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Compatibility between EESS (passive) in band 23.6–24 GHz and 5G in band 24.25–27.5 GHz

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Abstract. The 24.25–27.5 GHz band was allocated to IMT (International Mobile Telecommunication) during the World Radiocommunication Conference (WRC) after studies were elaborated between this potential allocation and the services in adjacent band and in particular with Earth Exploration by satellite in adjacent band. Several studies were evaluated during the WRC-19 cycle. This document describes only the studies undertaken by some European states for the protection of Earth exploration by satellite. The elements provided in this document are the basis of the European position for WRC-19 on the protection of passive EESS in 23.6–24 GHz.

Keywords. WRC-19, Passive EESS, 5G, Unwanted emissions, Sensors, IMT, Resolution ITU-R 750.
Available online 6th May 2021

1. Introduction

Many bands have been proposed for new IMT allocations during the cycle of WRC-19 under agenda item 1.13 (24.25–27.5 GHz, 31.8 33.4 GHz, 37–40.5 GHz, 40.5–42.5 GHz, 42.5–43.5 GHz, 45.5–47 GHz, 47–47.2 GHz, 47.2–50.2 GHz, 50.4–52.6 GHz, 66–71 GHz, 71–76 GHz and 81–86 GHz). These bands have been chosen primarily for the introduction of 5G broadband equipment in urban and suburban environments. Nine of these bands were already allocated to the mobile service, but by definition, an identification of the band by IMT changes the sharing conditions between the mobile service and other services in the band or adjacent band. The band 24.25–27.5 GHz appeared quickly the more appropriate band for 5G enabling at the same time, best propagation condition (in regards of other higher bands) and good data transfer capacities.

2. Usage and status of the band 23.6–24 GHz

Typically in the 22.21–22.5 GHz and 23.6–24 GHz bands, passive measurements focus primarily on the quantification and characterization of atmospheric water vapor [1]. The protected bands in this range are therefore usually used for atmospheric sounding. However, in this frequency range, radiometric measurements of water vapor are generally made in the high 23.6–24 GHz band in order to replace the strong dynamics of signals from the resonance of H_2O in 22.21–22.5 GHz. The 23.6–24 GHz bands is essential to all measurement performed in other passive

Table 1. Protection criteria of passive sensor in the band 23.6–24 GHz

Frequency band (GHz)	Total bandwidth (MHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded[(1)]
23.6–24	400	200	−166	0.01

[(1)] For a 0.01% level, the measurement area is a square on the Earth of 2000,000 km.

bands by radiometer by enabling the correction of these measurements in presence of water vapor.

Today, the World Meteorological Organization (WMO) has identified approximately 70 satellites in orbit that perform passive measurements in the 23.6–24 GHz band using a radiometer. Most of the listed satellites are meteorological and in particular:

- METOP satellites from Eumetsat operating AMSU-A (Advanced Microwave Sounding Unit—15 channels from 23 to 89 GHz [2]), MWS or MWI type radiometers.
- ROSHYDROMET satellite from Russians, METEOR type satellites carrying MTVZA-GY type radiometers (Advanced Microwave Sounding Unit—21 channels from 10.6 to 183 GHz [3]).
- NOAA US, NOAA or JPSS type satellites carrying AMSU-A type sensors.
- Chinese CMA, FY type satellites carrying MWRI (Micro-Wave Radiation Imager—6 channels from 10.65 to 150 GHz) or MWTS type radiometers.

In terms of status, the band 23.6–24 GHz bands is internationally protected by Radio Regulation in the footnote RR 5.340 (“all emissions are prohibited”).

3. Characteristics of EESS systems operating in the band 23.6–24 GHz

The various radiometers carried by these satellites are characterized today in Recommendation ITU-R RS.1861 [4]. It precisely defines all the parameters of these sensors (maximum size and gain of the antenna, integration period, etc.) as well as the orbital specificities of the satellites that transport them. The sensors are generically specified in the Recommendation (and not directly named). In the frequency band 23.6–24 GHz, 8 sensors are described.

