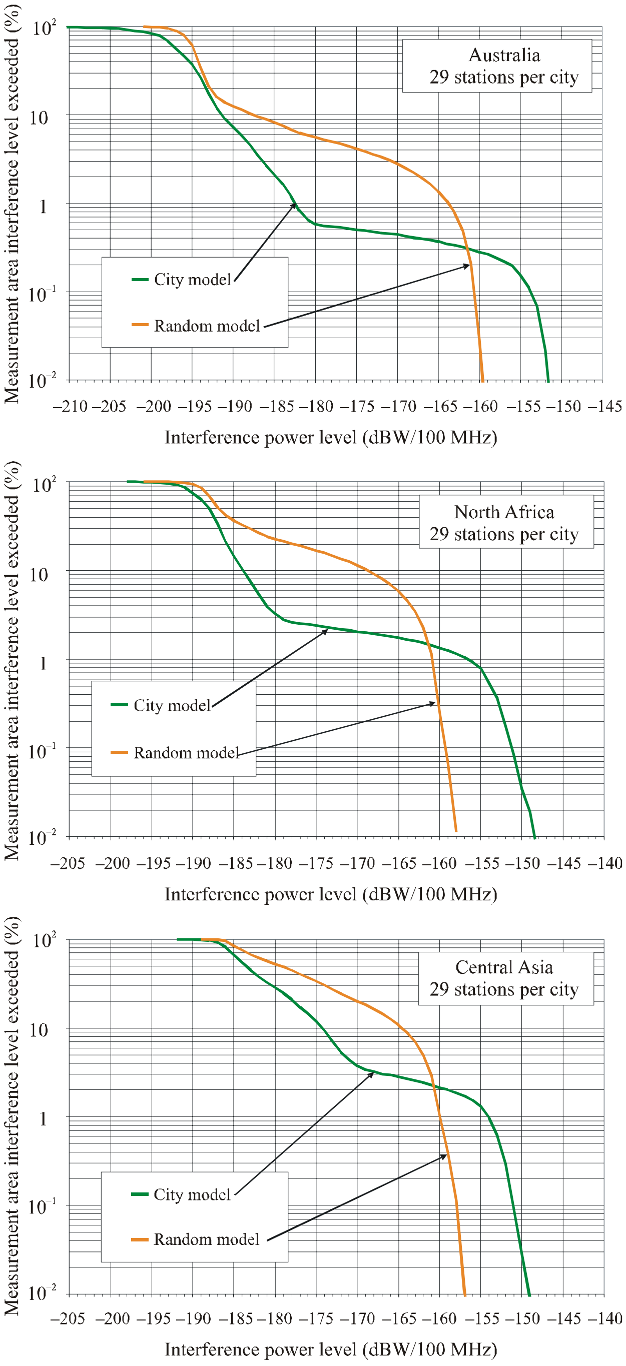

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FIGURE 12

P-P FS interference into AMSR-E
City models – 4, 8, 15, 29, and 57 stations per city

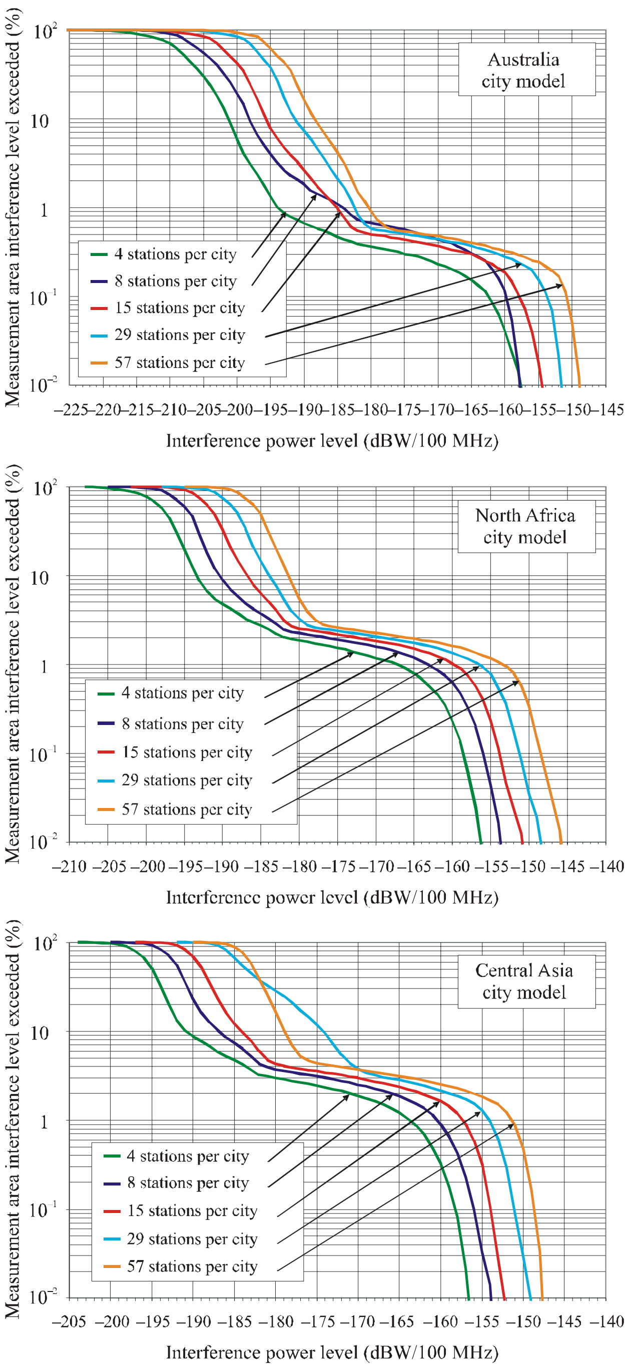
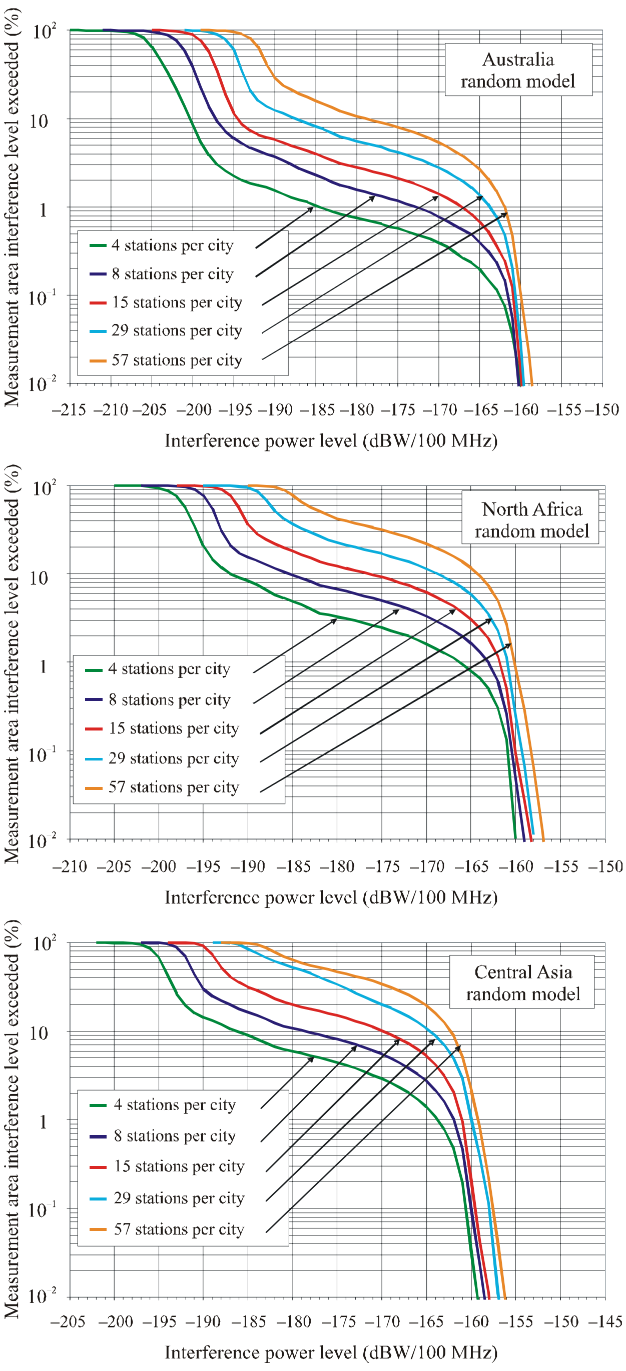


