REPORT ITU-R RS.2096

Sharing of the 10.6-10.68 GHz band by the fixed and mobile services and the Earth exploration-satellite service (passive)

(2007)

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1   Introduction

The purpose of this Report is to summarize the results of the studies related to sharing of the 10.6-10.68 GHz band by the fixed and mobile services and the Earth exploration-satellite service (EESS) (passive).

2   EESS (passive)

2.1   Applications

The band 10.6-10.7 GHz is of primary interest to measure rain, snow, sea state and ocean wind for ocean and land surfaces. This frequency band is considered as an all-weather region suitable for using multispectral systems to establish surface material properties.

–   Over land surfaces, the measurements performed at 10 GHz are suitable to estimate vegetation biomass once the soil moisture contribution is known.

–   Over sea surfaces, the band at 10 GHz is adequate for measuring the sea surface and wind speed. In particular, measurements at 10 GHz providing wind speed measurements are essential to get accurate knowledge of sea surface temperature using the 6 GHz data offering the best sensitivity to sea surface temperature.

A number of sensors are already using or are planning to use this frequency band in the near future for such measurements. These measurements are fully operational (regular use of the data, continuity of service, several usable data products) and are used on a worldwide basis. The retrieved data are used and exchanged between the meteorological organizations in all regions. It is to be noted that the retrieved parameters are actually derived from a set of measurements performed at five frequencies which are interrelated (6, 10, 18, 24 and 36.5 GHz).

2.2   Passive sensor parameters

Table 1 summarizes the parameters of conical scanning passive sensors that are or will be operating in the 10.6-10.68 GHz band as illustrated in Fig. 1.

TABLE 1

Passive sensor parameters

Channel 10.6-10.7 GHz	SENSOR 1 10 GHz	AMSR-E	CMIS
Channel bandwidth (MHz)	100	100	100
Pixel size across track (km)	56.7	27.5	42.9
Offset angle to the nadir or half-cone angle α (degrees)	44.3	47.5	48.6
Incidence angle i at footprint centre (degrees)	52	55	58.1
Polarization	H, V	H, V	H, V, R, L
Altitude of the satellite (km)	817	705	833
Maximum antenna gain (dBi)	36	42	45
Reflector diameter (m)	0.9	1.6	2.2
Useful swath (km)	1 594	1 450	1 893
Half-power antenna beam width $\theta 3$ dB (degrees)	2.66	1.4	1.02
Scan rate in rpm (rounds per minute)	20	40	31.6

H: horizontal　　　V: vertical　　　R: right　　　L: left

FIGURE 1

Geometry of conical scan passive microwave radiometers
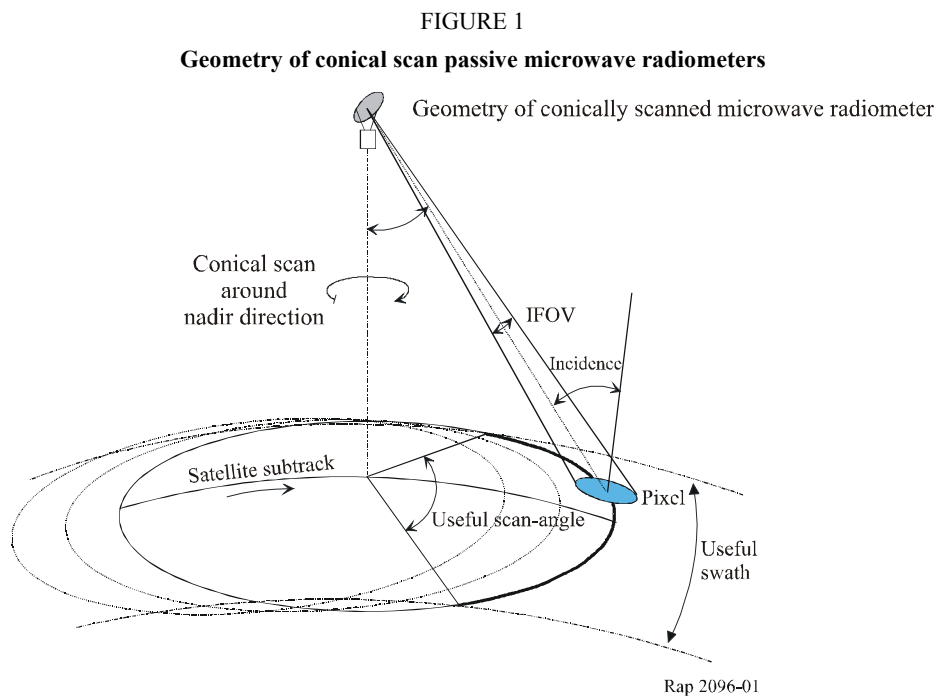
The antennas of passive sensors are modelled according to the following Figs. 2 to 4.
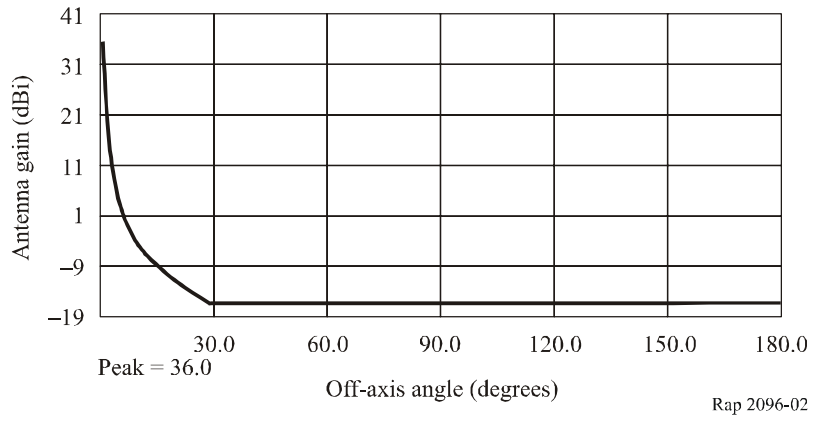
FIGURE 2

SENSOR-1 antenna gain pattern at 10.6 GHz

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FIGURE 3

AMSR-E antenna gain pattern at 10.6 GHz
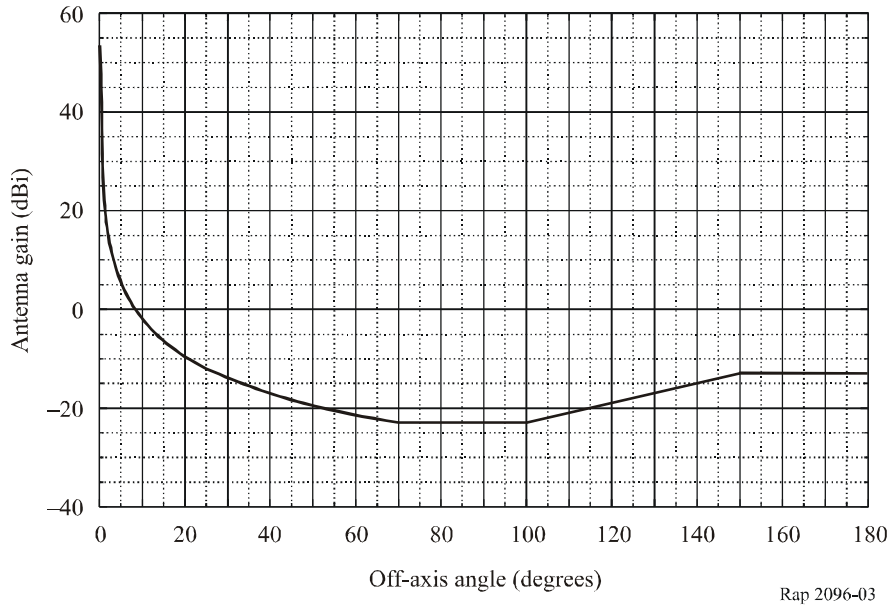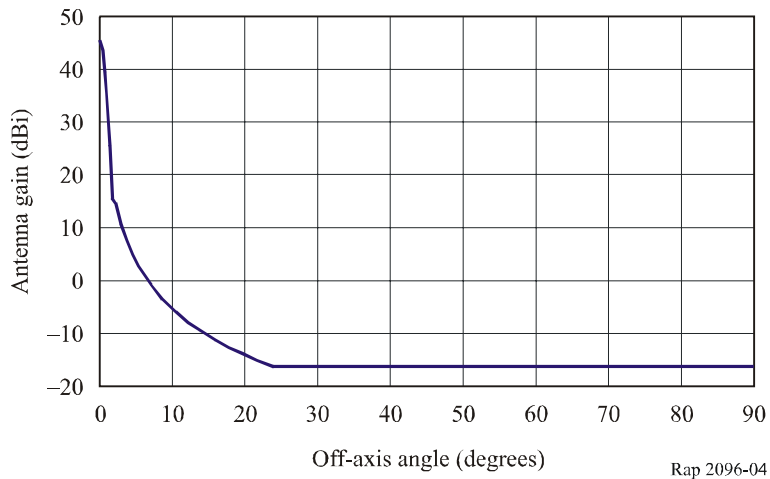

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FIGURE 4

CMIS antenna gain pattern at 10.6 GHz

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2.3 Permissible 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 10.6-10.7 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.

2.4 Current radio frequency interference in the 10.6-10.68 GHz

On a general basis, low levels of interference received at the input of passive sensors would degrade passive sensor operations acknowledging that, in particular, the sensors are not able to discriminate between these natural radiations and man-made radiations.

On the other hand, when levels of interference are very high, at several order of magnitude compared to the sensitivity, the corresponding levels may be detected as not natural and have to be disregarded.

Figure 5 is a global composite image of radio-frequency interference (RFI) in different microwave frequencies derived from one month of AMSR-E sensor data (August 2004) (yellow is the 6-7 GHz and red 10.6 GHz).

FIGURE 5

Radio frequency interference to AMSR-E passive sensor in the 6-7 GHz and 10.6 GHz bands

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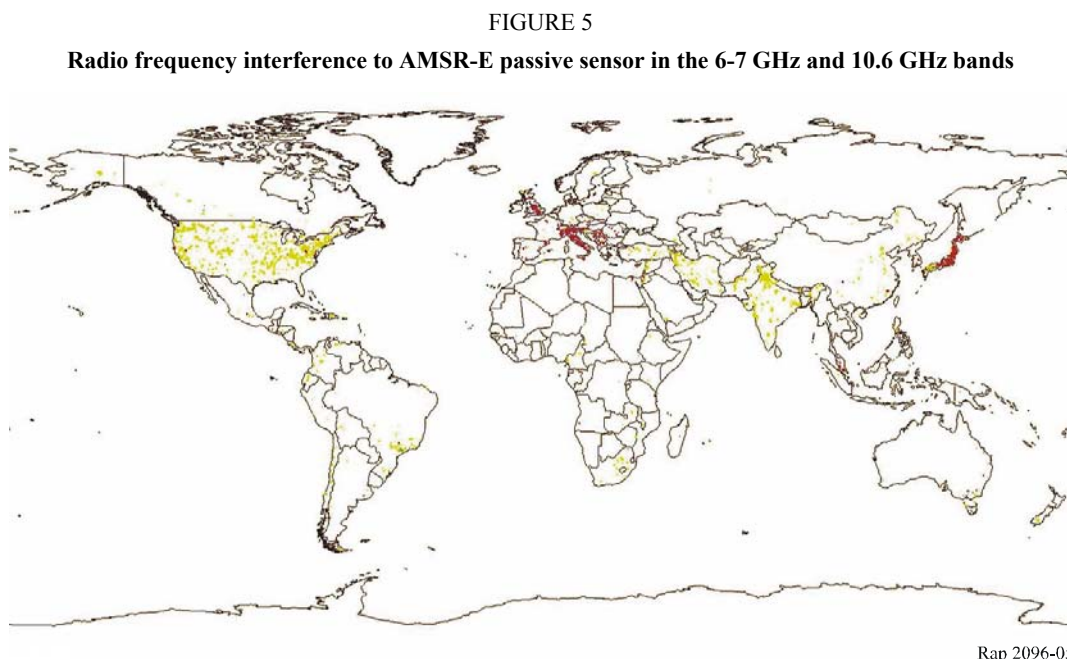
This figure is based on the analysis of both passive sensor measurements on the horizontal and vertical polarization for which a negative polarization differences (i.e. the difference between H and V polarizations) criteria of 5 K is used. Indeed, it is recognized that negative polarization higher than 5 K can only occur at these wavelengths through man-made emissions in H-polarization.

It should be noted that this figure only shows one form of interference (horizontal polarization emissions) and, overall, fails to show how extensive undetectable interference are. However it is reasonable to assume that in regions of extensive detectable RFI, it is likely to find larger areas of undetectable interference. Such detectable interference at high levels is therefore a symptom of a problem, but absence of detectable RFI does not imply that there is not a problem.

With regard to the potential interference level, acknowledging that these figures are presenting negative polarizations higher than 5 K, one can assume that, roughly, interference are, at a minimum, also higher than these 5 K (corresponding to −142 dBW/100 MHz).

Considering the current interference threshold as given in Recommendation ITU-R RS.1029 (i.e. 166 dBW/100 MHz corresponding to 0.02 K), it shows that these interferences are at least 24 dB above the threshold.

In addition, Recommendation ITU-R RS.1029 also provides, for 10.6-10.7 GHz, a 0.1% percentage of area permissible interference level may be exceeded over a 10 000 000 km^2 measurement area. Roughly considering the current impacted areas, one can show that the highly contaminated area already corresponds to 2.8%, also exceeding by far the area criteria (0.1%), stressing that other areas are contaminated without being detectable and are hence not considered in this estimation.

In case of such interference, the assimilation models would have to cope with the following situation that would lead to corrupted meteorological forecasts:

–   high level of interference, hence detectable, that would have to be disregarded but would hence lead to a lack of data over certain area;

–   undetectable levels of interference, more than likely to occur over large area, that would hence lead to corrupted data;

–   pixels for which no interference or interference below Recommendation ITU-R RS.1029 threshold would be experienced, hence providing correct data,

further noting that the situation pertaining to the last two bullets will not be discriminated.

3   Fixed and mobile service parameters

3.1   Fixed service

Tables 2 and 3 provide parameters of point-to-point (P-P) and point-to-multipoint (P-MP) FS systems, respectively, that were used in these compatibility studies.

The band 10.6-10.68 GHz is used in France only by fixed wireless equipments in case of rupture of backhaul and repairs of FS links in other bands. This use is therefore limited and temporary. The last column of Table 2 provides the characteristics of these emergency P-P FS links.

TABLE 2

Operating parameters of P-P fixed link equipment in the 10.6-10.68 GHz band

Source	Recommendation ITU-R F.758			Administration contributions		
Modulation	128-TM			ASK, PESKY	ASK, PESKY	4-PESKY
FS Simulation case[1]	1	2	3	4	5	6
Capacity (Mbit/s)	3.1	12.4	24.7	8	16	34
Channel spacing (MHz)	0.8	2.5	5	7	14	14
Channels/80 MHz	100	32	16	12	6	6
Antenna gain (maximum) (dBi)	51	51	51	49	49	36-45
Feeder/multiplexer loss (minimum) (dB)	0	0	0	0	0	4
Antenna type	Dish	Dish	Dish	Dish	Dish	Dish
Maximum TX output power (dBW)	−3	−3	−3	−2[2]	−2[2]	−7
e.i.r.p. (maximum) (dBW)	48[2]	48[2]	48[2]	47[2]	47[2]	34
Receiver IF bandwidth (MHz)	0.8	2.5	5	7	14	20.4
Receiver noise figure (dB)	4	4	4	3	3	8
Receiver thermal noise (dBW)	−141	−136	−133	−132.5	−129.5	−113
Nominal Rx input level (dBW)	−60	−60	−60	−60	−60	−68
Rx input level for 1×10^{-3} BER (dBW)	−110	−104	−101	−117	−114	−108

[1]   This table entry is used as a reference later in this Report in the description of certain simulation studies.