The Recommendation ITU-R RS.2017 [5] defines the protection criteria to be respected for the proper use of these radiometers. From a practical point of view, interfering emissions have the consequence of increasing the noise level of the receiver and therefore degrading its sensitivity. The protection criterion is therefore defined as an acceptable temperature variation of the noise of the radiometric receiver by the presence of an interfering emission (transcribed in terms of power in dBW). This variation is associated with a percentage of time during which this level must not be exceeded. In the 23.6–24 GHz band, the artificial interference in the receiver must not exceed the smallest measurable noise temperature difference (equal to 0.05 °K) during 99.99% of the time. In terms of power, this means that interference from all emission sources should not exceed −166 dBW/200 MHz for 99.99% of the time (Table 1). The measurement area, on which this percentage applied is a surface of 2000,000 km^2.

Due to the surrounding of the passive band by several active systems, one apportionment of the protection criteria was introduced. Below the passive band, the Fixed Service (FS) is massively deployed and above, the IMT will be introduced. The unwanted emission of this two services fall into the passive band 23.6–24 GHz and an apportionment of 3 dB are then applied to the protection criteria to ensure the compliance of the EESS protection from emission of both active services together. The acceptable interference power becomes −169 dBW/200 MHz for 0.01% of the time for IMT.

4. Characteristics of IMT systems operating in the band 24.25–27.5 GHz

Table 2 provides the planned characteristic of IMT in the band 24.25–27.5 GHz. These parameters were defined by the ITU-R expert group of IMT (Working Party 5D) several particularities have to be highlighted:

1. The 5G Network in millimetric band is based on Time Duplex Division, enabling some exchange in time between Base Station (BS) and User Equipment (UE) on the same frequency channel. The division in time (activity factor) is respectively 80% for the BS and 20% for the UE.
2. The unwanted emissions of BS and UE in the band 23.6–24 GHz are defined in terms of Total Radiated Power (TRP) and represent respectively −24 dBW/200 MHz and −20 dBW/200 MHz (3 dB of ohmic losses were applied to the estimated unwanted conducted power). This TRP is defined as the power radiated in the entire sphere around the antenna.
3. The BS and UE antennas used for 5G are Active Antenna System (AAS) and their beams are respectively formed by 8 × 8 or 4 × 4 radiated elements presented each an intrinsic gain of 5 dBi. Their antenna pattern is modeled in the Recommendation ITU-R M.2101 [6].
4. The BS and UE antennas, always point their maximum gain toward each other during communication.
5. Due to power control, the power transmit by the UE is not constant and depends on its position from the BS. The deployment considers that 5% of UE could be indoors.
6. Due to the number of UEs connected to BS, the maximum power of the BS is distributed on each UE.
7. In an IMT cell, for one operator, the proposed deployment consists in one BS and 3 UEs.
8. A channel aggregation factor of 2 dB was used in order to mainly take into account the summation of power in the passive band of the unwanted emission of IMT 2020 channels used by different operators.
9. The distribution of UEs in the BS coverage follows a Rayleigh distribution in terms of distance from BS ($\sigma = 32$) and a normal distribution in regards of its position in azimuth ($\mu = 0°$ and $\sigma = 30°$).
10. The proposed deployments of BS and UE per km^2 are provided in Table 2 (from 30 to 10 BS/km^2 for respectively urban and suburban deployment). It has to be noted that the deployment needs to be reevaluated by two factors Ra and Rb. Ra represents the real coverage rate of equipment in a building area (city) and Rb the rate of building area in a specific environment (urban, suburban, rural...).

During the cycle of studies, two different assumptions were discussed on the behavior of AAS antenna in unwanted domain (or more precisely in the band 23.6–24 GHz). Two options were assumed:

1. In unwanted domain, the correlation between radiated elements totally disappears and the antenna is not able to shape the main beam and the side lobes in an appropriate way. The radiated pattern could be described as the pattern of a single element (closed to omnidirectional) and the global antenna is not able to perform electrical pointing.
2. In unwanted domain, due to the facts that IMT equipment will be designed to operate in a large band (3.25 GHz) and that a low frequency distance between the center frequency of IMT equipment and passive band will exist (250 MHz, that means 1/13 of the total band), the AAS will be able to create beamforming in adjacent band. In this particular case, the parameter of the M.2101 model was modified in order to take into account the