FIGURE 13

P-P FS interference into AMSR-E
Random models – 4, 8, 15, 29, and 57 stations per city



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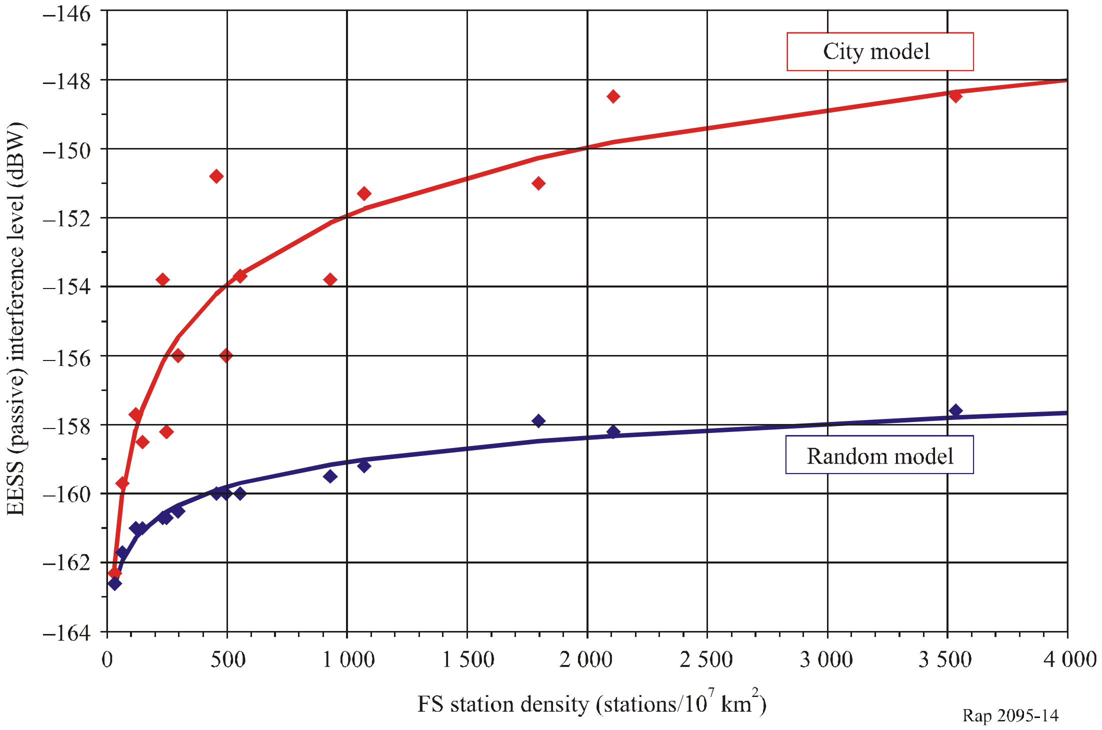
For each of the CDF in Figs. 12 and 13, the passive sensor interference power exceeded over all but 0.1% of the 10^7/km^2 measurement area was determined, and these values are presented as the individual data points in Fig. 13, which is a plot of passive sensor interference power with respect to the FS station density within the measurement area. In addition, a smoothed (best-fit) power function ($y = a{*}x^b$) was calculated for the city model and random distribution FS deployment models and included in Fig. 14.

FIGURE 14

Passive sensor interference level with respect to FS station density



4.4.2 P-MP FS systems

An additional study was conducted to analyze the P-MP FS transmit link described in Table 3 with two of the deployment areas given in Fig. 9. The FS deployment densities for each of these areas is based on the assumption of one frequency use of the channel plan described in Annex 4 to Recommendation ITU-R F.749 within each city. The resulting FS deployment densities are presented in Table 9 for the cases assumed in these simulations.

TABLE 9

FS deployment densities for P-MP simulation

	Australia	**Central Asia**
Channel bandwidth (MHz)	28	28
FS station/city	8	62
Hub station/city	32	248
Customer station/city	256	1 984

The FS stations in these simulations were assumed to conform to the parameters for the P-MP systems in Table 3.