[2]   Except in certain specified countries, RR No. 5.482 limits the e.i.r.p. to 40 dBW and transmitter power to −3 dBW absent agreement under RR No. 9.21. Simulations run using the RR No. 5.482 power limits would result in interference levels 7-8 dB lower than those indicated in Fig. 7.

TABLE 3

Operating parameters of P-MP fixed link equipment in the 10.6-10.68 GHz band

Parameter	Central (hub) station	Customer terminal station
Modulation	QPSK	
Access method	Time division multiplex (TDM)	
Bandwidth/carrier	3.5 MHz	3.5 MHz
Antenna type	Sectoral antenna	Dish
Antenna gain (dBi)	13, backlobe −10 dBi	19-26
Antenna beamwidth	120°	12°-7°
Number of active carriers/sector	5	5
Number of sectors	3	-
Path length (km)[1]	0.1-10	
Maximum transmit power per carrier (dBW)	−10	−10
Power control	No	Yes
Receiving system line loss (dB)	0	0
Nominal receiver input level/carrier (dBW)	−110	−110

[1]   Path lengths greater than 10 km are possible depending on environmental blockage factors.

P-MP systems in this band are predominantly deployed in urban and suburban areas, with few if any systems in rural areas. Given the radio-frequency block arrangements in Recommendation ITU-R F.1568, i.e. five block pairs, two of which overlap the band 10.6-10.68 GHz, and a typical wireless access cell radius of up to 10 km, one might expect a maximum of two wireless access networks operating in a given major urban/suburban area. According to the radio frequency channel arrangement, each block can have a bandwidth up to 25 or 30 MHz. In addition, the maximum number of terminal stations may be of the order of 300. The terminal and hub stations for these systems would not both be transmitting in the band 10.6-10.68 GHz, given that the majority of P-MP systems will likely employ frequency division duplex (FDD) techniques.

Antenna gain and beamwidths for P-MP terminal stations in this band are in the range 19-26 dBi, with 12° to 7° beamwidths. A typical terminal station antenna height in this band would be 20 m above ground level (rooftop mounts). This implies that a typical hub station antenna down-tilt angle will be of the order of 4° or less, below the horizontal plane.

Consequently, three P-MP deployment configurations are possible for any urban/suburban area:

–   Each of the two hub stations in a city area operates on one of the two frequency blocks falling within the passive sensor bandwidth.

–   One hub station operates on one of the frequency blocks falling within the passive sensor bandwidth, and 150 customer terminal stations operate on the other frequency block.

–   No hub station operates on the frequency blocks falling within the passive sensor bandwidth, but the 150 customer terminal stations associated with each of the two hub stations do operate within the passive sensor band, for a total of 300 interfering transmitters for the city area.

Customer terminal antenna gain and beamwidths for P-MP terminal stations in this band are in the range 19-26 dBi, with 12° to 7° beamwidths. A typical terminal station antenna height in this band would be 20 m above ground level (rooftop mounts). This implies that a typical hub station antenna down-tilt angle will be of the order of 4° or less, below the horizontal plane.

3.2   Mobile service

Technical characteristics of mobile systems operating in the band 10.6-10.68 GHz are shown in Table 4. This band is especially used for occasional temporary P-P video links (including electronic news gathering, television outside broadcast and electronic field production), which may be considered as part of the mobile service. 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.

4   Simulation studies

4.1   General simulation methodology

The current 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 square kilometre 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.

TABLE 4

Frequency band	10.6-10.68 GHz			
ARIB standard	STD-B33	STD-B33	STD-B11	Usage of omnidirectional antenna
Channel spacing (MHz)	9 (SDTV)	18 (HDTV)	18 (HDTV)	18
Capacity (payload) (Mbit/s)	Up to 30	Up to 60	Up to 66	Not available
Modulation	QPSK-OFDM 16-QAM-OFDM 32-QAM-OFDM 64-QAM-OFDM		QPSK 16-QAM 32-QAM 64-QAM	Not available
Typical transmit antenna gain (dBi)	29-35	29-35	29-35	0
Transmit antenna type	Parabolic	Parabolic	Parabolic	Omni
Transmit power (maximum) (dBW)	−3	−3	−3	-3
EIRP (maximum) (dBW)	40	40	40	-3
Typical receive antenna gain (dBi)	29-35	29-35	29-35	Not available
Receive antenna type	Parabolic	Parabolic	Parabolic	Not available
Receive feeder loss (maximum) (dB)	1	1	1	Not available
Receiver IF bandwidth (MHz)	9	18	18	Not available
Receive noise figure (dB)	4	4	4	Not available
Receiver thermal noise (dBW)	−130.5	−127.4	−127.4	Not available

NOTE 1 – Elevation angles are not specified as the receiving stations are mounted on vehicles, airborne and tall building or tower. This means that the antenna has a possibility to point any elevation angle for avoiding the obstacles on the ground and their transmitting antennas are moving because the receiving antenna has a possibility to be mounted on the vehicles or airborne. Events may take place at any time of the day, with significantly fewer events taking place at night; between about 12 p.m. and 6 a.m. Collections are typically between about 1/2 to 1 hour in duration. However, special event collections may involve durations of between 2 to 5 hours. In some cases operations may be extended over days or even weeks.

NOTE 2 – Some administrations indicate that the band 10.6-10.68 GHz is used by a ENG/TVOB/EFP for mobile and portable application. Most of these corresponding characteristics can be found in Table 4. However, some ENG/OB systems are not represented in these studies and this table, and the technical specifications of these systems can be found within ERC Report 38 (transmitter power of 6 dBW and e.i.r.p. between 6 and 16 dBW) (see Handbook of Radio equipment and systems Video links for ENG/OB usage).

NOTE 3 – Additional information about the digital terrestrial Electronic News Gathering can be seen in the Report ITU-R BT.2069).

4.2 Simulation study number 1

This simulation study is based on the assumption that FS systems are deployed in urban and suburban areas, with few if any systems in rural areas. A number of simulation studies were conducted on the basis of randomly distributing FS stations around cities within the simulation area, with the number of FS stations per city based on a single use of the band in each city area. Figure 6 illustrates six such deployment areas used in the simulations. Information regarding the number of cities associated with each of these measurement areas is provided in Table 5.

FIGURE 6

EESS measurement areas used in simulations
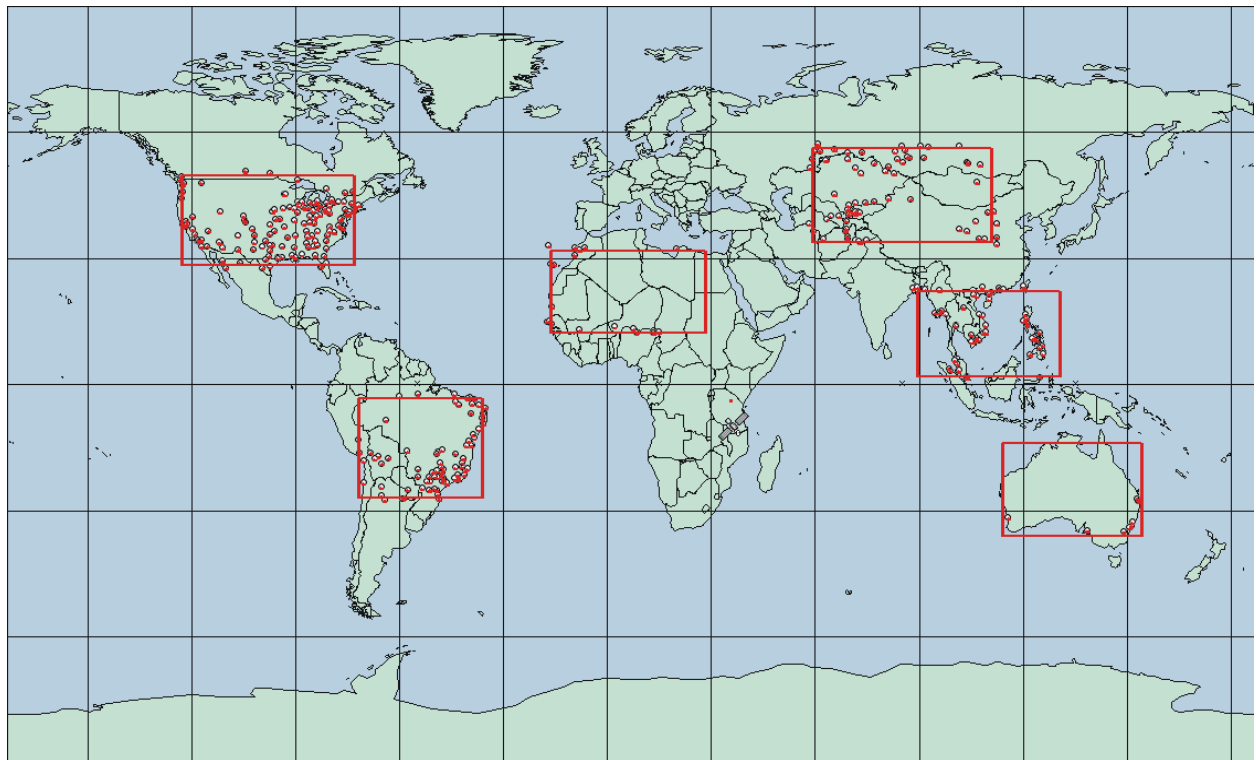
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TABLE 5

Measurement area city densities

Measurement area	Cities in simulation	Cities within measurement area
Australia	8	8
North Africa	18	9
South East Asia	65	50
South America	82	69
Central Asia	74	60
USA mainland	157	142

4.2.1   Point-to-point FS systems

Five types of P-P FS systems were assumed in these simulations. Key parameters of each of the P-P FS systems, and the range of interference over the six measurement areas and two passive sensors are presented in Table 6. The CDFs produced by theses simulations are presented in Fig. 7.

TABLE 6

Results for P-P FS deployment model over six measurement areas and two sensors
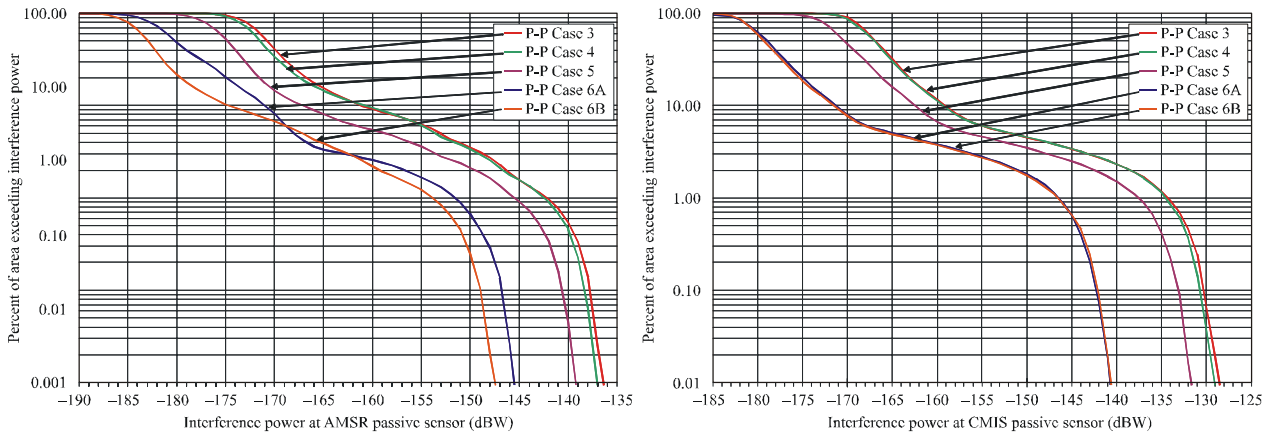
FS system reference	Case-3	Case-4	Case-5	Case-6A	Case-6B
Channel spacing (MHz)	5	7	14	14	14
Number of channels in 80 MHz	16	12	6	6	6
Antenna gain (dBi)	51	49	49	36	45
Feeder/multiplexer loss (dB)	0	0	0	4	4
Transmitter output power (dBW)	−3	−2	−2	−7	−7
e.i.r.p. (dBW)	48	47	47	25	34
Interference power exceeded over 0.1% of measurement area (dBW)	−142 to −131	−142 to −131	−146 to −134	−151 to −142	−151 to −142

FIGURE 7

P-P FS interference into AMSR-E and CMIS passive sensors at 10.6 GHz
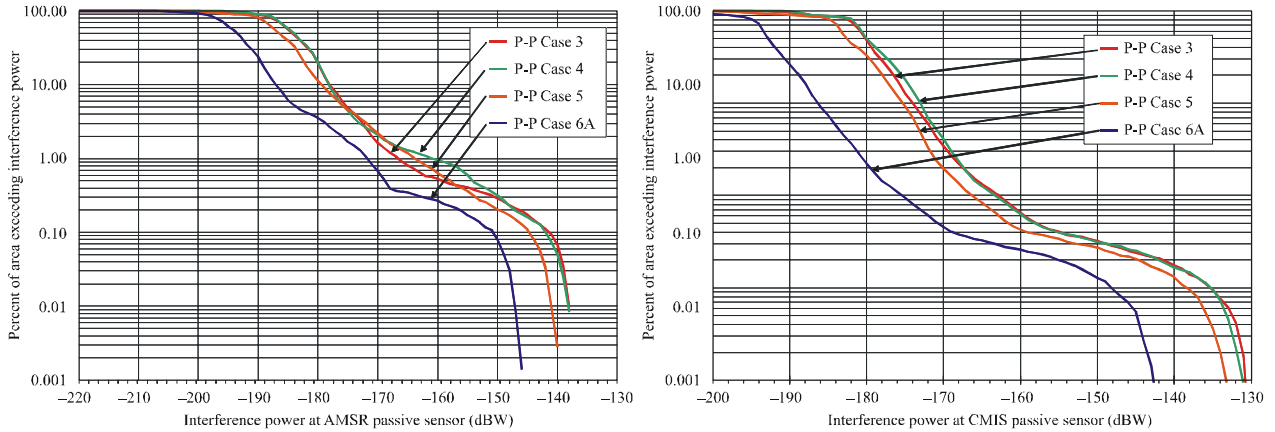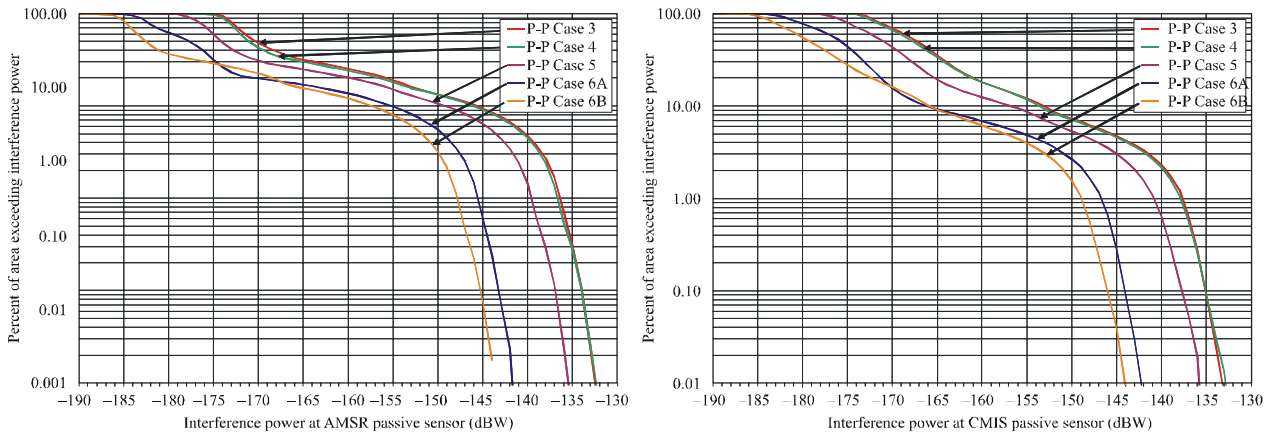