Table 2. Parameter of simulations

Sensor	F1	F2	F3	F4		F5		F6	F7		F8
Type of sensor	Conical	Conical	Conical	Mechanical (cross-track)		Mechanical (cross-track)		Conical	Push-broom		Conical
Sensor geometric characteristics											
Orbit altitude (km)	817	705	828	833		824		835	850		699.6
Nadir angle (°)	44.5	47.5	46.6	±48.33	0.0	±52.725	0.0	55.4	±50	0.0	47.5
Elev at ground Θ (°)	37.7	35.0	34.8	32.4	90.0	26.01	90.0	21.4	29.7	90.0	35.1
Slant path distance (km)	1228	1124	1309	1378	833	1563	824	1767	1482	850	1114
Footprint size (km^2)	1880	452	169	9298	1847	35,983	4395	2430	201	201	306
Antenna gain (dBi)	40	46.7	52	34.4	34.4	30.4	30.4	43	45	45	48.5
Protection criteria (dBW/200 MHz)	−166	−166	−166	−166	−166	−166	−166	−166	−166	−166	−166
Apportionment (dB)	3	3	3	3	3	3	3	3	3	3	3
Propagation losses											
Free space losses (dB)	181.72	180.95	182.27	182.72	178.34	183.81	178.25	184.88	183.35	178.52	180.87
Atmospheric losses (dB)	0.69	0.73	0.74	0.78	0.42	0.95	0.42	1.15	0.85	0.42	0.73
Clutter losses (dB)(5)	Distributed (see Figure 1)										
Polarisation losses (dB)	3	3	3	3	3	3	3	3	3	3	3
Urban BS characteristics											
Unwanted emission (dBW/200 MHz)	−21	−21	−21	−21	−21	−21	−21	−21	−21	−21	−21
Ohmic losses (dB)	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3
Unwanted TRP (dBW/200 MHz)	−24	−24	−24	−24	−24	−24	−24	−24	−24	−24	−24
Urban deployment (BS/km^2)	30	30	30	30	30	30	30	30	30	30	30
Urban area (km^2)	200	200	169	200	200	200	200	200	200	200	200
Ra (%) urban	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Number of BS(1)	420	420	338	420	420	420	420	420	420	420	420
Sensor geometric characteristics											
Suburban Deployment (BS/km^2)	10	10	10	10	10	10	10	10	10	10	10
Remaining area (km^2)	1680	252	−31	9098	1647	35,783	4195	2230	1	1	106
Ra (%) suburban	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Rb (%)	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Number of BS(1) in remaining area	202	30	0	1092	198	4294	503	268	0	0	13
Total number of BS	622	450	420	1512	618	4714	923	688	420	420	433
Loading factor (%)	20	20	20	20	20	20	20	20	20	20	20
TDD factor (%)	80	80	80	80	80	80	80	80	80	80	80
Antenna gain (dBi)(2)	Distributed										
Channel Aggregation (dB)	2	2	2	2	2	2	2	2	2	2	2
Urban UE characteristics											
Unwanted emission (dBW/200 MHz)	−17	−17	−17	−17	−17	−17	−17	−17	−17	−17	−17
Ohmic losses (dB)	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3
Unwanted TRP (dBW/200 MHz)	−20	−20	−20	−20	−20	−20	−20	−20	−20	−20	−20
Mean power control attenuation (dB)	Distributed										

(continued on next page)

Table 2. (continued)