For each deployment scenario, a simulation was run to produce the CDF over a simulation run of 16 days with a 200 m/s step size when the passive sensor was able to sample points within the measurement area. The CDF of the interference from the P-MP FS systems into the AMSR-E passive sensor are presented in Figs. 15 and 16 and in Table 10.

FIGURE 15

P-MP FS interference into AMSR-E over Australia

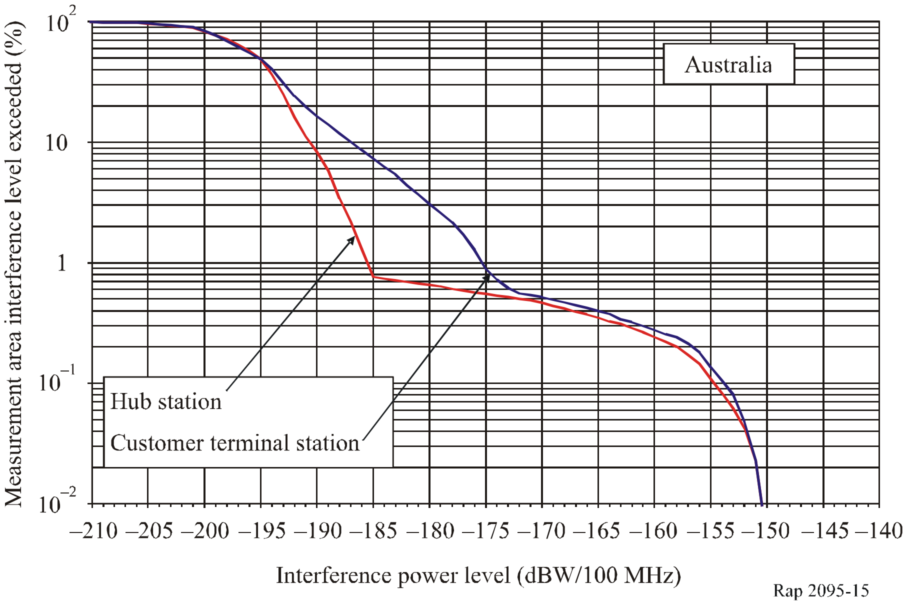


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FIGURE 16

P-MP FS interference into AMSR-E over Central Asia

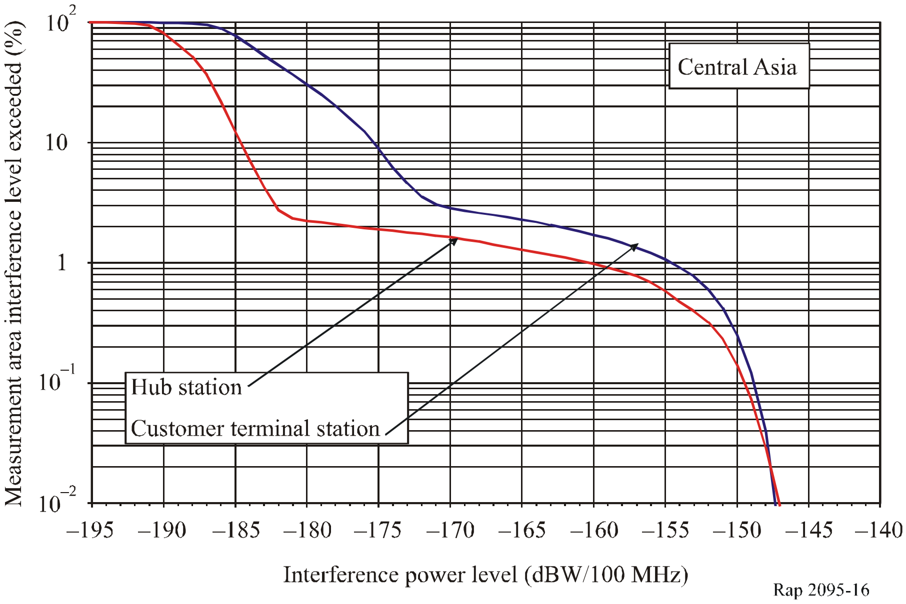

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TABLE 10

Results of the dynamic analysis as in Figs. 15 and 16

	Australia		**Central Asia**	
	Hub only	**Customer only**	**Hub only**	**Customer only**
Interference level exceeded over 0.1% of area (dBW/100 MHz)	–154.7	–153.8	–149.4	–148.7
Polarization mismatch(1)	–2		–2	
Permissible interference level (dBW/100 MHz)	–156		–156	
Excess over permissible level (dBW/100 MHz)	–0.7	0.2	4.6	5.3

(1) The polarization mismatch factor accounts for the loss in received energy from the interference coming from the sidelobes of the FS antenna which does not have a well defined sense of polarization into the polarized passive sensor main beam which has a high degree of cross-polarization rejection.

4.5 Simulation study number 4

This study analyzes the situation between mobile systems and EESS (passive) radiometers in this band.

Assumptions of sharing studies are shown in the Tables 1 and 4. As for the EESS (passive) parameters, AMSR-E parameters were used and MS-2 parameters in Table 4, the highest power application which is currently reported to be used in the world, were used for the mobile system. Simulations were conducted for one month with a time increment of 0.5 s. Other parameters used in the simulations are listed in the Table 11. Here, interference into the passive stations is evaluated under free space propagation conditions, and an additional loss due to the atmospheric (gaseous) absorption was not included.

TABLE 11

Parameters of mobile service stations used for the simulation

Parameter	**Value**
Elevation angle (degrees)	–90~90
Azimuth direction (degrees)	0~360 (Note 1)
Number of stations	49 (Note 2)
Distribution	Uniform
Activity factor	See Table 12

NOTE 1 – Azimuth direction of each station is random in 360°.

NOTE 2 – The number of stations is assumed to be in proportion to the population of each area in the measurement area, using the number of the stations in the country (See Fig. 17).

NOTE 3 – This is derived based upon statistics of utilization of mobile service stations in Japan. It is the ratio of station operating hours in the 36-37 GHz band during the year to the total number of hours in a year.