a) Australia measurement area

b) Central Asia measurement area

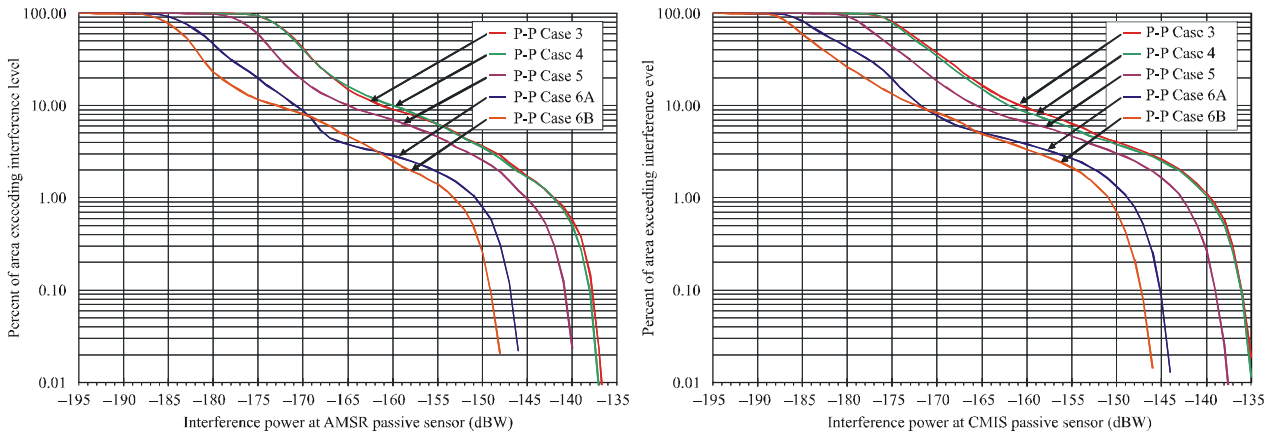CDFs for cases 6A and 6B, and for cases 3 and 4, are very similar and appear to overlap on this chart

c) US Mainland measurement area

Note –1 The slight differences between these CDFs result in apparently overlapping plots.

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FIGURE 7 (*end*)

P-P FS interference into AMSR-E and CMIS passive sensors at 10.6 GHz

d) South America measurement area

e) North Africa measurement area

CDFs for cases 6A and 6B, and for cases 3 and 4, are very similar and appear to overlap on this chart
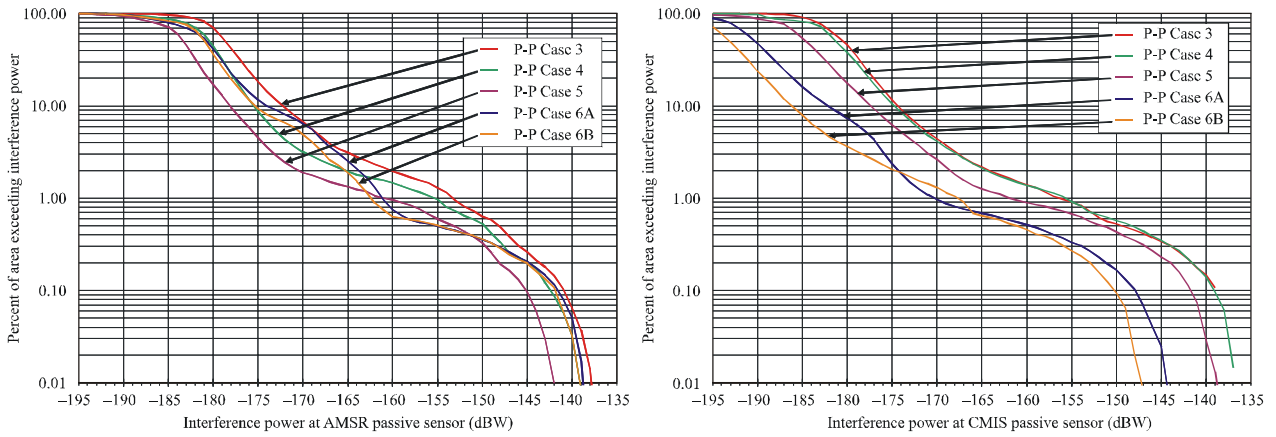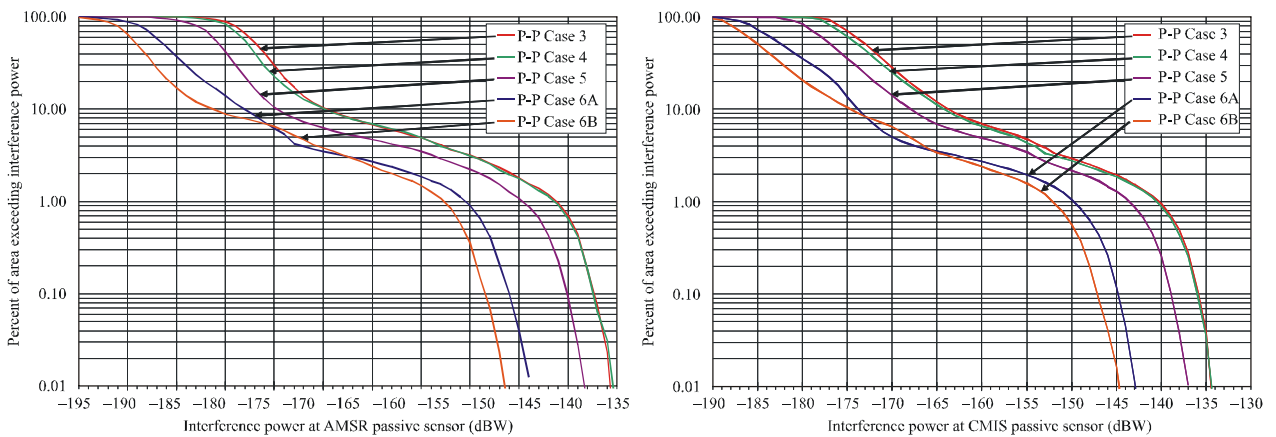
f) Asia measurement area

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4.2.2   Point-to-multipoint FS systems

The same dynamic simulation model was used to calculate the interference levels produced by P-MP system deployments for each of the six measurement areas for the three possible configurations of the two channels of the Recommendation ITU-R F.1568[1] channel plan falling within the 10.6-10.68 GHz band, i.e. two hub stations, one hub station and customer station (CS) in the other channel, and customer stations in both channels. The results are presented in Table 7. The CDFs produced by theses simulations are presented in Fig. 8.

TABLE 7

Results for P-MP FS deployment model over six measurement areas and two sensors

P-MP configuration	Hub + Hub	Hub + CS	CS + CS
Interference power exceeded over 0.1% of measurement area (dBW)	−147 to −137	−143 to −130	−144 to −127

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[1] Recommendation ITU-R F.1568: Radio-frequency block arrangements for fixed wireless access systems in the range 10.15-10.3/10.5-10.65 GHz.

FIGURE 8

P-MP FS interference into AMSR-E and CMIS passive sensors at 10.6 GHz
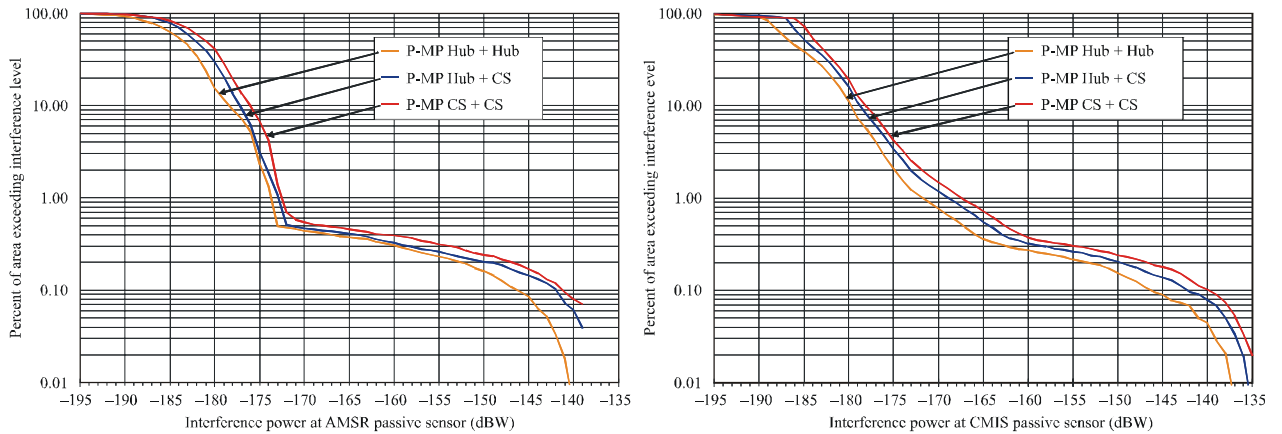
a) Australia measurement area

b) Central Asia measurement area

CDFs for cases 6A and 6B, and for cases 3 and 4, are very similar and appear to overlap on this chart

c) US Mainland measurement area

Note –1 The slight differences between these CDFs result in apparently overlapping plots.

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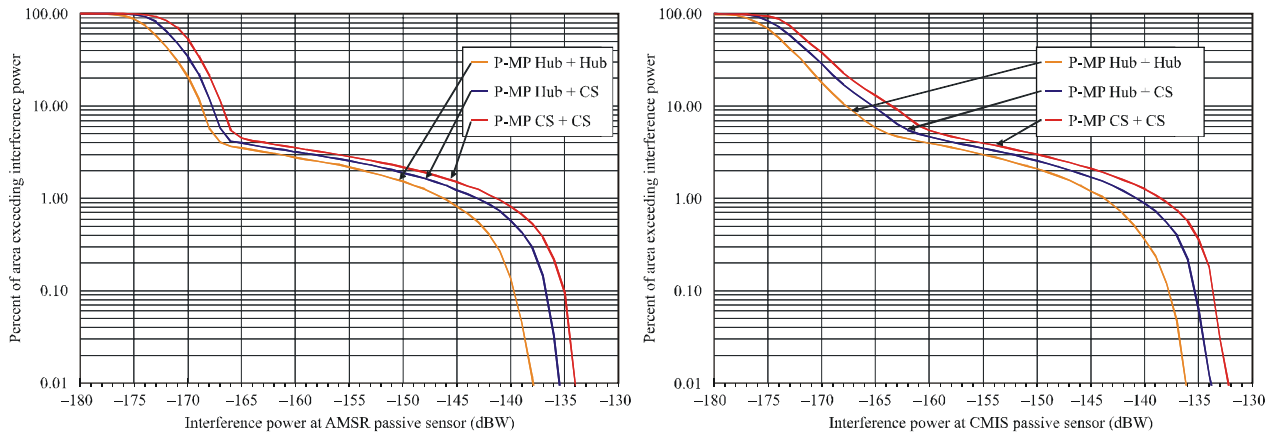
FIGURE 8 (*end*)