Sensor	F1	F2	F3	F4		F5		F6	F7		F8
Type of sensor	Conical	Conical	Conical	Mechanical (cross-track)		Mechanical (cross-track)		Conical	Push-broom		Conical
Urban deployment (UE/km^2)	100	100	100	100	100	100	100	100	100	100	100
Urban area (km^2)	200	200	169	200	200	200	200	200	200	200	200
Ra (%)	7	7	7	7	7	7	7	7	7	7	7
Number of UE$^{(1)}$	1400	1400	1183	1400	1400	1400	1400	1400	1400	1400	1400
Suburban deployment (UE/km^2)	30	30	30	30	30	30	30	30	30	30	30
Suburban area (km^2)	1680	252	0	9098	1647	35,783	4195	2230	1	1	106
Ra (%)	3	3	3	3	3	3	3	3	3	3	3
Rb (%)	5	5	5	5	5	5	5	5	5	5	5
Number of UE$^{(1)}$	664	100	0	3594	651	14,134	1657	881	0	0	42
Total number of UE	2064	1500	1183	4994	2051	15,534	3057	2281	1400	1400	1442
Loading factor (%)	20	20	20	20	20	20	20	20	20	20	20
TDD factor (%)	20	20	20	20	20	20	20	20	20	20	20
Antenna gain (dBi)$^{(2)}$	Distributed										
Body loss (dB)	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4
Channel aggregation (dB)	2	2	2	2	2	2	2	2	2	2	2
Total received power by sensor from UE and BS											
Interference power (dBW/200 MHz)	Distributed (see Section 6)										

changes in terms of wavelength of the radiated element and the spacing between them in the unwanted domain.

5. Scenario of study

5.1. *Surface of study and IMT deployment*

The scenario of study is principally based on the characteristics and protection of Earth Exploration satellites. If some consideration of long time is taken, it is possible to establish that the satellite footprints cover uniformly all the Earth surface on which the sensor could fly (depending of its orbit inclination). The acceptable interference power can exceed −169 dBW/200 MHz for 0.01% of the time. As depicted in the Recommendation ITU-R RS.2017, this criterion has to be applied to a surface on the Earth of 2000,000 km^2. Considering the long time assumption, the 0.01% of time can be translated as 0.01% of the surface and finally the protection criteria should be respected if only a surface of 200 km^2 presents an exceedance of power. This kind of surface is closed to the surface of a city like Paris.

In the deployment of BS and UE in the satellite footprints, the Ra and Rb parameters are used. If the considered sensor footprint is:

1. Lower than the city dimension, only the value of Ra for urban environment was used (Rb was taken equal to 1).
2. Higher that the city, the value of Ra for urban environment was used only on 200 km^2 of the footprint and the value of Ra and Rb for suburban environment was used in the remaining area.

For each footprint, the total number of deployed equipment is calculated based on the previous element. In a second step, the total number of equipment that emit in the same time

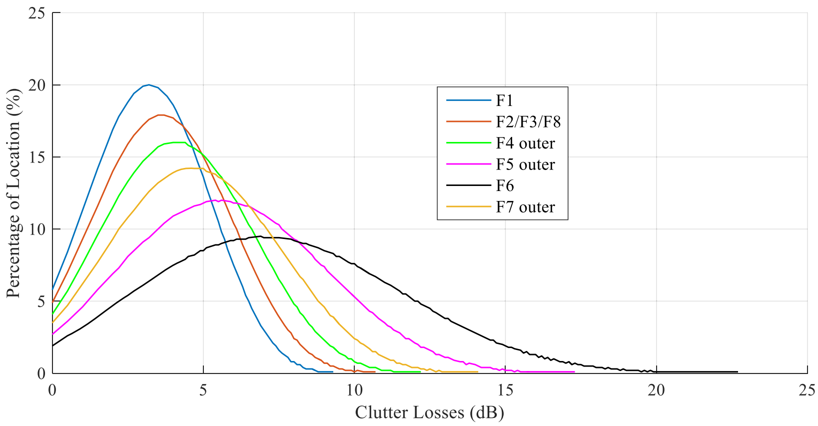

Figure 1. Distribution of clutter losses for different elevation angle between mobile systems and satellite. Elevation is taken from ground.

is assumed by using the loading factor (20%). And finally the global emission toward satellite is split between 80% of BSs and 20% of UEs.