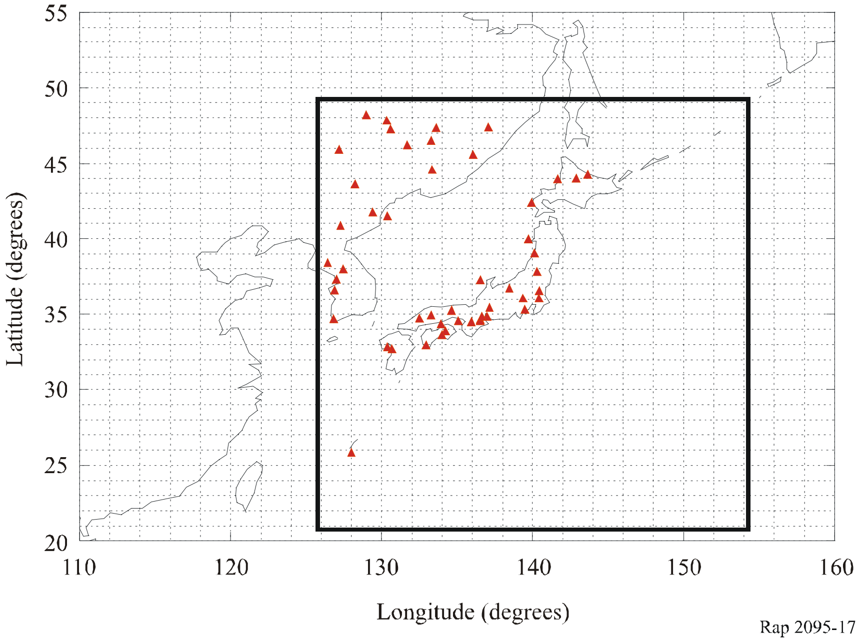
TABLE 12

Numbers of mobile service stations for various activity factors

Activity factor (%)	Total number of mobile service stations
2	1
2.97	2
10	5
20	10
50	25
100	49

FIGURE 17

Deployment of mobile stations
(Activity factor 100%, 49 stations)



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Results of the simulation study are shown in Fig. 18. This figure shows that interference time rate of the EESS (passive) sensor as the CDF of interference level for various activity factors listed in Table 12.

Figure 19, which is obtained from Fig. 18, shows the CDF interference level as the function of the activity factor for the interference level. The simulation results are not exactly on a straight line, because the distribution of mobile service stations was randomly taken for each activity factor and the direction of the antenna of each mobile service stations is also randomly taken. Approximate straight line indicated in Fig. 19 shows that the activity factor 60% meets the permissible interference level of –156 dBW/100 MHz and 20% meets the permissible interference level of –166 dBW/100 MHz.

FIGURE 18

Interference CDF curves for various activity factors

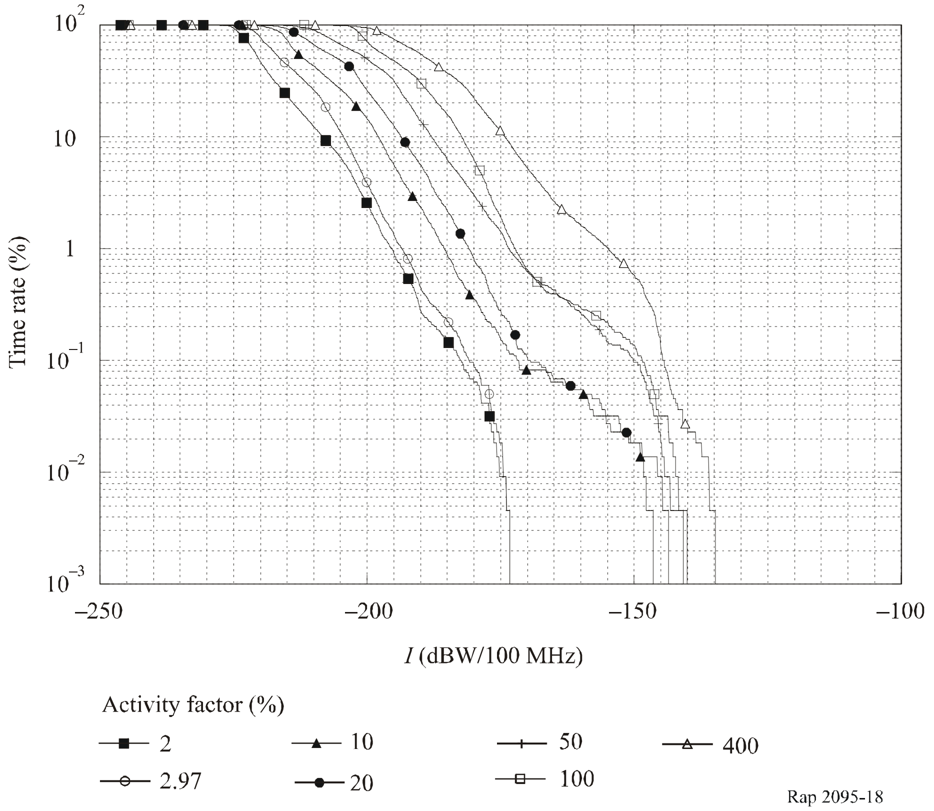
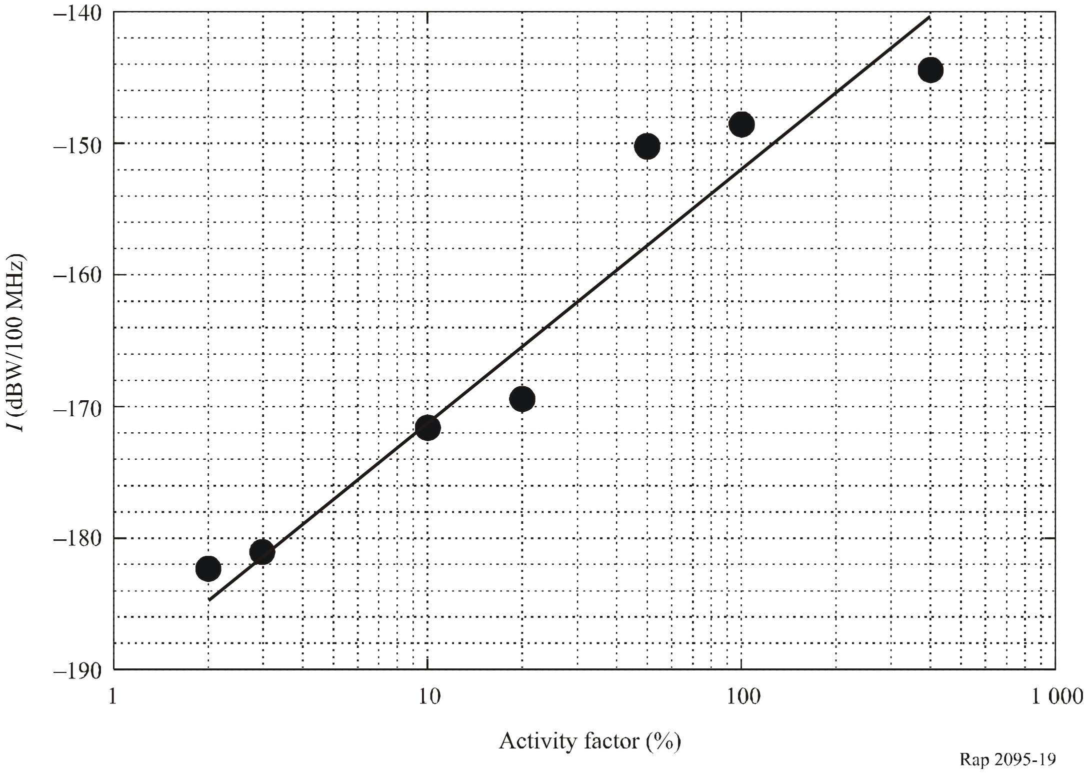