P-MP FS interference into AMSR-E and CMIS passive sensors at 10.6 GHz

d) South Americs measurement area
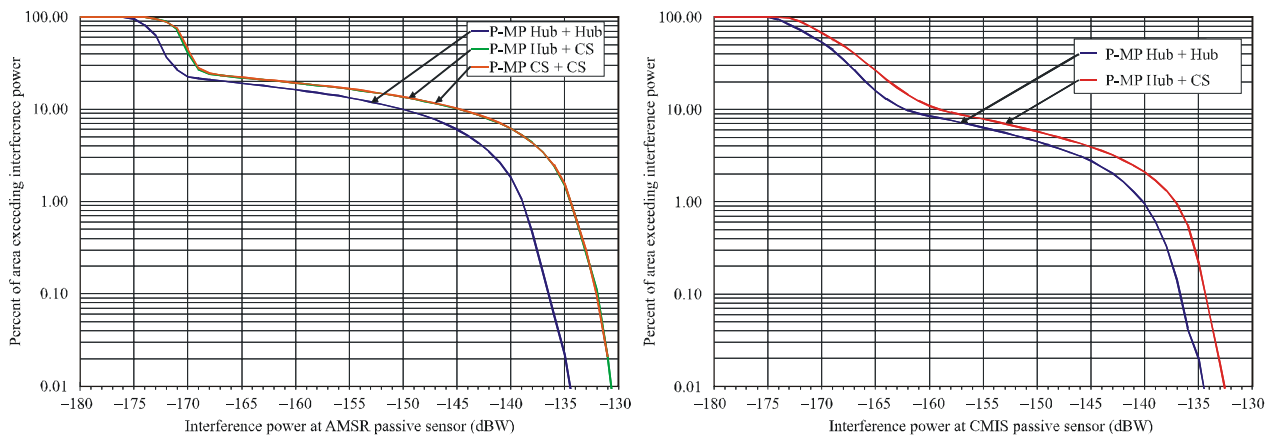

e) North Africa measurement area

CDFs for cases 6A and 6B, and for cases 3 and 4, are very similar and appear to overlap on this chart
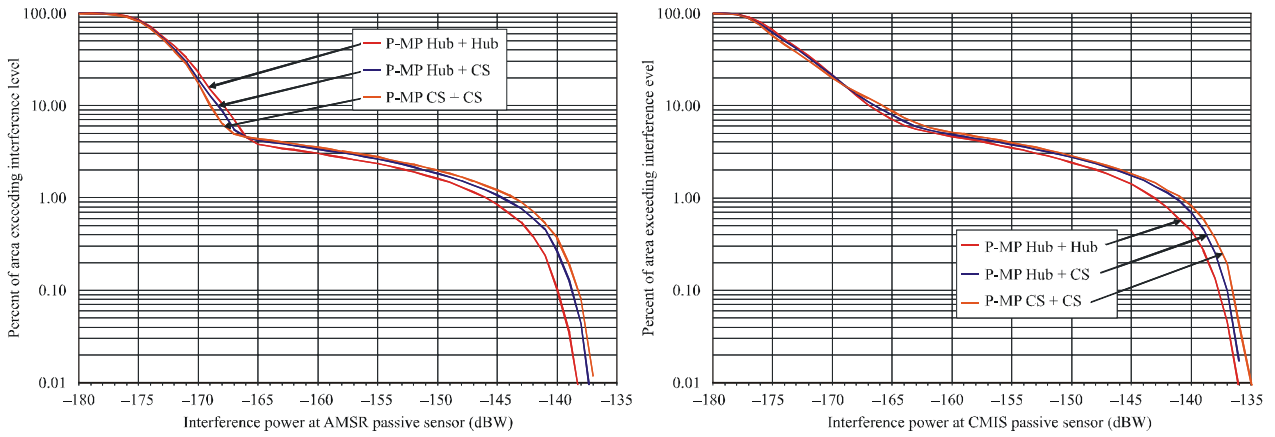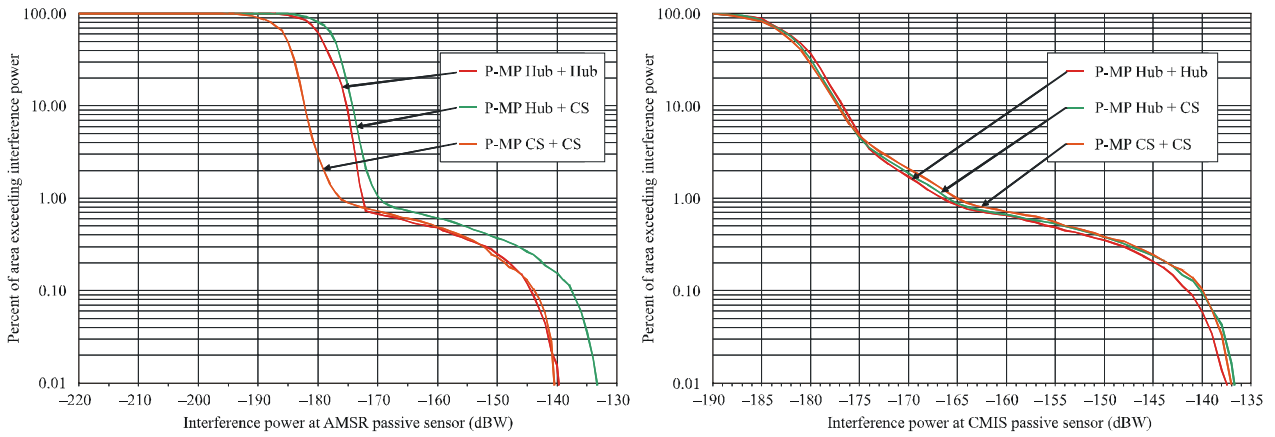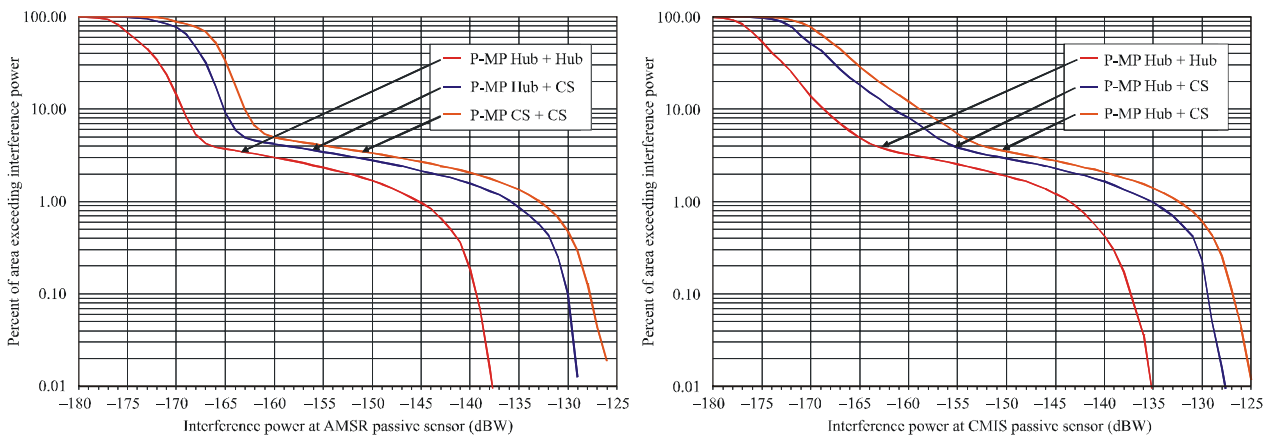

f) SE Asia measurement area

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4.3 Simulation study number 2

Publicly available data on stations licensed in the United States of America and Australia in 2005 was made available in a format that allowed a dynamic simulation model to be constructed in order to conduct a comparison of the interference CDFs produced by FS deployment models based on licensed data and on random distributions of FS stations around major cities. Figures 9 and 10 illustrate the FS deployment models for passive sensor measurement areas covering the United States of America and Australia, respectively. The individual dots represent FS stations whose parameters were specified by the licensed station data. These parameters include geographic coordinates, pointing azimuths, transmitter powers, maximum antenna gains and 3 dB beamwidths for 2 652 and 966 of these stations in the United States of America and Australia, respectively. A set of reference antenna patterns based on Recommendation ITU-R F.1245[2] was defined to cover the range of FS antenna gains and 3 dB beamwidths in the licensed data for each country. The antenna pattern for each FS station in the simulation model was chosen as the one closest to the gain and beamwidth of the station's gain and beamwidth specified in the license data.

FIGURE 9

United States of America FS deployment models
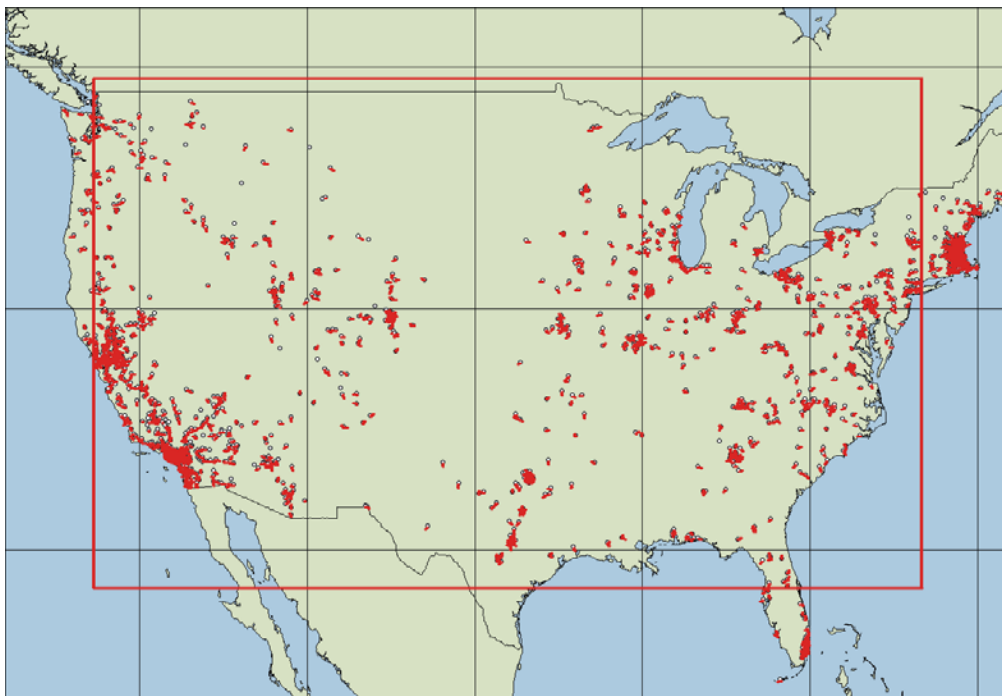
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The eight larger circles with associated city names in Fig. 10 illustrate the area within which FS stations were randomly distributed in the theoretical city-based FS deployment models used in some of the earlier simulations for this area described in § 4.2. Each station in those simulation models had the same antenna pattern and transmit power, but the locations were randomly distributed to lie between 0.1 and 30 km from the nominal city center and the pointing azimuths randomly selected between −180° and 180° with a uniform probability distribution.

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[2] 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.

FIGURE 10

Australia FS deployment models

Rap 2096-10
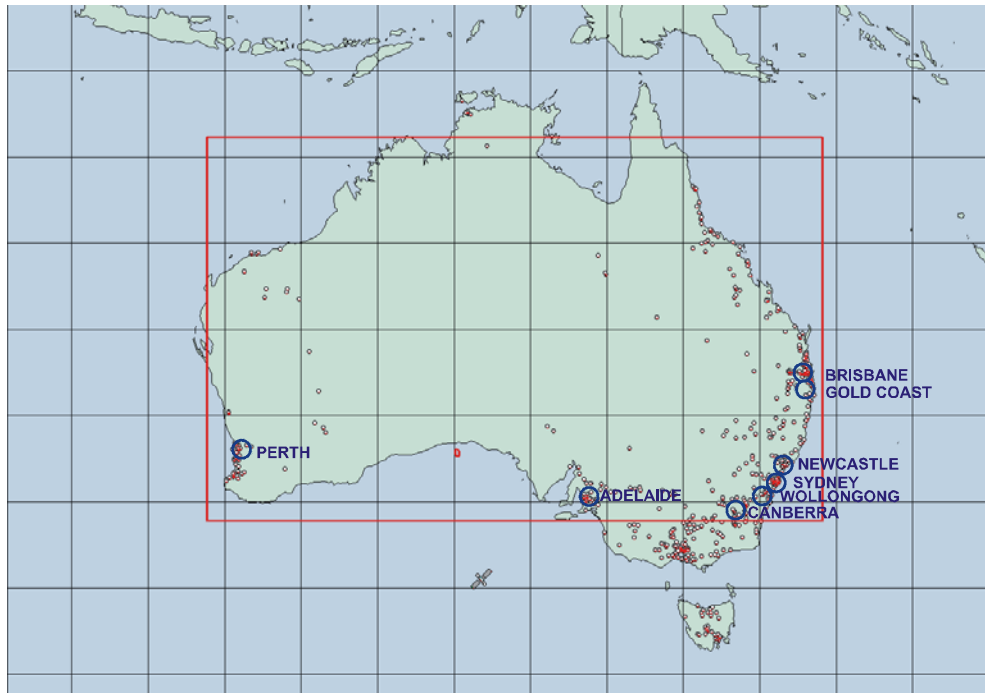
Figures 11 and 12 present the results of the simulations using these FS deployment models. Three other cases are plotted for comparison. One case used the same licensed FS station deployment model, but assumed that all stations have a transmitter power of −3 dBW instead of the actual licensed power level. The other two cases are presented for comparison with the earlier theoretical city-based deployment models. The references in these figures are to the P-P cases reported in Fig. 7 in § 4.2.1.

FIGURE 11

Comparison of interference CDFs for several United States of America FS deployment models
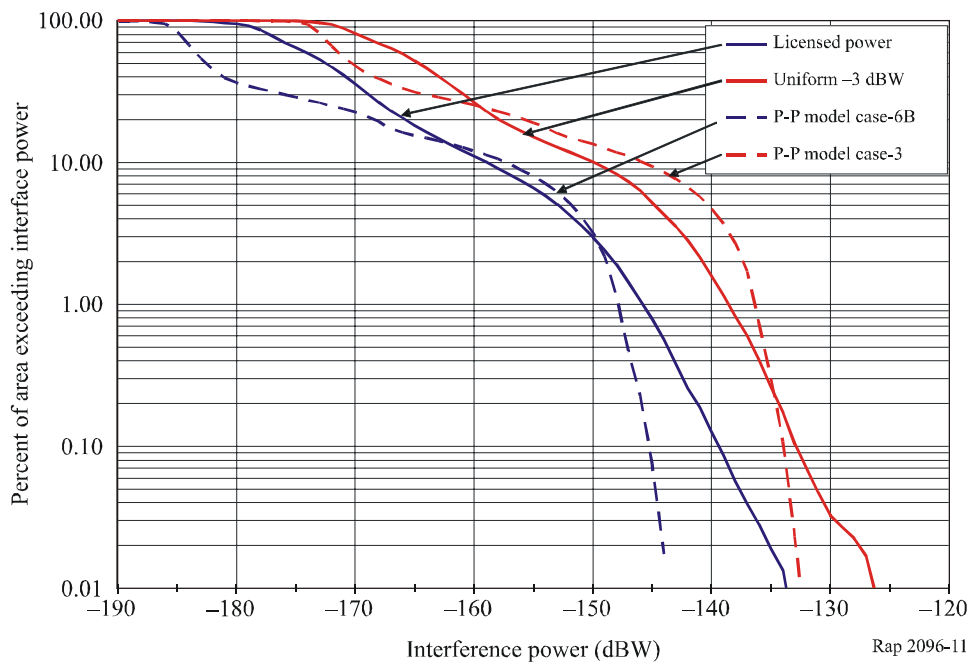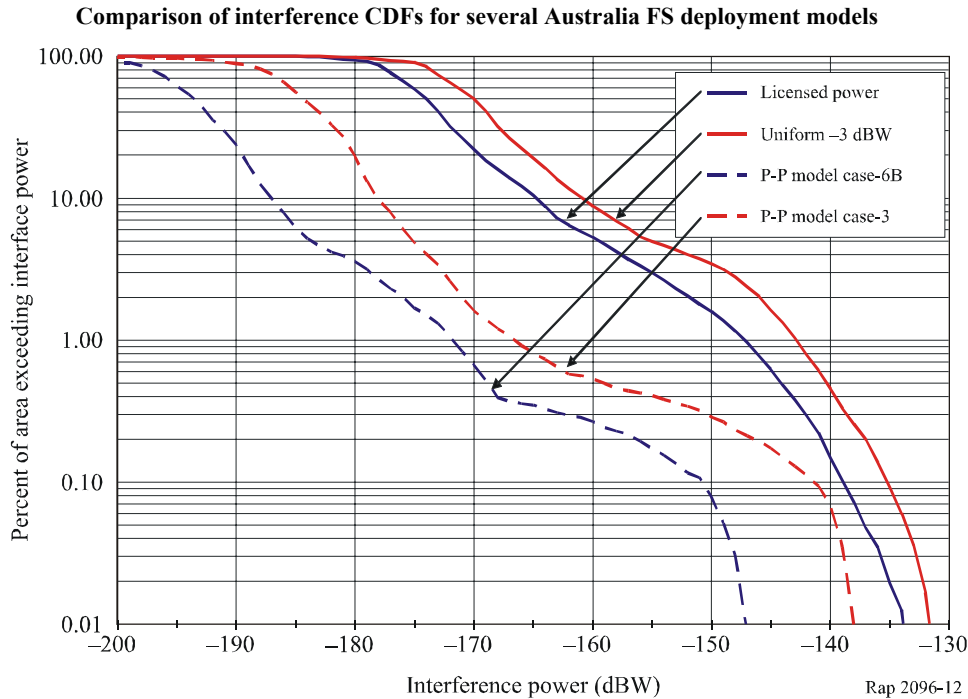

Interference power (dBW)

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FIGURE 12

Comparison of interference CDFs for several Australia FS deployment models

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The interference CDF for the currently licensed FS stations in the United States of America in Fig. 11 falls between the highest and lowest density cases used in the theoretical FS deployment model simulations. However, the CDF for currently licensed FS stations in Australia in Fig. 12 indicates higher interference levels than any of the earlier theoretical FS deployment models. This difference appears to be the result of the much smaller number of cities used in the Australia theoretical model (8 compared to 157 for the United States of America), and which does not consequently include interfering stations in large areas of the country outside of these few urban areas where a significant number of FS stations are licensed to operate.

4.4   Simulation study number 3

This study presents the results of dynamic simulations for several deployments of P-MP, P-P and mobile systems. Simulations were run until the cumulative distribution become stable.

4.4.1   Point-to-multipoint FS Systems

For the P-MP dynamic simulations, 200 P-MP stations are evenly spread within an area located within North America (Canada, United States of America) and are in operation within the shared passive band 10.6-10.68 GHz. Two hub stations are operating in a city area and one of the two frequency blocks is falling within the passive sensor bandwidth. Each hub station transmits 5 carriers per sector (120°), resulting in a transmit power of −3 dBW (−10 dBW + 10 log(5)) with a sectoral antenna having a maximum gain of 13 dBi. Each subscriber station transmits a power of −10 dBW with an antenna having a maximum gain of 26 dBi (beamwidth of 7°).

Figure 13 presents the CDFs produced by the P-MP Systems.

Table 8 compares the results of these simulations in terms of the interference level, I_{EESS}, exceeded at the passive sensor over 0.1% of the measurement area with the permissible interference criteria of Recommendation ITU-R RS.1029 and indicates the maximum FS transmit power, P_t, that would just satisfy this criteria.