5.2. *Losses between IMT network emissions and satellite*

The losses between active IMT systems and passive satellite can be summarized as:

1. Free space losses calculated on the slant path distance. From the satellite, all emitters in the footprint can be "seen" as an aggregation of emitters deployed on a point. The distance between all emitters in the footprint and the satellite are identical.
2. Atmospheric losses, based on Recommendation ITU-R P.676 [7].
3. Clutter losses extracted form Recommendation ITU-R P.2108 [8] for different incident angles from the ground (angle under which that emitters "see" the satellite). Figure 1 presents the Probability Distribution Functions (PDF) of clutter for different elevation angle (matching with the elevations of the sensors from ground). For an elevation angle of 90°, when satellite is in the zenith of IMT equipment (i.e., nadir of mechanical sensor satellite) the clutter losses are equal to 0 dB.
4. 3 dB of polarization losses due to the IMT emissions in cross polarization and the EESS reception in linear.

5.3. *Simulations*

The simulations were performed for each footprint, considering the total number of equipment (Table 2). Between each snapshot (Figure 2), most of parameters are considered as fixed, except the position of UEs in regard of BSs resulting in some changes for:

1. The antenna gains from BS to UE and reciproqually and from BS/UE to EESS satellites.
2. The UE conducted power, as a consequence of the UE power control.
3. The Clutter losses in a given elevation. Each snapshot, this factor is randomly chosen for each path between UEs and BS towards satellite (considering it elevation angle from ground).

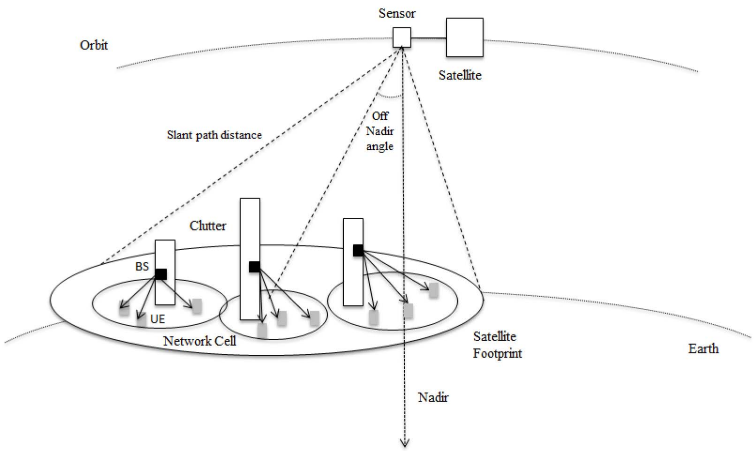

Figure 2. Scenario of simulations.

The total interference level I_{tot} (in linear) in the satellite sensor F_x can be expressed as:

$$I_{\text{tot}} = 10^{\left[\frac{(G_{\text{sat}}+\text{AF})}{10}\right]}\left[F_{\text{BS}}\sum_{i=1}^{i=\text{Nb}_{\text{BS}}} 10^{\left[\frac{(P_{\text{BS}_i}+G_{\text{BS}_i}-L_{\text{BS}_i})}{10}\right]} + F_{\text{UE}}\sum_{j=1}^{j=\text{Nb}_{\text{UE}}} 10^{\left[\frac{(P_{\text{UE}_i}+G_{\text{UE}_i}-L_{\text{UE}_i})}{10}\right]}\right]$$

where

- Nb_{BS} and Nb_{UE}: the total number of active BS and UE in the footprint of F_x
- F_{BS} and F_{UE}: the TDD factor of active BSs and UEs in the footprint (%)
- P_{BS_i} and P_{UE_i}: the conduced power of the ith BS or jth UE (dBW/200 MHz)
- G_{sat}: the satellite gain (dBi)
- L_{BS_i}: the total losses between BS_i and satellite. These losses include free space on the slant path, clutter, polarization and atmospheric losses (dB)
- L_{UE_i}: the total losses between UE_i and satellite. This losses are equal to L_{BS_i} with additional losses due to body loss (dB)
- AF: Multi-operator aggregation factor (dB).

6. Results

The following Table 4 provides the summary of some results of Monte Carlo simulations performed on all sensors considering the antenna pattern in adjacent band as single element or as beamforming antenna.

In the case of beamforming in unwanted domain, the result of interference is taken at 99% of the interference cumulative distribution. In the case of single element behavior in unwanted domain, the result of interference is based on the average (weighted sum) of the distribution.