FIGURE 19

Activity factors and interference level for interference time percentage 0.1 %



4.6 Summary of sharing study results

4.6.1 Sharing between the FS and the EESS (passive)

Each of the preceding studies compared the interference level received by the EESS (passive) receiver with the permissible interference levels specified in Recommendation ITU-R RS.1029. However, in evaluating the results of these studies, several additional factors have to be taken into account.

First, all of the simulations calculate the interference received by the passive sensor as the average power integrated by the radiometer. Thus, the value of FS transmitter powers assumed in the dynamic simulations should be interpreted as average or mean power levels. However, regulatory limits are typically specified in terms of peak power levels, which are 2 to 4 dB above the average (mean) level for digital transmissions. Second, passive sensor antenna beams are linearly polarized with a high level of polarization purity, while FS interference typically comes from the side-lobe or back-lobe of the station which has little if any defined sense of polarization. This factor, which would reduce calculated interference levels by 2 to 3 dB, has generally not been included in the interference calculations.

Finally, in two simulations based on FS stations in the 36-37 GHz band, it was shown that the passive sensor interference level calculated with the actual power levels was 3.8-6.4 dB below the interference level at the 0.1% CDF level calculated on the assumption that every station transmitted at the maximum power level.

The summaries of the simulation studies use the CDFs of the passive sensor interference developed by the dynamic simulations to determine the maximum FS power that would just satisfy the permissible interference criteria of Recommendation ITU-R RS.1029 if all FS stations operated at the same power level. Taking into account the three factors described above, the power levels used in setting any recommended limit specified as peak transmit powers to be applied as a regulatory measure would be equivalent to applying an average power that was 7.8 to 13.4 dB less than these permissible transmit power levels determined by adjusting the interference CDFs obtained from the dynamic simulations.

Table 13 summarizes the sharing studies described above. For each simulation study, the first two columns are used to identify the type of FS station considered in the simulation and the FS transmitter power assumed for each station in the FS deployment model. In some of these studies, dynamic simulations were conducted over a range of different FS deployment densities based on the number of major cities in different assumed measurement areas and the number of radio channels available within each city based on ITU-R channel plans. The lowest and highest FS station densities used in the simulations included in each study are indicated in Table 13. Each dynamic simulation produced a CDF of the interference received by the passive sensor, I_{EESS}. The level of I_{EESS} exceeded over 0.1% of a passive sensor measurement area is indicated in Table 13, or, in the case where simulations were conducted over a range of FS station deployment densities, the lowest and highest values of I_{EESS} at 0.1%. Table 13 also identifies the highest and lowest calculated FS transmitter powers that would just satisfy the –166 dBW permissible interference criteria of Recommendation ITU-R RS.1029 for currently operational passive sensors that correspond to the lowest and highest values passive sensor interference levels obtained from the simulation CDFs. Two correction factors, one for polarization mismatch (2-3 dB) and another for the distribution of power levels (3.8-6.4 dB) are discussed below. These factors are applicable to using the interference CDF developed by these dynamic simulations to develop any possible sharing criteria. The rightmost columns of Table 13 indicate the range of calculated permissible FS power levels for each simulation case, with the lowest value corresponding to the lowest adjusted FS transmit level and smallest combined correction factor of 5.8 dB and the highest value corresponding to the highest adjusted FS transmit level and the largest combined correction factor of 9.4 dB. It should also be noted that all of the power levels used in Table 13 are average or mean power levels that are integrated by the passive sensor radiometer during each measurement, and that a further correction factor is discussed in § 4 if sharing criteria are to be developed in terms of peak power levels.

It should be noted that licensed data from two administrations indicate current FS deployment densities between about 1 000 and 2 500 per 10^7 km^2 in the 80 MHz of spectrum at 10.6-10.68 GHz. For the 1 000 MHz of spectrum in the 36-37 GHz band, an equivalent level of deployment would be about 10 times higher than the number of FS stations assumed in the simulations summarized in Table 13.

TABLE 13

Summary results of 36 GHz simulation studies

36-37 GHz Simulation study number	**Station type**	**Transmitter power (dBW)**	**Station density (station/10^7km^2)**	**I_{EESS} at 0.1%_(dBW)**	**Maximum pt (dBW) to satisfy Rec. ITU-R RS.1029**	**Maximum (dBW) with correction factors as in § 4.6**
1 – MADRAS	P-P	–10	200	–166	–10	–4.2 to –0.6
1 – AMSR-E	P-P	–10	200	–172	–4	1.8 to 5.4
1 – CMIS	P-P	–10	200	–152	–24	–18.2 to –14.6
2	FS-2	–11	130 to 2 640	–160 to –152 (2)	–17 to –25	–19.2 to –7.6
3 – P-P City	FS-2	–10	32 to 3 534	–162.3 to –148.5 (2)	–13.7 to –27.5	–21.7 to –4.3
3 – P-P Random	FS-2	–10	32 to 3 534	–162.6 to –157.6 (2)	–13.4 to –18.4	–12.6 to –4
3 – P-MP City	Hub	–5	32 or 248	–154.7 or –149.4 (2)	–16.3 to –21.6	–15.8 to –6.9
3 – P-MP City	Customer	–10	256 or 1 984	–149.4 or –148.7 (2)	–26.6 to –27.3	–21.5 to –17.2
4 – AMSR-E	Mobile	–3	2 (activity factor 2.97%)	–180.9	11.9	17.7 to 21.3
4 – AMSR-E	Mobile	–3	10 (activity factor 20%)	–169.5	0.5	6.3 to 9.9
4 – AMSR-E	Mobile	–3	49 (activity factor 100%)	–149.5	–19.5	–13.7 to –10.1