FIGURE 13

CDF for P-MP interference into passive sensors
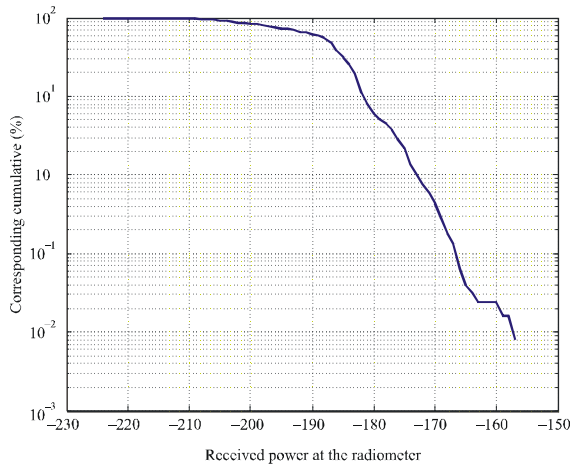
a) 200 P-MP Hub stations into sensor 1
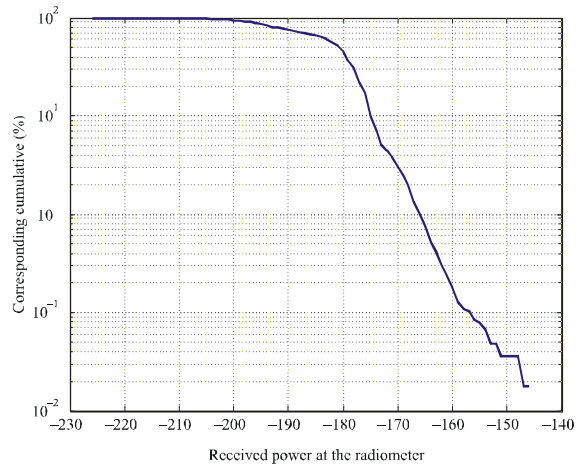
b) 200 P-MP Hub stations into AMSR-E
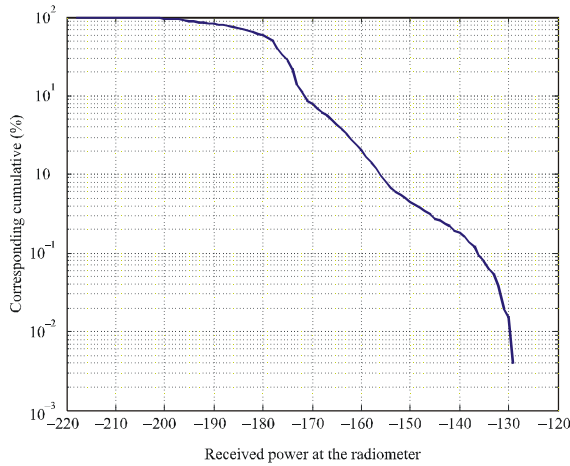
c) 200 P-MP Hub stations into CMIS
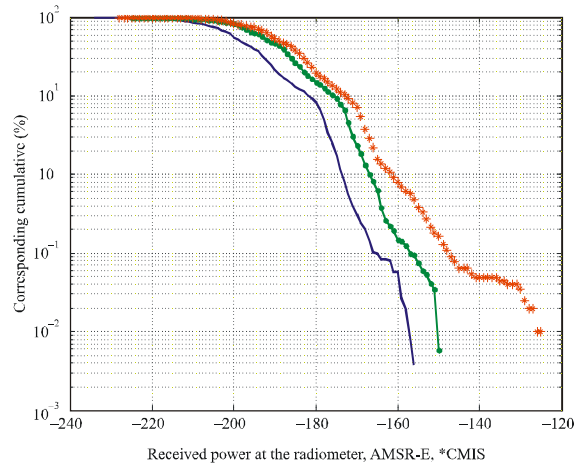
d) 200 P-MP subscriber stations into sensor 1, AMSR-E and CMIS

Rap 2096-13

TABLE 8

Summary of simulation results

Simulation case	I_{EESS} at 0.1%	Current sensor criteria		Future sensor criteria	
		Margin	Maximum P_t (dBW)	Margin	Maximum P_t (dBW)
200 P-MP hub stations into sensor 1	−167 dBW/100 MHz	Positive	0	Positive	−10
200 P-MP hub stations into AMSR-E	−156 dBW/100 MHz	Positive	−10	−10	−10
200 P-MP hub stations into CMIS	−136 dBW/100 MHz	−20 dB	−30	−30	−40
200 P-MP subscriber stations into sensor 1	−166 dBW/100 MHz	Positive	0	Positive	−10
200 P-MP subscriber stations into AMSR-E	−157 dBW/100 MHz	Positive	−10	−9	−19
200 P-MP subscriber stations into CMIS	−148 dBW/100 MHz	−8 dB	−18	−18	−28

4.4.2 Point-to-point FS systems

The P-P FS deployment models assumed 100 P-P systems. These P-P stations are evenly spread within the rectangle 40° N, 0° E and 60° N, 20° E. Each station transmits a power of −3 dBW with a dish antenna having a maximum gain of 50 dBi. It should be noted that some fixed stations are operated with lower powers.

Despite lack of information concerning the number frequency blocks transmitting within the band of the passive sensor 10.6-10.68 GHz, it is assumed that only one frequency block is used.

Figure 14 presents the P-P CDFs produced by the P-P systems.

Table 9 compares the results of these simulations in terms of the interference level I_{EESS} exceeded at the passive sensor over 0.1% of the measurement area with the permissible interference criteria of Recommendation ITU-R RS.1029 and indicates the maximum FS transmit power P_t that would just satisfy these criteria.

FIGURE 14a

CDF for P-P interference into sensor 1 (100 P-P systems)

Rap 2096-14a

FIGURE 14b

CDF for P-P interference into AMSR-E (100 P-P systems)

Received power at the radiometer

Rap 2096-14b

FIGURE 14c

CDF for P-P interference into CMIS (100 P-P systems)

Received power at the radiometer

Rap 2096-14c
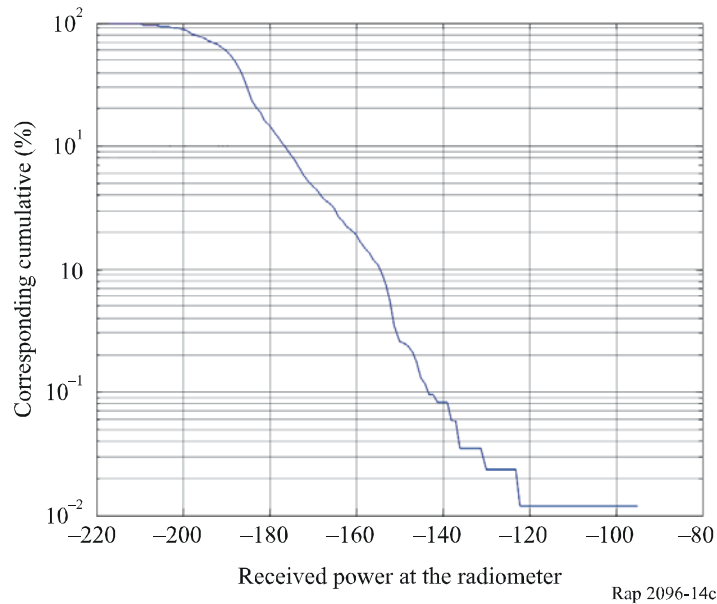
TABLE 9

Summary of simulation results

Simulation case	I_{EESS} at 0.1%	Current sensor criteria		Future sensor criteria	
		Margin (dB)	Maximum P_t (dBW)	Margin (dB)	Maximum P_t (dBW)
100 P-P into sensor 1	−155 dBW/100 MHz	0	−3	−11	−14
100 P-P into AMSR-E	−148 dBW/100 MHz	−8	−11	−18	−21
100 P-P into CMIS	−144 dBW/100 MHz	−12	−15	−22	−25

4.4.3 Mobile systems

The mobile deployment density assumes a 100 video links in operation and evenly spread within Europe. Each stations transmit at −3 dBW with antenna gain of 32 dBi (beamwidth = 4.5°).

Figure 15 presents the CDF produced by the mobile systems.

Table 10 compares the results of these simulations in terms of the interference level I_{EESS} exceeded at the passive sensor over 0.1% of the measurement area with the permissible interference criteria of Recommendation ITU-R RS.1029 and indicates the maximum FS transmit power P_t that would just satisfy these criteria.
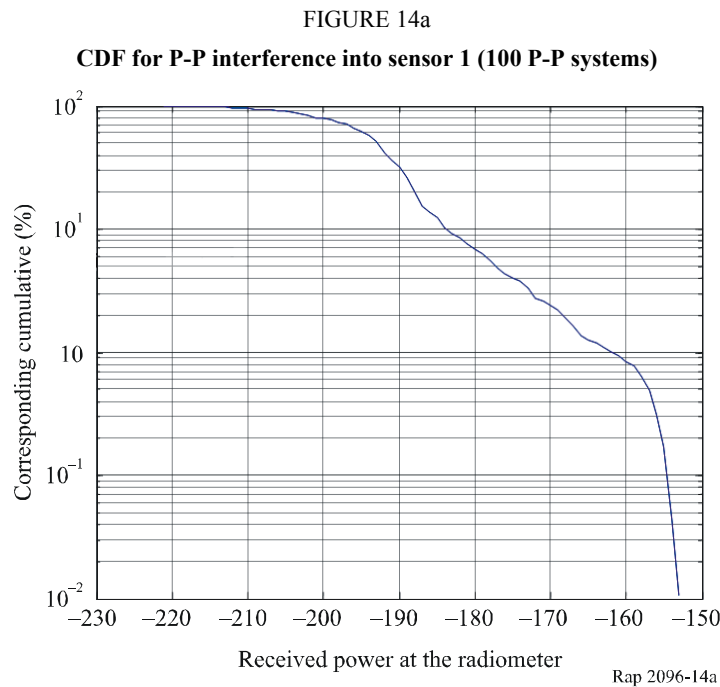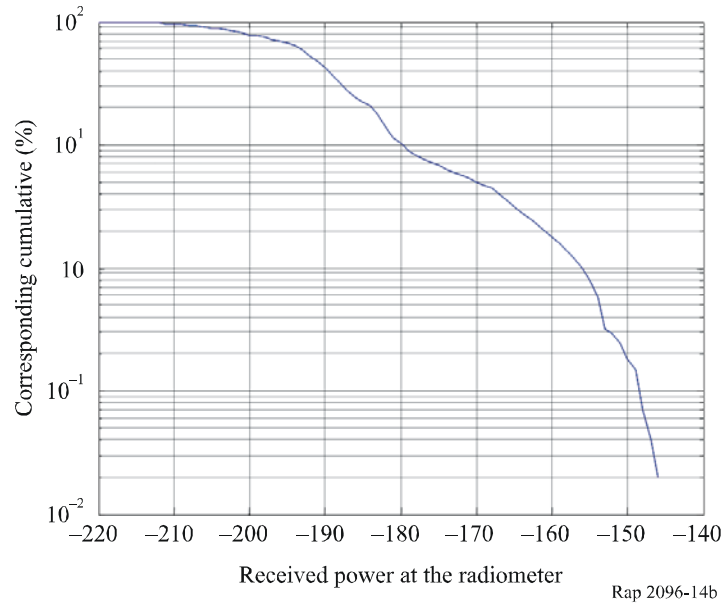
FIGURE 15

CDF for mobile interference into passive sensors

Received power at the radiometer
SENSOR1, - AMSR-E, CMIS

Rap 2096-15
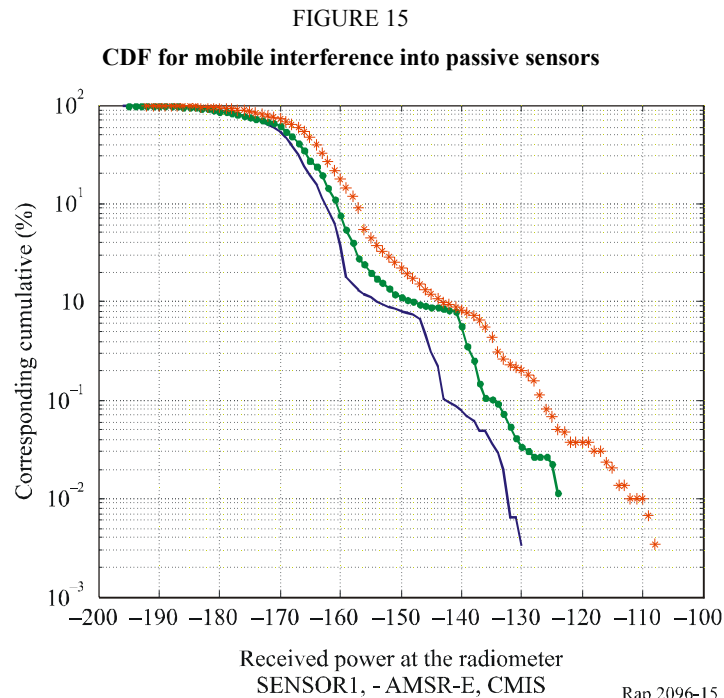
TABLE 10

Summary of simulation results

Simulation case	I_{EESS} at 0.1%	Current sensor criteria		Future sensor criteria	
		Margin (dB)	Maximum P_t (dBW)	Margin (dB)	Maximum P_t (dBW)
100 video links into sensor 1	−142 dBW/100 MHz	−14	−17	−24	−27
100 video links into AMSR-E	−135 dBW/100 MHz	−21	−24	−31	−34
100 video links into CMIS	−126 dBW/100 MHz	−30	−33	−40	−43

4.5   Simulation study number 4

This study presents the results of dynamic simulations for FS and mobile systems. Simulations were conducted for one month with a time increment of 0.5 s.

4.5.1   Point-to-point FS systems

Sharing studies were performed using dynamic computer simulations to create a CDF of the interference levels received by a passive sensor AMSR-E scanning conically from a deployment of fixed service stations while taking measurements over a 10^7 km^2 measurement area, based upon the permissible interference levels indicated in Recommendation ITU-R RS.1029. Assumptions of sharing studies are shown in Tables 11 and 12. Simulations were conducted for one month with a time increment of 0.5 s.

TABLE 11

Parameters of EESS (passive) (AMSR-E/AQUA)

Parameter	Value
Altitude (km)	705
Orbital inclination (degrees)	98.2
Antenna gain (dBi)	42.4
Antenna pattern	See Fig. 3
Off-nadir angle (degrees)	47.5
Frequency range (GHz)	10.6-10.68

TABLE 12

Parameter of fixed service station

Parameter	Value
Transmitter power (dBW)	−3.0
Bandwidth (MHz)	18
Antenna gain (dBi)	43.0
eirp (dBW)	40.0
Elevation angle (degrees)	0~20° (uniform distribution)
Azimuth direction (degrees)	0~360° (see Note 1)
Antenna pattern	Recommendation ITU-R F.1245
Number of stations	51 stations (see Note 2)
Distribution	Uniform distribution
Activity factor (%)	100

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

NOTE 2 – The number of 51 stations is derived by the fact that there are 32 stations in Japan and 19 outside Japan. The number of stations in foreign countries is estimated considering the ratio between the population in Japan and that in foreign countries in the measurement area (see Fig. 16.)

The calculated CDF curve for fixed service stations indicated by Fig. 16 is shown in Fig. 17.