This choice of result analysis could be explained by two different facts:

1. First, the spread of the distribution of interference when beamforming assumptions are considered in the passive band. Globally for conical sensors that point every time in the same elevation, the dynamics of the distribution considering the single element assumption is around 6 dB. In the case of beamforming pattern assumptions, this dynamics is between 11 to 14 dB.
2. Secondly, 99% of the interference, for beamforming assumption, could be explained by the fact that 2000,000 km^2 represent approximately half of the European Union surface

Table 3. Summary of results: Monte Carlo simulation for both assumptions in adjacent band (single element and beamforming antenna)

Sensor		F1	F2	F3	F6	F8
Beamforming antenna	99% (dBW/200 MHz)	−160.2	−153.3	−150.6	−161.6	−151.5
	Margin (dB)	8.8	15.7	18.4	8.4	17.5
Single element	Average (dBW/200 MHz)	−153.8	−147.5	−144.6	−153.5	−145.8
	Margin (dB)	15.2	21.5	24.4	15.5	23.2

Conical sensors (F1, F2, F3, F6 and F8).

Table 4. Summary of results: Monte Carlo simulation for both assumptions in adjacent band (single element and beamforming antenna)

Sensor		F4		F5		F7	
Footprint position		Nadir	Outer	Nadir	Outer	Nadir	Outer
Beamforming antenna	99% (dBW/200 MHz)	−162	−165	−165	−168	−152.9	−157.6
	Margin (dB)	7	4	4	1	16.1	11.4
Single element	Average (dBW/200 MHz)	−161.7	−156	−163.9	−156	−153	−151.5
	Margin (dB)	7.3	13	7.1	13	16	17.5

Mecanical sensors (F4, F5, F7).

and in this area, at least 100 cities present a surface closed or higher than 200 km^2, so only one "pixel" of 200 km^2 can exceed the protection criteria.

As shown in Figures 3 and 4, considering only the shape of the distribution, the interference increases by around 10 to 15 dB for high percentage and by 5 to 7 dB in low percentage if the "single element" assumption is taken to model the antenna behavior in adjacent band.

The studies have shown that the sensor F3 was the most sensitive sensors to interference from IMT 2020 in both assumptions of antenna radiation pattern. The position of CEPT was based on the capability of AAS to build a beam in adjacent band and a reduction of IMT unwanted emission by 18 dB (Table 3 for F3) was proposed in order to ensure the protection of every sensors, resulting of unwanted emission of respectively −42 and −38 dBW/200 MHz for BS and UE.

During WRC-19, the final decision, based on a two-steps principle was inserted in the Resolution ITU-R 750 [9]:

1. In a first time, a reduction of 9 dB (−33 and −29 dBW/200 MHz for BS and UE) is imposed to IMT equipment. This value is mandatory until September 2027.
2. After this date, the reduction will be equal to 15 dB (−39 and −35 dBW/200 MHz for BS and UE).

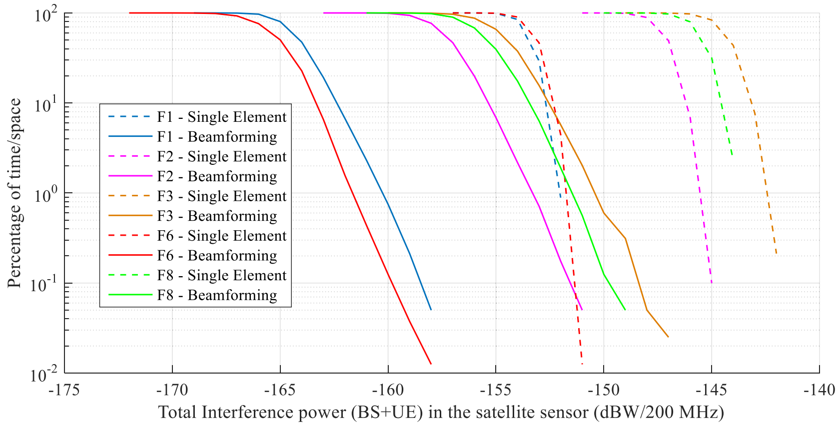

Figure 3. Distribution of interference power in conical sensors (F1, F2, F3, F6 and F8).