NOTES: Recommendation ITU-R RS.1029 Criteria = –166 dBW/100 MHz

(1) Range of FS stations per city throughout world scaled to average 10^7 km^2 area

(2) Range of FS stations per city and number of cities in different measurement areas

(3) All transmitter powers are “mean” values for FS and “peak” values for MS

In several cases, the permissible power levels indicated in the rightmost columns exceed the FS power level assumed for the simulation study, and it can be concluded that compatibility between the FS and EESS (passive) has been demonstrated for these cases. For those cases where the indicated permissible power levels are below the assumed values, the interference CDF produced by the simulations were examined to determine the impact on the EESS (passive) in terms of the percentage of the measurement area over which the permissible interference power level of –166 dBW is exceeded if the FS transmitter power were to be limited to the value assumed for the simulations. These results are presented in Table 14.

TABLE 14

Percentage of measurement area exceeding permissible interference power level

36-37 GHz Simulation study number	Station type	Transmitter power (dBW)	Station density (station/10^7 km^2)		Measurement area exceeding –166 dBW(1) (%)	
1 – MADRAS	P-P	–10	200	---	< 0.1	---
1 – AMSR-E	P-P	–10	200	---	< 0.1	---
1 – CMIS	P-P	–10	200	---	0.3	---
2	FS-2	–11	130	2 640	< 0.1	3
3 – P-P City	FS-2	–10	32	3 534	< 0.1	2.5
3 – P-P Random	FS-2	–10	32	3 534	< 0.1	2
3 – P-MP City	Hub	–5	32	248	0.23	1
3 – P-MP City	Customer	–10	256	1 984	0.28	1.5
4 – AMSR-E	Mobile	–3	2 (activity factor 2.97%)	---	< 0.1	---
4 – AMSR-E	Mobile	–3	10 (activity factor 20%)	---	< 0.1	---
4 – AMSR-E	Mobile	–3	49 (activity factor 100%)	---	< 0.4	---

(1) Including 5.8 dB correction for polarization mismatch and distribution of powers.

4.6.2 Sharing between the MS and the EESS (passive)

In the sharing study, two types of the MS systems were considered; the first one was the case of the MS-2 systems which are used mainly for video transmission in nomadic applications and its activity factor is relatively low, and the other one was the case of the MS-3 systems which are similar to fixed stations and are used for government applications. The simulation results were included in Table 13 in § 4.6.1.

Under the latter case, the result is same as the FS in § 4.6.1.

In the former case, which is dealt in the simulation study number 4 in § 4.5, sharing is possible with higher power level than the fixed use because of its relatively low activity factor.

The simulation results shows that sharing is possible at the existing system's highest power level of –3 dBW and the activity factor of 20%.

However, for the mobile case, if the mitigation factors which are not included in the simulation study number 4 were considered, are similar to the FS in the previous section.

– Difference between polarizations of EESS (passive) and mobile stations (2-3 dB).

– Difference between peak power and average receiving power of EESS (passive) (2-4 dB).

According to Fig. 19, the activity factor up to 40%, satisfies the permissible interference level of –166 dBW/100 MHz.

5 Mitigation techniques

5.1 EESS (passive)

Current and future passive sensors integrate the signal received at the satellite and it is not possible to differentiate between the natural and the artificial emissions. If interference exceeds permissible levels, there is a risk to get corrupted measurements from several areas that may impact reliable weather forecasts or other scientific applications using the sensor data products. There are no proven techniques for identifying passive sensor measurements corrupted by interference and mitigating the impact of such corrupted measurements on weather predictions or other scientific studies using this data.

Consequently, mitigation techniques applicable to the EESS (passive) focus on approaches that may reduce the interference level received at the satellite.

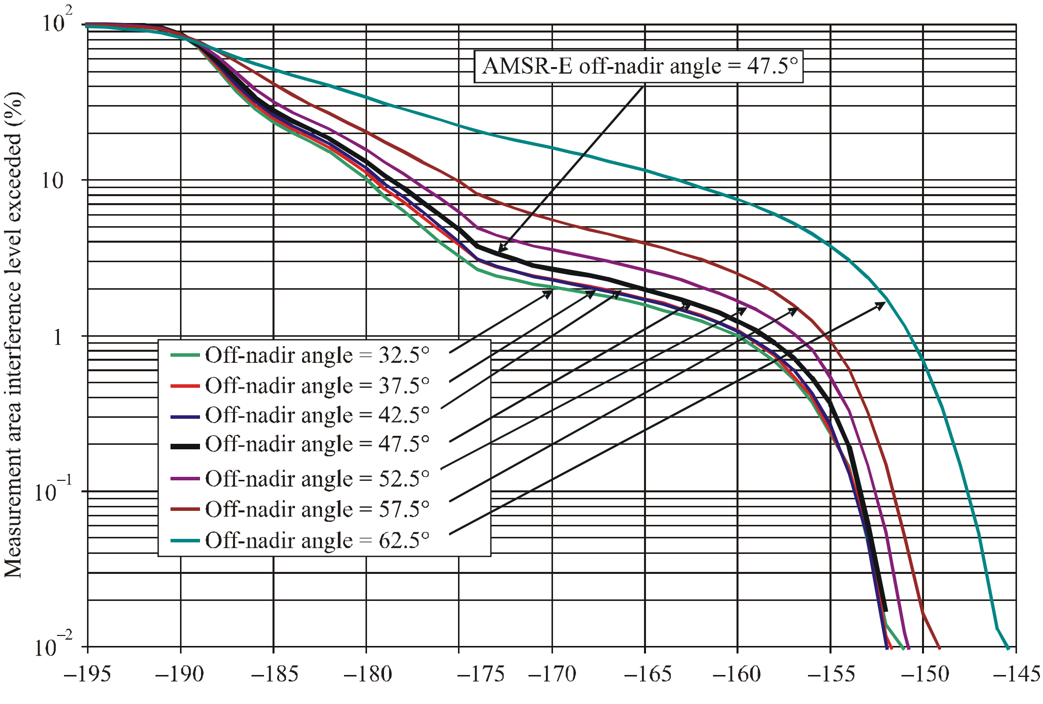
The following technical and operational characteristics of an EESS (passive) instrument were considered and evaluated as possible approaches to mitigate or minimize the chance of interference:

- A limitation on the maximum incidence angle controls the amplitude of the direct coupling between the terrestrial active services and the EESS (passive) receiver. However, reducing the off-nadir pointing angles of conical scanning passive sensors below current design values does not significantly reduce interference levels.
- A requirement for a minimum main beam efficiency directly controls the shape of the antenna pattern and will enable a decrease of interference power received outside the main beam region.
- A limit on the spatial resolution could decrease the likelihood of interferers, or the number thereof, within a certain pixel of the EESS (passive) instrument.
- Improved EESS (passive) antenna side-lobe performance may decrease interference levels. For example, a comparison between the reference antenna pattern under development for EESS (passive) and a FSS antenna pattern, specified in Recommendation ITU-R S.672 – Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites, shows that reduction of a side-lobe level leads to smaller interference percentage.

The main beam of conically scanned passive sensors intersect the Earth's surface at a constant elevation angle that is determined by the satellite altitude and the off-nadir pointing angle of the receiving antenna. To examine the impact of such FS elevation angle variations, one of the previously reported simulation models for the AMSR-E passive sensor was re-run for a range of passive sensor off-nadir pointing angles. The results of these simulations are presented in Fig. 20.

FIGURE 20

Interference results based on variations in EESS off-nadir angle



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5.2 FS

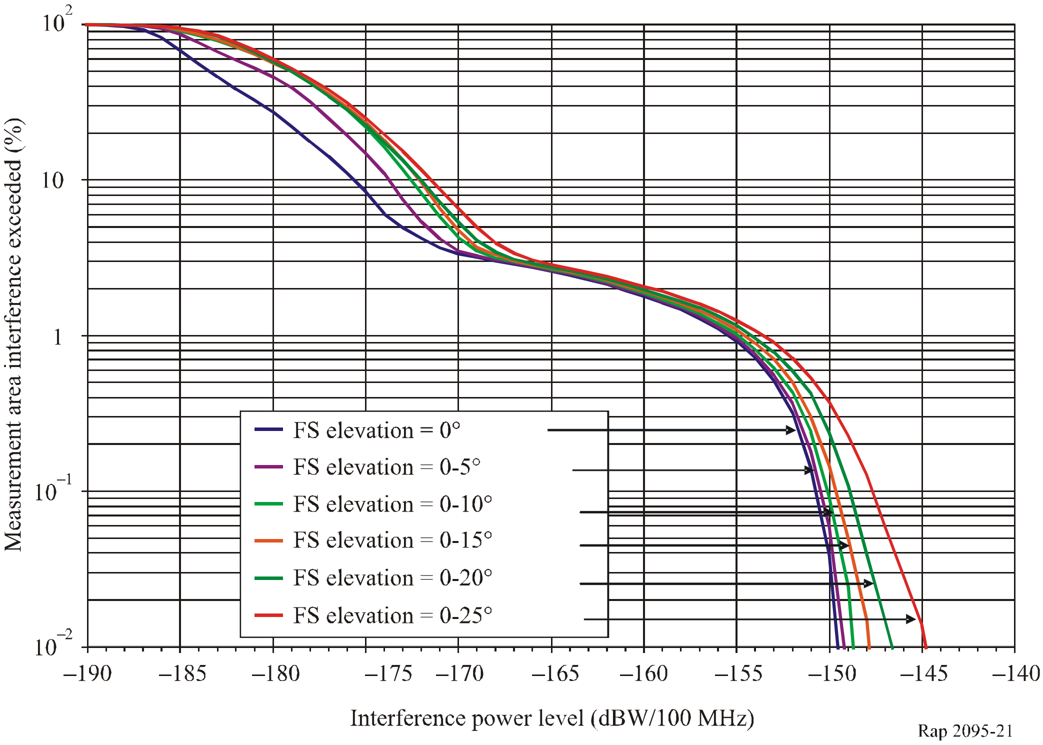
The following technical and operational characteristics of an FS station were considered and evaluated as possible approaches to mitigate or to minimize the chance of interference as FS operations are implemented in this band:

- A limit on the maximum FS station e.i.r.p..
- A requirement on the maximum elevation angle of an FS station main beam; however, for a uniform distribution of FS elevation angles, which is an unfavourably unrealistic distribution for sharing studies, the interference levels into a conical scanning passive sensor do not increase significantly until the upper limit on FS elevation angle exceeds about 20°.
- A requirement to set the FS transmit power to the value that provides the desired received signal level under clear sky conditions with a specified fade margin; this approach can significantly reduce interference levels into a passive sensor.

Previous interference simulations have generally assumed that all FS transmitters operate at a 0° elevation angle. However, some variation in FS elevation angle is expected among real FS systems. To examine the impact of such FS elevation angle variations, one of the previously reported simulation models based on 0° FS elevation angles was re-run with each FS station randomly assigned an elevation angle based on a uniform distribution of elevation angles between 0° and an upper limit of 5° to 25°. A uniform distribution of FS elevation angles was assumed in these simulations for simplicity, although actual FS elevation angle distributions are more likely to be Gaussian in nature. The results of these simulations are presented in Fig. 21.