FIGURE 16

Deployment of fixed service stations

(32 stations in Japan and 19 stations outside Japan)

Rap 2096-16

FIGURE 17

CDF curve for interference from fixed service stations
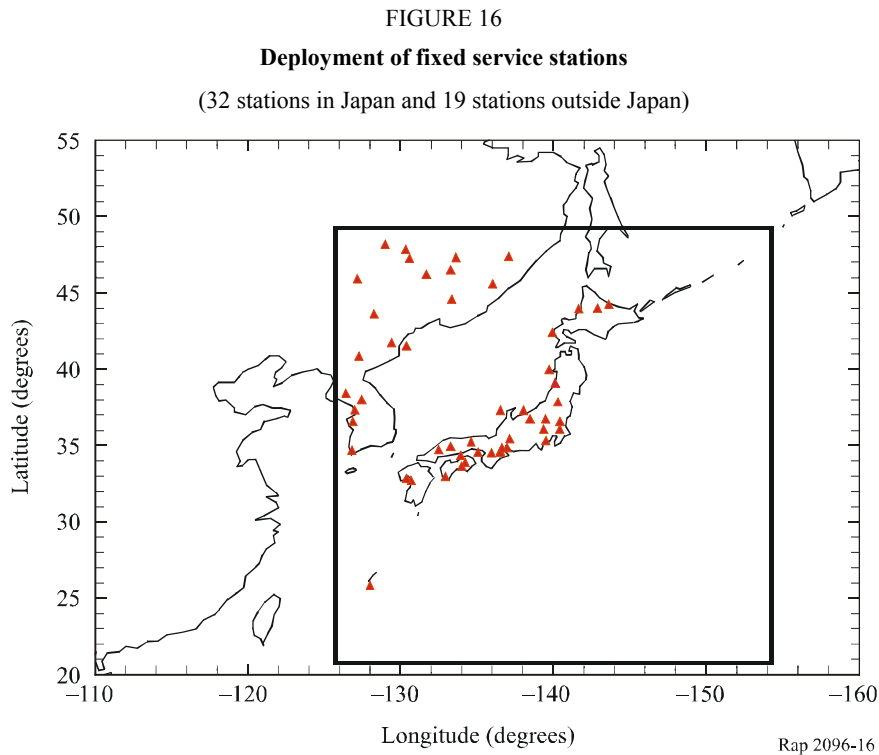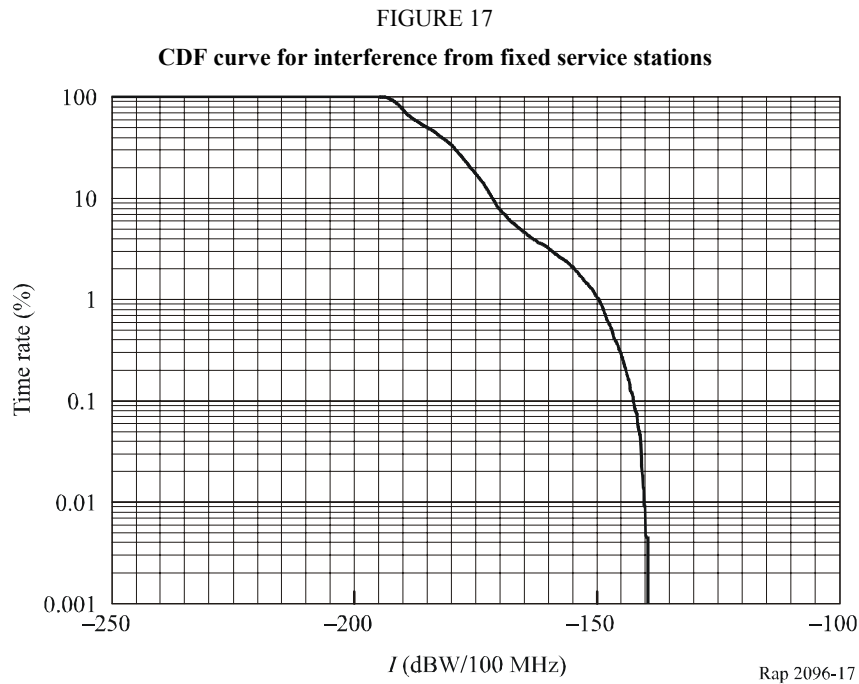
Table 13 shows interference time percentages of 2.3% and 5.1% exceeding the permissible interference levels of −156 dBW/100 MHz and −166 dBW/100 MHz, respectively.

Table 14 shows the excess above permissible interference levels, transmitter power and eirp in order to meet interference criteria. Concerning a permissible interference level for future passive sensors of −166 dBW/100 MHz, there is a negative margin of about −24 dB, transmitter power is not more than −27 dBW and EIRP is not more than 16 dBW. Concerning a permissible interference level for current passive sensors of −156 dBW/100 MHz, there is negative margin of about −14 dB, transmitter power is not more than about −17 dBW and eirp is not more than about 26 dBW.

The negative margin may be reduced by using the following items not used in this simulation:

–   automatic transmitter power control (ATPC) or other power setting control;

–   polarization mismatch;

–   feeder loss of FS transmitter.

TABLE 13

**Interference time percentage exceeding permissible
interference levels**

Permissible interference levels (dBW/100 MHz)	Interference time percentage (%)
−166	5.1
−156	2.3

TABLE 14

**Excess above permissible interference levels, transmitter power
and eirp to meet interference criteria**

Permissible interference levels (dBW/100 MHz)	Interference level for 0.1% (dBW/100 MHz)	Excess above permissible interference levels (dB)	Transmitter power (dBW)	eirp (dBW)
−166	−142.4	23.6	−26.6	16.4
−156	−142.4	13.6	−16.6	26.4

4.5.2   Mobile systems

Sharing studies were performed using dynamic computer simulations to create a CDF of the interference levels received by a passive sensor AMSR-E scanning conically from a deployment of mobile service stations (ENG/OB type) while taking measurements over a 10^7 km^2 measurement area, based upon permissible interference levels indicated in Recommendation ITU-R RS.1029. Assumptions of sharing studies are shown in Tables 15 and 16. As for antenna pattern, mobile stations in this band employ not only parabolic antenna but also several types of antennas as well including omnidirectional antenna, helix antenna and horn antennas and simulations were performed for parabolic and non-directional antenna cases. Simulations were conducted in one month with a time increment of 0.5 s.

TABLE 15

Parameters of EESS (passive) (AMSR-E/AQUA)

Parameter	Value
Altitude (km)	705
Orbital inclination (degrees)	98.2
Antenna gain (dBi)	42.4
Antenna pattern	See Fig. 3
Off-nadir angle (degrees)	47.5
Frequency range (GHz)	10.6-10.68

TABLE 16

Parameters of mobile service stations

Parameter	Value	
Transmitter power (dBW)	−3.0	
Bandwidth (MHz)	18	
Antenna type	Parabolic antenna	Omnidirectional antenna
Antenna gain (dBi)	35.0	0
eirp (dBW)	32.0	–3
Elevation angle (degrees)	−90~ 90°	
Azimuth direction (degrees)	0~360° (see Note 1)	
Antenna pattern	Recommendation ITU-R F.1245	Omnidirectional 0 dBi
Number of stations	628 stations in Japan and 354 outside Japan (see Note 2)	
Distribution	Uniform distribution	
Activity factor (%)	0.34 (see Note 3)	

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

NOTE 2 – Number of stations in foreign countries is estimated considering the ratio between the population in Japan and that in foreign countries in the measurement area (see Fig. 18.)

NOTE 3 – This value is an estimate based upon statistics of utilization of mobile service stations in Japan. It is the ratio of station operating hours in the 10.6-10.68 GHz band during the year to the total number of hours in a year.

FIGURE 18a

Deployment of mobile stations

(Activity factor 100% 628 Japanese stations, 354 stations outside Japan)
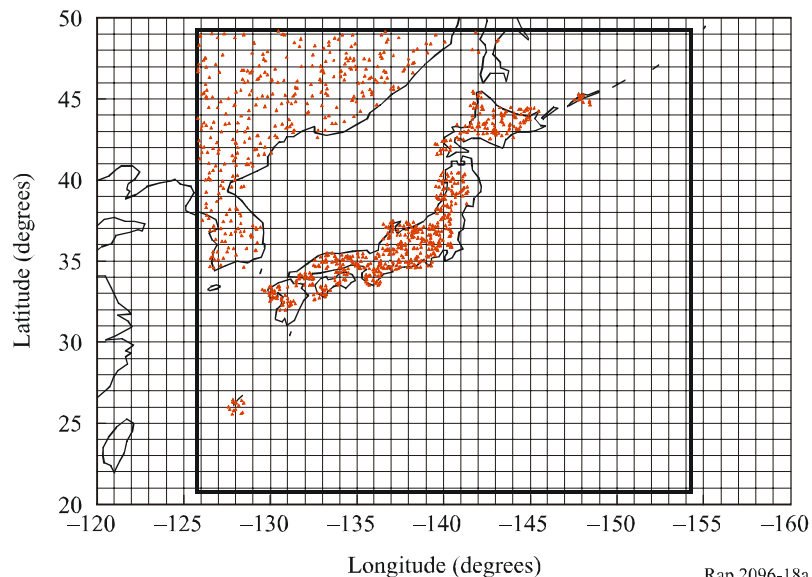
Rap 2096-18a

FIGURE 18b

Deployment of mobile station

(Activity factor 0.34%, two Japanese stations and one station outside Japan)

Rap 2096-18b
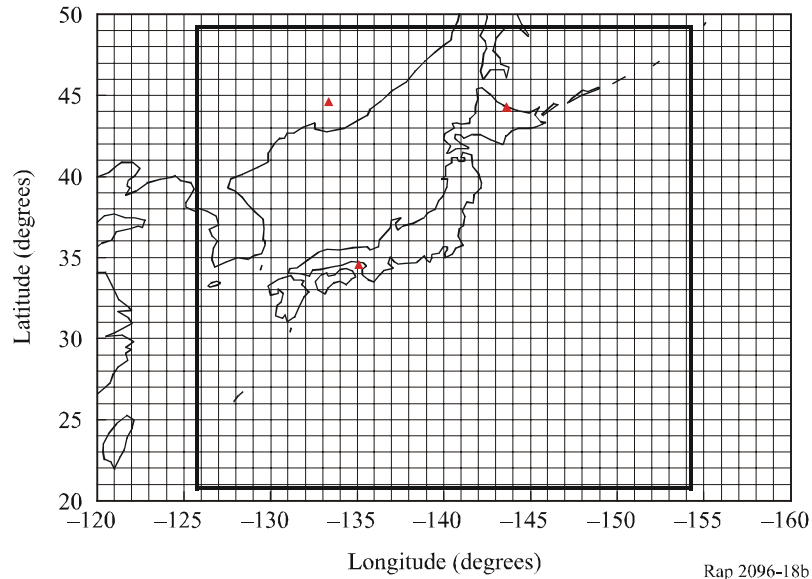
The calculated CDF curve for deployment of mobile service stations indicated in Fig. 18a and 18b is shown in Fig. 19. Three mobile stations randomly selected under activity factor 0.34% are shown in Fig. 18b. Figure 19 shows the difference between CDF curves with activity factors of 100% and 0.34% for two different antenna patterns.

Table 17 shows interference time percentages exceeding the permissible interference level of −156 dBW/100 MHz for current passive sensors for activity factors of 0.34% and 100%. In the case of an activity factor of 0.34%, the interference time percentage exceeding −156 dBW/100 MHz is 0.16% for a parabolic antenna and 0.32% for an omnidirectional antenna.

FIGURE 19

CDF for activity factors 100% and 0.34%

Activity factor 0.34% Parabolic antenna 35 dBi
Activity factor 100% Parabolic antenna 35 dBi
Activity factor 0.34% Omnidirectional antenna 0 dBi
Activity factor 100% Omnidirectional antenna 0 dBi

Rap 2096-19
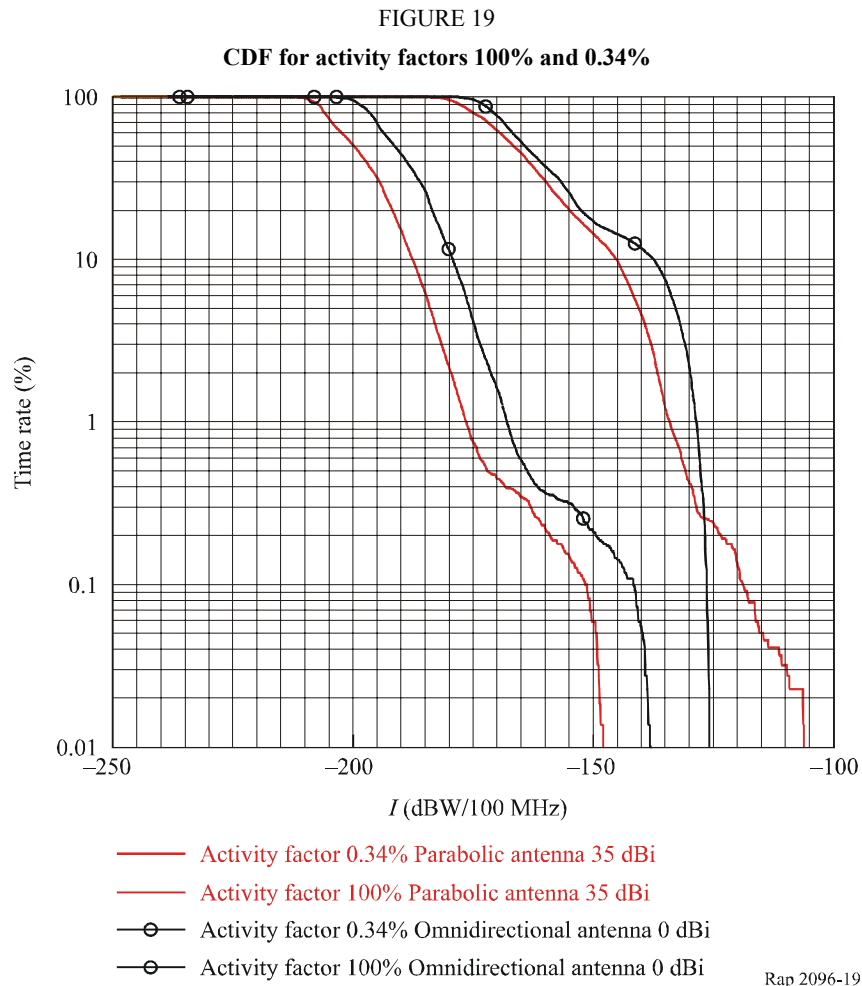
TABLE 17

Interference time percentage exceeding permissible interference level

Activity factor (%)	Antenna type	Permissible interference level (dBW/100 MHz)	Interference time percentage (%)
0.34	Parabolic antenna 35 dBi	−156	0.16
		−166	0.37
	Omnidirectional antenna 0 dBi	−156	0.32
		−166	0.675
100	Parabolic antenna 35 dBi	−156	21.9
		−166	48.2
	Omnidirectional antenna 0 dBi	−156	28.1
		−166	57.0

Table 18 shows the excess above permissible interference levels, transmitter power and EIRP in order to meet interference criteria. When −156 dBW/100 MHz is considered as interference criteria, with an activity factor of 0.34% there is the negative margin of −4.4 dB for a parabolic antenna and of −14.4 dB for an omnidirectional antenna.

TABLE 18

Excess above permissible interference level, transmitter power and EIRP to meet interference criteria

Activity factor (%)	Antenna type	Interference level for 0.1% (dBW/100 MHz)	Permissible interference level (dBW/100 MHz)	Excess above permissible interference levels (dB)	Transmitter power (dBW)	EIRP (dBW)
0.34	Parabolic antenna 35 dBi	−151.6	−156	4.4	−7.4	27.6
			−166	14.4	−17.4	17.6
	Omnidirectional antenna 0 dBi	−141.6	−156	14.4	−17.4	−17.4
			−166	24.4	−27.4	−27.4
100	Parabolic antenna 35 dBi	−119	−156	37	−40	−5
			−166	47	−50	−15
	Omnidirectional antenna 0 dBi	−126	−156	30	−33	−33
			−166	40	−43	−43

Higher levels of interference are mainly caused by coupling between the main beam of space-borne passive sensors and the side-lobe level of mobile service stations when the activity factor is low.