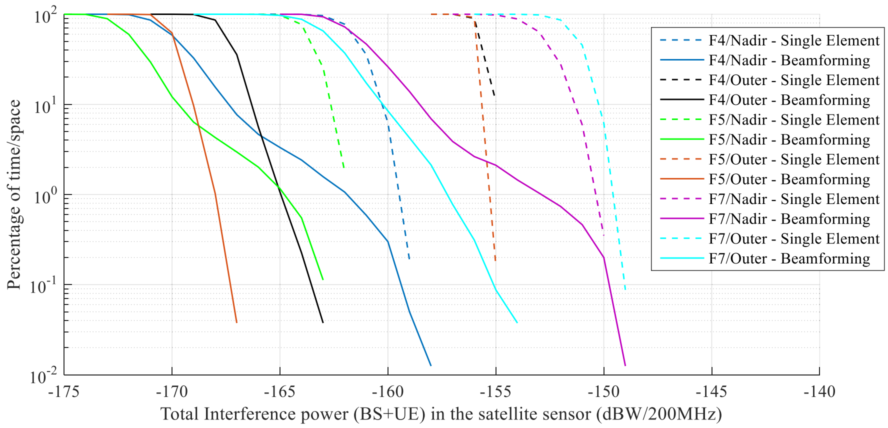

Figure 4. Distribution of interference power in mechanical sensors (F4, F5 and F7).

Europe, by ECC, took the decision to minimize the impact of IMT on passive EESS by reducing the time during which the unwanted emission will be higher. In Europe, the 15 dB of reduction will apply from January 2024 instead of September 2027. In addition, since the long term limit of −39 dBW/200 MHz, instead of −42 dBW/200 MHz, was justified by not taking into account the 3 dB apportionment factor, Europe also enshrined in its decisions that the frequency band below 23.6 GHz shall not be used by high density broadband systems.

7. Conclusions and discussion

This document proposed to explain the calculation performed by some European States in order to protect the meteorological space system in the band 23.6–24 GHz. All the parameters and assumptions provided in this document were intensively discussed during the WRC-19 cycle in ITU (International Telecommunication Union) and some of them were not agreed by all member States. Particularly, it was the case for the 2 dB of channel aggregation and the 3 dB of protection criteria apportionment.

Based on these assumptions, the European position to WRC-19 was to impose a reduction of 18 dB to IMT system in the unwanted domain. Long discussions took place during the WRC and some compromises were made, coming to an approach in two steps.

With or without these elements, the Sensors F3 seems to be the most sensitive sensors to interference. It can be mostly explained by its high gain (52 dBi) in regards of the other sensor gains. It should be noted that this sensor is planned to be used but not deployed yet in space. However, it could be noticed that the results of studies for sensors F2 and F8, already in orbit, are closed to those for F3 by respectively around 3 dB and 1 dB. Their respective antenna presents a lower gain than F3 antenna but in the same time their own slant path distance is lower too (so the propagation losses are lower).

The way to model the IMT antenna has an important impact on the results. The decision was taken for WRC-19 to use the assumption of beamforming in adjacent band. Some monitoring of effective IMT stations and deployment parameters (including active antenna but also base station density, real unwanted emission level, tilt statistic, etc.) will be necessary to ensure the absence of satellite interference in the long term.

Abbreviations

AAS	Active Antenna System
AMSU	Advanced Microwave Sounding Unit
BS	Base Station
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CMA	China Meteorological Administration
CMR	Conférence Mondiale des Radiocommunications
ECC	Electronic Communications Commitee
EESS	Earth Exploration Satellite Systems
IMT	International Mobile Telecommunication
ITU	International Telecommunication Union
JPSS	Joint Polar Satellite System
MWI	Microwave Imager
MWRI	Micro-Wave Radiation Imager
MWS	Microwave Sounder
MWTS	Microwave Temperature Sounding
NOAA	National Oceanic and Atmospheric Administration
SETS	Service d’Exploration de la Terre par Satellite
UE	User Equipment
UIT	Union Internationale des Télécommunications
WMO	World Meteorological Organization
WRC	Word Radiocommunication Conference

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