FIGURE 21

Interference results based on variations in FS elevation angles



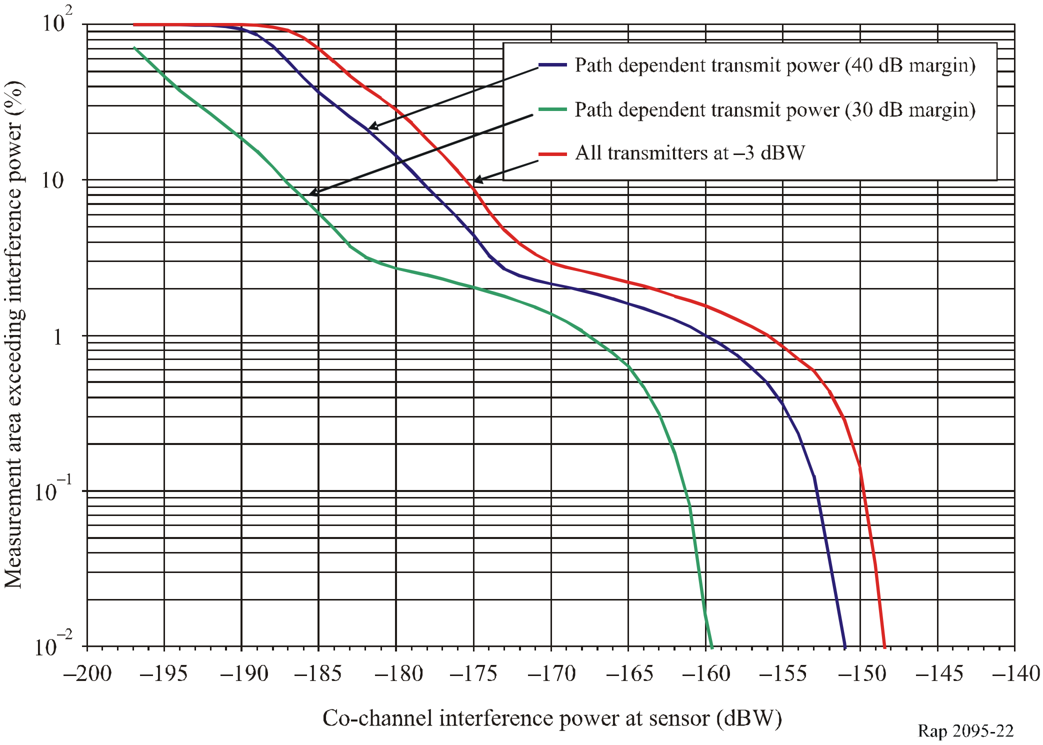
NOTE 1 – Although these studies considered FS elevation angles up to 25° in order to identify the elevation angle at which in the interference level significantly increases, FS elevations above 5° are rare in actual operating systems.

Previous interference simulations have generally assumed that all FS transmitters operate at the same power. However, examination of some license records in other FS bands indicate a variation of authorized transmitter powers. One basis for transmitter power variation could be differences in radio-link path lengths.

A simulation model was constructed that assigned P-P FS station transmit powers at levels that just provided a specified receive level under free space propagation conditions. The specified receive level included fade margins of 30 and 40 dB. Fig. 22 illustrates the impact on the passive sensor interference levels of employing this technique to assign transmit power levels compared to the case where all transmitters are assumed to operate at the same maximum transmit power level.

FIGURE 22

Interference results based on path length dependent transmit powers



5.3 MS

For the nomadic use of the MS systems, a limit on the maximum MS station was considered and evaluated as possible approach to mitigate or to minimize the chance of interference as MS operations are implemented in this band. Sections 4.5 and 4.6.2 provide detailed discussions of this mitigation approach.

For the MS applications that have similar characteristics to those of P-P FS systems, the mitigation considerations discussed in § 5.2 apply to these MS applications.

6 Summary and conclusions

This report presents the results of several simulation studies to evaluate the potential interference levels that might be received by EESS (passive) receivers in the 36-37 GHz band from several types of FS stations. Section 4.6 summarizes the results of these studies. Table 13 identifies the range of FS and MS power levels that would satisfy the criteria of Recommendation ITU-R RS.1029 for the various FS and MS deployment models and EESS passive sensors considered in the studies. Table 14 indicates the percentage of the passive sensor measurement area over which the passive sensor permissible interference level of Recommendation ITU-R RS.1029 would be exceeded for the FS and MS power levels assumed in the studies.

Several simulation studies were also performed to characterize the interference levels received by passive sensors operating in the 36-37 GHz band and to assess the sensitivity of these interference levels to changes in system parameters to assess the effectiveness of possible mitigation approaches.

A number of technical and operational characteristics of EESS (passive) sensors and FS and MS systems were considered and evaluated as possible approaches to mitigate or minimize the level of interference. Table 15 identifies possible limits on the technical and operational characteristics of these systems that can facilitate the sharing of the 36-37 GHz band between EESS (passive) and the FS and MS.

TABLE 15

Possible sharing criteria in the band 36-37 GHz

EESS (passive)	FS	MS
Incidence angle ≤ 60°, where the incidence angle is defined as the angle at the Earth's surface between the local vertical and the centre of the passive sensor antenna beam	Elevation angle range ≤ 20°	
Spatial resolution ≤ 50 km, where the spatial resolution is defined as the maximum cross-section of the passive sensor –3 dB contour on the Earth's surface	Maximum P-P transmitter power ≤ –10 dBW Maximum P-MP transmitter power: ≤ –5 dBW hub stations ≤ –10 dBW customer stations	Maximum transmitter power ≤ –10 dBW Maximum transmitter power ≤ –3 dBW (if activity factor less than 40 %)
Main beam efficiency ≥ 92 %, where the main beam efficiency is defined as the energy (main and cross-polarization components) within 2.5 times the –3 dB beamwidth region, relative to the total energy within all angles	Maximum P-MP hub station e.i.r.p. ≤ +12 dBW	

Each of the individual entries in Table 15, such as maximum power, is based on simulations that assume that no mitigation techniques are applied by the active service. The limits indicated in Table 15 may be relaxed if mitigation techniques are applied. Possible mitigation techniques include flexible power setting (power level control (ATPC)) to mitigate fading and use of high performance directional antennas. In the case of FS P-P systems using ATPC, the maximum transmitter power limit may be increased by the corresponding amount of ATPC employed by the system. The interference levels to EESS (passive) indicated by the results of simulation studies using the values indicated in Table 15 exceed the permissible interference criteria of Recommendation ITU-R RS.1029 for some of the deployment models considered in the sharing studies. Nevertheless, such a result is considered acceptable for EESS (passive) systems in view of the need to find an equitable burden sharing in establishing sharing criteria for the services sharing this band.

7 Supporting documents

[1] Recommendation ITU-R RS.1803: Technical and operational characteristics of passive sensors in the Earth exploration-satellite (passive) and space research (passive) services to facilitate sharing with the fixed and mobile services in the 10.6-10.68 GHz and 36-37 GHz bands.