In this interference criterion, a negative margin of about −4.4 dB or −14.4 dB may be compensated for by using the proper power setting technique or other possible mitigation techniques not used in this simulation.

In order to share with EESS (passive), an omnidirectional antenna is not recommended to be used.

It was found that there is a negative margin of −14.4 dB relative to the permissible interference level of −156 dBW/100 MHz for the current passive sensors. When various types of antennas are used at mobile service stations, average excess above the permissible interference level may be in between the two antenna cases.

4.6 Summary of sharing study results

Figure 20 displays the results from § 4.2.1 of dynamic simulations conducted for P-P FS deployment models in terms of the interference power exceeded for 0.1% of the measurement area as determined from each CDF and plotted as a data point in the figure against the density of FS stations in the simulation producing the CDF. The interference levels were normalized to a −3 dBW FS transmit power, and, where multiple CDFs were produced by different simulations with the same FS station densities, the average value of the interference levels for the same density was plotted. These results are to be considered in relation to the permissible level in Recommendation ITU-R RS.1029 of −156 dBW/100 MHz at this percentage. A best-fit curve to these data points is also plotted in the figure, where the curve is defined by a function of the form $I = a*x^b$ where I is the interference power, x is the FS deployment density, and a and b are constants. The results of the

dynamic simulations based on licensed station data in Australia and the United States of America in § 4.2 are also included, with data points based on the actual licensed power of each station and on the assumption that each station operates at a −3 dBW transmit power for comparison with the other simulation results, as well as the results of P-P simulations from § 4.1, 4.3 and 4.4. The results of these studies based on licensed station data in the 10.6-10.68 GHz band are consistent with the earlier studies based on theoretical models and appear to provide a basis for identifying reasonable ranges of FS deployment densities in theoretical deployment scenarios assumed in other dynamic simulations.

FIGURE 20

Comparison of 10 GHz P-P dynamic simulation results

Rap 2096-20
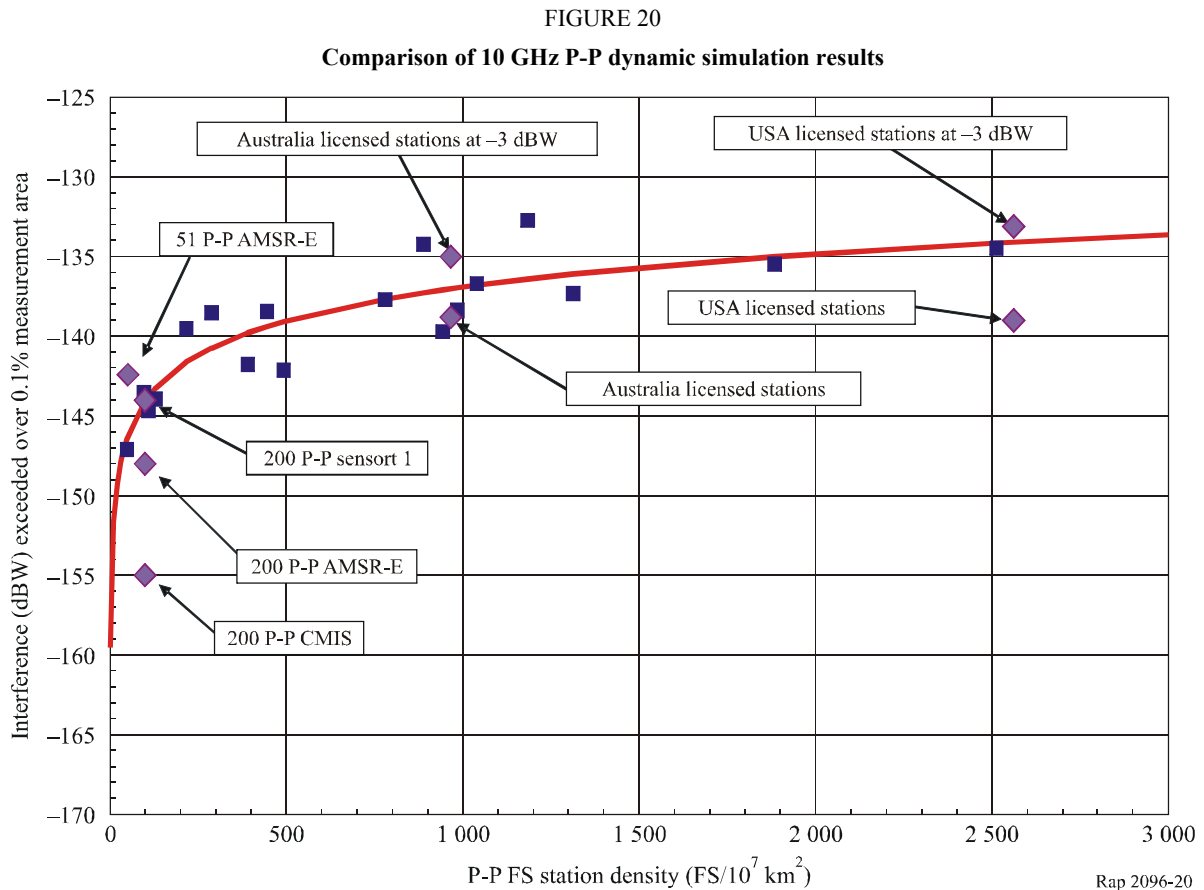
Figure 21 displays the results of dynamic simulations conducted for P-MP FS deployment models in section 4.2.2 and the CDFs resulting from point-to-multipoint (P-MP) FS deployments around major cities in six different parts of the world presented in Fig. 7. The interference power exceeded for 0.1% of the measurement area was determined from each CDF and plotted as a data point in Fig. 21 against the density of P-MP systems in the simulation producing the CDF. A best-fit curve to these data points is also plotted in Fig. 21. "H" denotes a hub station and "C" denotes customer stations for the three possible configurations for the two P-MP radio channels falling within the 10.6-10.68 GHz EESS (passive) band.

FIGURE 21

Comparison of P-MP dynamic simulation results

Rap 2096-21
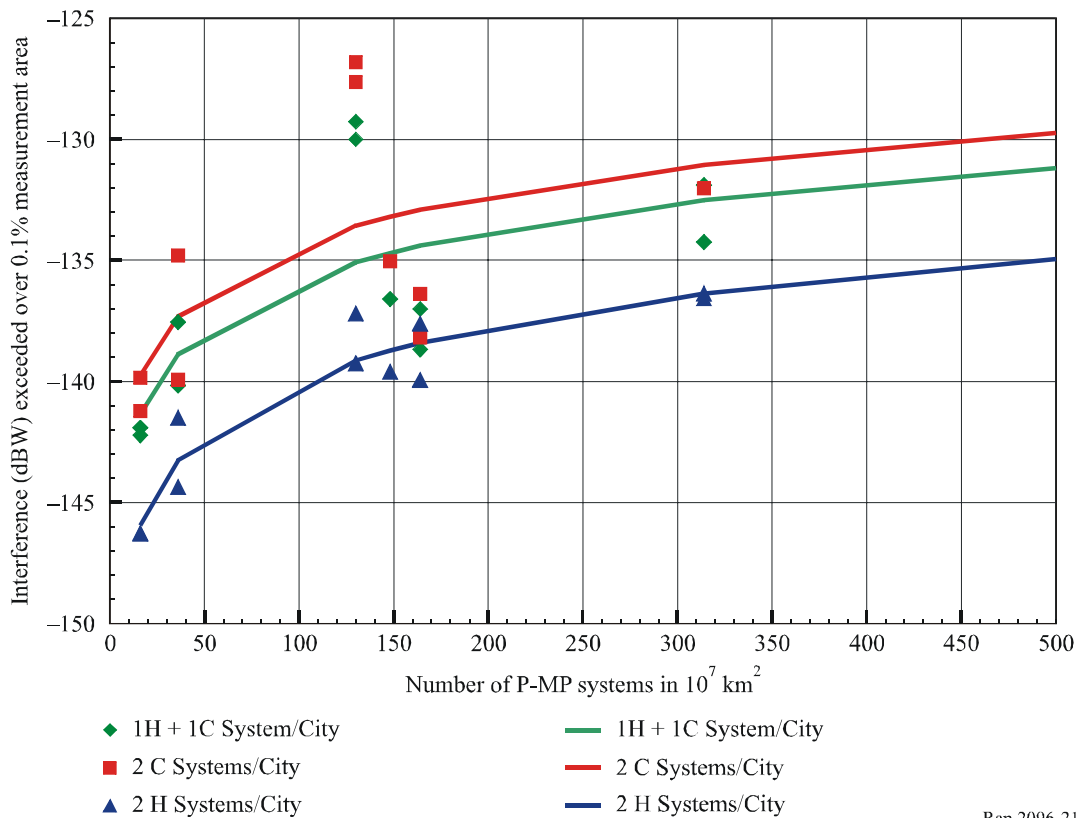
Each of the preceding studies compared the interference level received by the EESS (passive) receiver with the permissible interference levels specified in Recommendation ITU-R RS.1029. However, in evaluating the results of these studies, several additional factors have to be taken into account.

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 backlobe 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 licensed FS stations in the 10.6-10.68 GHz band, it was shown that the passive sensor interference level calculated with the actual licensed 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 regulatory limit. The summaries of the simulation studies use the cumulative distribution functions 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 from 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 19 summarizes the sharing studies described above. For each simulation study, the first two columns are used to identify the type of FS or mobile station considered in the simulation and the FS or mobile transmitter power assumed for each station in the FS or mobile 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 each study are indicated in the table. 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 the Table 1, 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%. The table also identifies the highest and lowest calculated FS transmitter powers that would just satisfy the −156 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 licensed power levels (3.8-6.4 dB) are discussed below. These factors are applicable to using the interference CDFs developed by these dynamic simulations to develop any possible sharing criteria. The rightmost columns of Table 19 indicate the range of calculated permissible FS/mobile 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 19 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 section 4 if sharing criteria are to be developed in terms of peak power levels. For the P-MP cases, "H" denotes hub station and "C" denotes customer stations for the three possible configurations (1H + 1C, 2H or 2C) for the two P-MP radio channels falling within the 10.6-10.68 GHz EESS (passive) band.

TABLE 19

Summary results of 10 GHz simulation studies

10 GHz simulation study number	NOTES	Trans-mitter power P_t (dBW)	FS/MS station density per 10^7 km^2	I_{EESS} for 0.1% in dBW	Maximum P_t (dBW) to satisfy protection levels in Recommendation ITU-R RS.1029	Maximum P_t (dBW) taking into account the 5.8-9.4 dB correction factor
1	P-P	−3	48 to 2 512	−151 to −130.5[(1)]	−8 to −28.5[(5a)] −18 to −38.5[(5b)]	−22.7 to 1.4 −32.7 to −8.6
1	P-MP (1H1C)	−3	16 to 314	−142.2 to −129.3[(1)]	−16.8 to −29.7[(5a)] −26.8 to −39.7[(5b)]	−23.9 to −7.4 −33.9 to −17.4
1	P-MP (2C)	−10	16 to 314	−141.2 to −126.8[(1)]	−24.8 to −39.2[(5a)] −34.8 to −49.2[(5b)]	−33.4 to −15.4 −43.4 to −25.4
1	P-MP (2H)	−3	16 to 314	−146.3 to −136.4[(1)]	−12.7 to −22.6[(5a)] −22.7 to −32.6[(5b)]	−16.8 to −3.3 −26.8 to −13.3
2	Australia database	−3	966	−135.2	−23.8[(5a)] −33.8[(5b)]	−18 to −14.4 −28 to −24.4
2	USA database	−3	2 652	−132.9	−26.1[(5a)] −36.1[(5b)]	−20.3 to −16.7 −30.3 to −26.7

TABLE 19 (*end*)

10 GHz simulation study number	NOTES	Transmitter power P_t (dBW)	FS/MS station density per 10^7 km^2	I_{EESS} for 0.1% in dBW	Maximum P_t (dBW) to satisfy protection levels in Recommendation ITU-R RS.1029	Maximum P_t (dBW) taking into account the 5.8-9.4 dB correction factor
3	200 P-MP	−10	200	−167 to −136[3]	−10 to −30[5a] −10 to −40[5b]	−4.2 to −20.6 −4.2 to −30.6
3	100 P-P	−3	100	−155 to −144[3]	−3 to −15[5a] −14 to −25[5b]	2.8 to −5.6 −8.2 to −15.6
3	100 mobile	−3	100	−142 to −126[3]	−17 to −33[5a] −27 to −43[5b]	−11.2 to −23.6 −21.2 to −33.6
4	51 P-P	−3	51	−142.4	−16.6[5a] −26.6[5b]	−10.8 to −7.2 −20.8 to −17.2
4	982 mobile	−3	100	−126 or −119	−33 or −40[5a] −43 or −50[5b]	−27.2 to −23.6 −37.2 to −33.6
4	3 Mobile	−3	100	−151.6 or −141.6	−7.4 or −17.4[5a] −17.4 to −27.4[5b]	−1.6 to 2 −11.6 to −8

[1]   Range of FS densities and different sensors.

[2]   Values for two FS densities.

[3]   Values for three different sensors.

[4]   All FS powers are "mean" powers, while MS powers are "peak" powers.

[5a]   Values obtained using the Recommendation ITU-R RS.1029 criterion of −156 dBW/100 MHz.

[5b]   Values obtained using the Recommendation ITU-R RS.1029 criterion of −166 dBW/100 MHz.

In several cases, the permissible power levels indicated in the rightmost columns of Table 19 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 FS transmit power levels, the interference CDFs produced by the simulations were examined to determine the impact on currently operational passive sensors in terms of the percentage of the measurement area over which the permissible interference power level of −156 dBW (or −166 dBW) is exceeded if the FS transmitter power were to be limited to the value assumed in the simulations, or, in the case of simulation number 4, the licensed values for the stations which are assumed to be specified as peak power levels. The range of percentage values for simulation number 2 cover the range of FS station deployment densities, which the range of values in simulation number 3 represent the impact on different passive sensors from the same deployment model. These results are presented in Table 20.

TABLE 20

Percentage of measurement area exceeding permissible interference power level

10 GHz simulation study number	FS/MS type	Transmitter power P_t in dBW	FS/MS station density per 10^7 km^2	Percent of measurement area exceeding −156 dBW	Percent of measurement area exceeding −166 dBW
1	P-P	−3	48 to 2 512	< 0.1 to 13	0.4 to 30
1	P-MP (1H1C)	−3	16 to 314	0.2 to 13	0.2 to 20
1	P-MP (2C)	−10	16 to 314	0.2 to 13	0.2 to 20
1	P-MP (2H)	−3	16 to 314	0.1 to 10	0.8 to 10
2	Australia database	−3	966	1.8	0.5 to 20
2	USA database	−3	2 652	3.6	10 to 30
3	200 P-MP	−10	200	< 0.1 to 0.8	0.1 to 11
3	100 P-P	−3	100	< 0.1 to 0.6	1 to 5
3	100 mobile	−3	100	1 to 3	11 to 50
4	51 P-P	−3	51	1.1	3.3
4	982 mobile (35 dBi antenna)	−3	982	14.6	31
4	982 mobile (0 dBi omni antenna)	−3	982	17.44	38
4	3 mobile (35 dBi antenna)	−3	3	0.06	0.2
4	3 mobile (0 dBi omni antenna)	−3	3	0.22	0.4

5 Mitigation approaches

5.1 Earth exploration-satellite service (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.
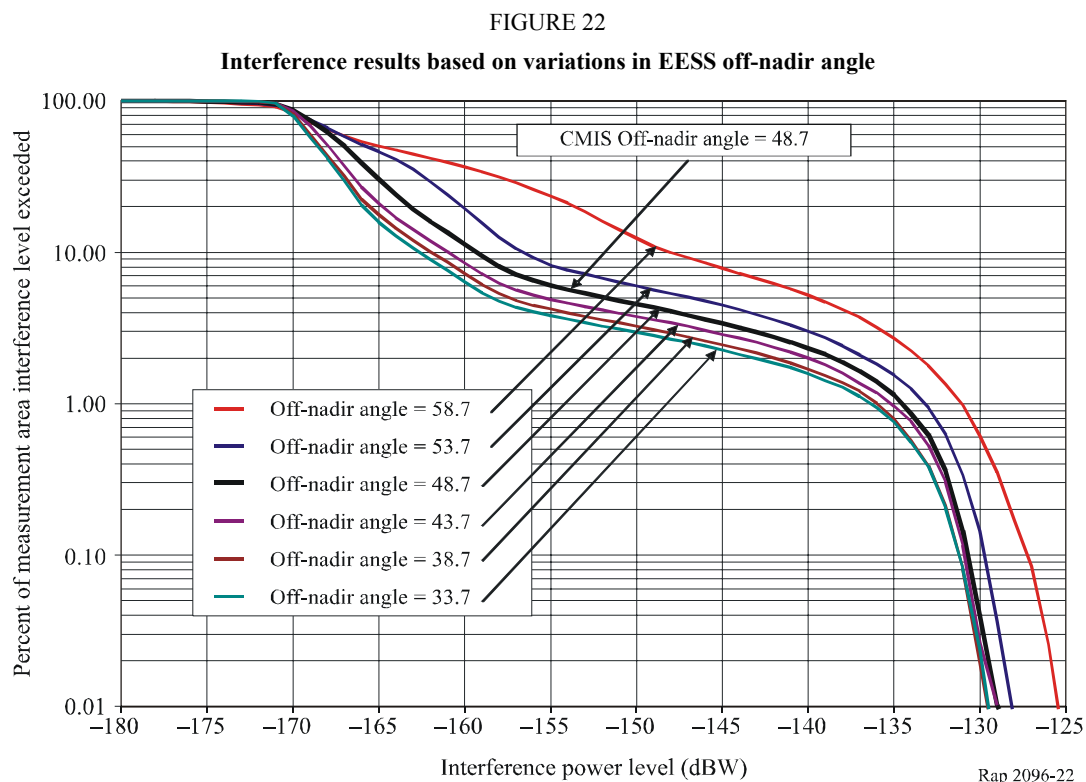
The following technical and operational characteristics of an EESS (passive) instrument were considered and evaluated as possible approaches to mitigate or minimize the chance of interference:

− 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 an FSS antenna pattern specified in Recommendation ITU-R S.672[3] 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 EESS elevation angle variations, one of the previously reported simulation models was rerun different passive sensor off-nadir pointing angles ranging from 15° lower to 10° greater than the 48.7° CMIS off-nadir angle. The results of these simulations are presented in Fig. 22.

Examination of this figure indicates that reducing the off-nadir angle from the current CMIS off-nadir angle does not significantly reduce the interference level. However, such a reduction would significantly reduce the passive sensor swath and the amount of area over which data is collected on each satellite pass. Increasing the off-nadir angle beyond the current CMIS angle does appear to significantly increase the interference levels.

FIGURE 22

Interference results based on variations in EESS off-nadir angle

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[3]   Recommendation ITU-R S.672: Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites.

5.2   Fixed service

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 EIRP.

–   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 rerun with each FS station randomly assigned an elevation angle based on a uniform distribution of elevation angles between 0° and an upper limit ranging from 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 FS deployment model is the one designated as FS P-P case-4 parameters for the CMIS passive sensor and the Central Asia measurement area in a previous contribution. The results of these simulations are presented in Fig. 23.

Examination of this figure indicates a slow increase in the interference level at the 0.01% of measurement area with maximum FS elevation angle from 0° to 20°, with a significantly larger increase between 20° and 25°.

FIGURE 23

Interference results based on variations in FS elevation angles

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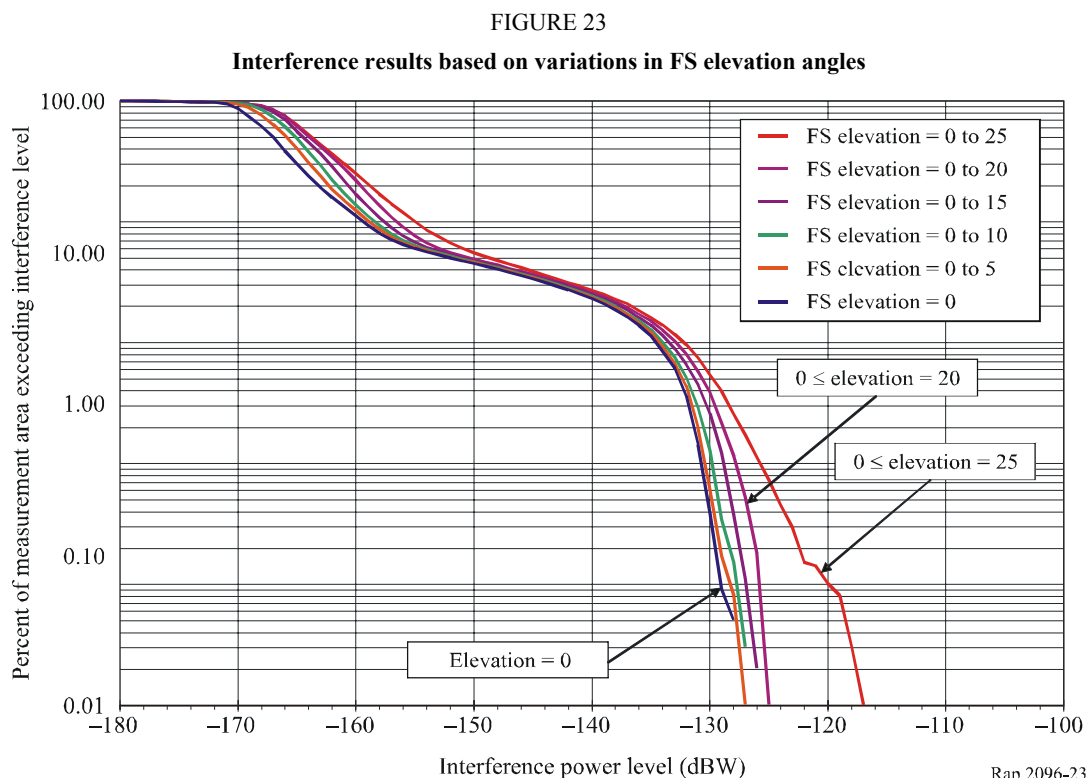
NOTE – Although these studies considered FS elevation angles up to 25° in order to identify the elevation angle at which in the interference level significantly increases, FS elevations above 5° are rare in actual operating systems.

Previous interference simulations have generally assumed that all FS transmitters operate at the same transmit power level. However, examination of some license records 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 between −30 dBW and −2 dBW that just provided a specified receive level under free space propagation conditions over path lengths randomly chosen between 0.5 and 30 km with a uniform probability distribution. The specified receive level included fade margins between 30 and 60 dB above minimum −117 dBW desired receive signal level. Figure 24 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. The figure also includes the CDF for the case where each FS station transmits at the specified −2 dBW maximum power level.

FIGURE 24

Interference results based on P-P path length dependent transmit powers
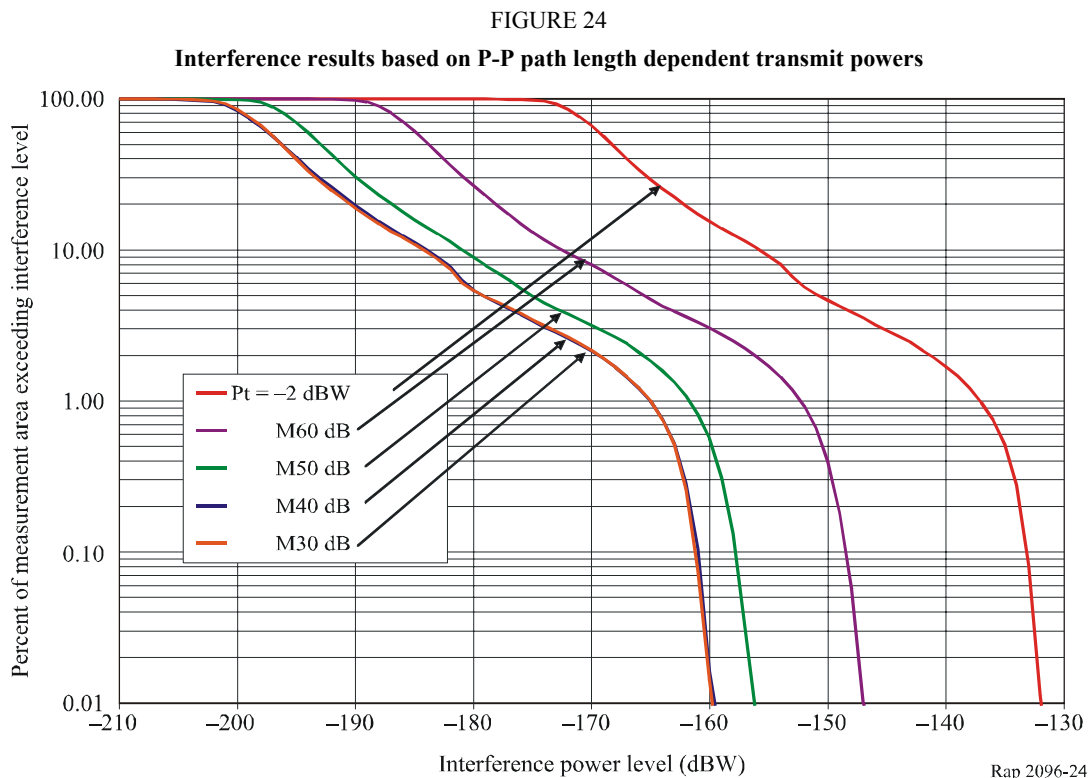
NOTE – Designations such "M30dB" used to label the CDFs refer to the margin over free space propagation provided by the FS transmitter power setting.

Additional simulations were conducted for P-MP systems in which the transmit powers of the customer station links in the P-MP systems were adjusted between the limits of −10 and −30 dBW to provide the nominal receive signal level of −110 dBW . Hub stations were assumed to operate with a −3 dBW transmitter power in all cases. A customer station antenna gain of 23 dBi was assumed in these simulations, and the path lengths were randomly varied between 0.1 and 10 km. The results of these simulations are presented in Fig. 25. These simulations indicate a significant reduction in passive sensor interference levels when power control is used on the customer links compared to the case when both of the P-MP channels in the passive band are used by hub stations

at the −3 dBW maximum transmitter power level. However, the passive sensor interference level would be even lower for the case when hub stations use the channels with their total transmitter power limited to the −10 dBW value.

FIGURE 25

Interference results based on P-MP path length dependent transmit powers

Rap 2096-25
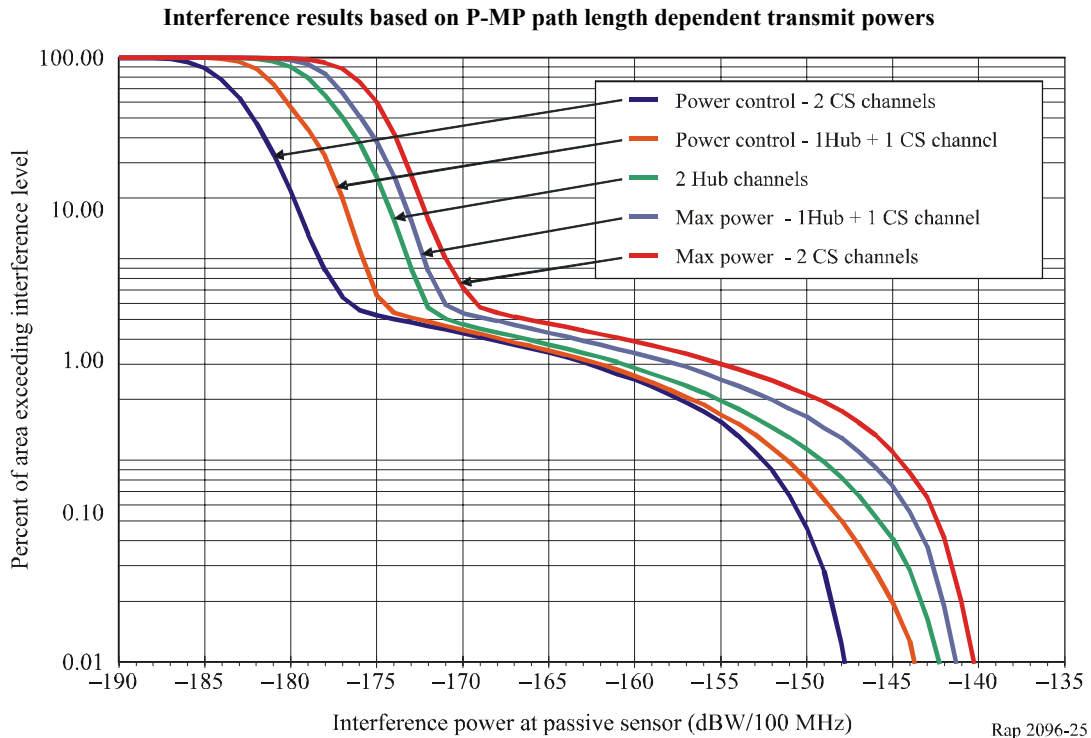
5.3   Mobile service

Since the MS applications considered in these studies are based on MS systems with similar characteristics to those of P-P FS systems, the mitigation considerations discussed in § 5.2 apply to these MS applications.

6   Conclusion

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 10.6-10.68 GHz band from several types of FS and MS stations. Section 4.6 of this report summarizes the results of these studies. Table 19 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 20 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.

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. The following table identifies possible limits on the technical and operational characteristics of these systems that can facilitate the sharing of the 10.6-10.68 GHz band between EESS (passive) and the FS and MS. It should be noted that in developing this table, there was an attempt to specify limits that struck the proper balance between avoiding undue constraints on the active services while providing adequate protection of the EESS (passive).

TABLE 21

Possible sharing criteria in the band 10.6-10.68 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 ≤ 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:
	  ≤ −15 dBW, or
	  ≤ −5 dBW with 10 dB ATPC
	Maximum P-MP transmitter power:
	  ≤ −17 dBW hub stations
	  ≤ −10 dBW customer stations
		Maximum transmitter power −17 dBW

Main beam efficiency ≥ 85%, 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. ≤ −4 dBW	

Each of the individual entries in this table, such as maximum power, is based on simulations that assume that no mitigation techniques are applied by the active service unless specified in the table. The limits indicated in the table may be relaxed if mitigation techniques are applied. Possible mitigation techniques include flexible power setting, 10 dB or more ATPC to mitigate fading, and use of high performance directional antennas. The ATPC entry in the table above specifies, for example, the case in which a 10 dB ATPC is used. In the case of 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 this table 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 ITU-R documents

Recommendation ITU-R F.758: Considerations in the development of criteria for sharing between the terrestrial fixed service and other services.

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.