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|  U.S. Radiocommunications SectorFact Sheet |
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| **Purpose/Objective:**  Submit further information impacts of using 24 GHz ISM band for WPT Beam |
| **Abstract:** New/revised material will further address protection of adjacent passive services in RAS and EESS (passive) |

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**Background**

Report ITU-R SM.2505-0 was approved in 2022 to provide administrations with guidelines the impact spectrum impact and human hazard issues for wireless power transmission via radio frequency beam. The United States is also developing a variant of this technology for use in the 24 GHz ISM band.

**Proposal**

The United States proposes that Report ITU-R SM.2505-0 be amended with the material in the attachment that documents the impacts of Beam WPT use in 24.1-24.15 GHz. The proposed changes only involve Study F (24.1-24.15 GHz). Except for adding several near 24 GHz bands of other services for consideration in the “Studies on the impact to the incumbent systems” section, other parts of the document are unchanged.

**Attachment**: Working document towards a preliminary draft revision of Report ITU-R SM.2505-0

**In order to keep the size of this document manageable, this excerpt contains only the parts of the Chairman’s Report document for which changes are proposed. These changes only concern 24 GHz Beam WPT and do not affect any other bands.**

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|  Working document towards a preliminary draft revision of REPORT ITU-R SM.2505-0  |
| **Impact studies and human hazard issues for wireless power transmission via radio frequency beam** |

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# 3 Studies on the impact to the incumbent systems

The possible incumbent systems that may require impact studies are as follows:

– Wireless LAN (2.4 GHz, 5.6 GHz band);

– DSRC (5.8 GHz band);

– IMT (900 MHz band);

– MCA (920 MHz band);

– LPWA (920 MHz band);

– RFID (920 MHz band);

– Amateur radio (2.4 GHz band, 5.7 GHz band);

– Radar (5.6 GHz band);

– Microwave link (5.9 GHz band);

– Mobile satellite communication system (2.5 GHz band);

– Radio astronomy (1.4 GHz band, 2.7 GHz band, 4.8 GHz band, adjacent 23.6-24.0 GHz band);

– EESS (active) (co-frequency 5 470-5 570 MHz, 24.05-24.25 GHz band, adjacent 5 250-5 470 MHz band,);

– EESS (passive) (adjacent 23.6-24.0 GHz band);

* IMT (adjacent 24.25-27.5 GHz)

– Other systems operated in adjacent frequency bands and/or frequency range where harmonic emissions may occur.

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## 3.6 Study F (24.1-24.15 GHz)

[Editor’s note: Study F was not discussed during the June 2023 WP 1A meeting and will require a more thorough analysis at the next meeting, in particular considering the assumptions and scenarios used, including the 10 MHz bandwidth.]

### 3.6.1 United States Industrial, Scientific and Medical regulations

In the US, the Federal Communications Commission (FCC) regulates the use of radiocommunications frequencies for civil applications. The FCC rules and regulations are codified in Title 47 of the US’ Code of Federal Regulations (CFR). Part 18 deals with Industrial, Scientific and Medical (ISM) devices. FCC has determined that in the US WPT is regulated as an ISM usage and is subject to its Part 18 rules.

### 3.6.2 24 GHz ISM BAND and Radiation Limits

FCC identifies 24-24.25 GHz band with a centre frequency of 24.125 GHz and maximum operating bandwidth of 250 MHz for ISM use consistent with the provisions of RR No. **5.150.** FCC radiation limits of the field strength level of emissions which lie outside the 24 GHz ISM band is a field strength limit of 25 μV/m as measured at a distance of 300 metres. Using the e.i.r.p. formula, we get a value e.i.r.p. of –27.27 dBm, or –57.27 dBW.

For unlicensed field disturbance sensors, excluding perimeter protection systems, in 24.075-24.175 GHz and general unlicensed devices, the maximum emission outside the specified band, other than for harmonics, must attenuated by at least 50 dB below the level of the fundamental or 500 μV/m at 3 m, whichever is less.

### 3.6.3 24 GHz ISM Beam WPT Parameters

This section provides examples of the characteristics of the 24 GHz beam WPT system being developed in the United States.

Other sets of parameters could come from other developers for alternative 24 GHz WPT systems.

The multielement antenna in the system being developed in the US has a different far field gain for OOBE that are uncorrelated over the various antenna elements than it has for the coherent in band signals at each antenna element.

TABLE 15

Radio Characteristics of Example Beam WPT System within 24 GHz band

|  |  |
| --- | --- |
| System | System |
| Frequency | 24.1-24.15 GHz |
| Bandwidth | 10 MHz |
| Output Power (W) | 50 |
| Antenna gain in ISM band (dBi) | 40 |
| E.i.r.p. in ISM band (dBm) | 87 |
| E.i.r.p. below 24 GHz (dBm) | –27.27 |
| Field strength limit at 300 m (uV/m) | 25 |

### 3.6.4 Human hazard issues for 24.1-24.15 GHz WPT

Technology being considered for these bands used phased array multiple elements beams to focus power on a small area for efficient power transfer. This creates a high-power flux density (pfd) at and near the power receiving area that could violate applicable safety standards. This situation is avoided by active measures that detect the presence of objects near the high pfd volume and reduces or ceases power transmissions when such objects are detected.

The strategy is to make sure applicable safety standards are met. Systems will employ multiple, independently operating and independently testable safeguards that will ensure that exposure requirements are met. These sensors are arranged so that significant power is only transmitted if there is an authorized power destination in a position ready to receive power and without any humans or pets in a nearby position where that would be exposed to unacceptable RF power levels. Examples of these sensors are the ability to evaluate the orientation of the device being charged, including whether it is moving, fixed, or set on a stable surface; the ability to passively sense nearby movement and beam interruption; and the ability to detect Doppler signals from the device being charged or people that are moving. In this way, the distances between the beam, the charging device, and any people located in the vicinity can be calculated in milliseconds, ensuring that the power transfer will cease before a person enters the path of a beam. These independent safety features are all native to the WPT system, meaning that they are inherent in the function of the beam formation apparatus of the WPT system.

In the case of the US, Maximum Permissible Exposure (MPE) to radiofrequency electromagnetic fields have been established for both bands and are shown in Table 16. At these high frequencies RF is generally absorbed by the skin and specific absorption rate (SAR) standards are not applicable.

TABLE 16

US RF Safety Standard Levels for 24GHz bands

|  |  |
| --- | --- |
| MPE for Occupational/Controlled Exposure (mW/cm2) | MPR for General Population/Uncontrolled Exposure (mW/cm2) |
| 5.0 | 1.0 |

### 3.6.5 Protection of Cochannel and adjacent Allocations

As discussed in the beginning of Section 3, Beam WPT in 24 GHz could potentially impact several services with cochannel or adjacent allocations. These include the 23.6-24.0 GHz allocation for Earth exploration-satellite (passive) (EESS(p)), the Radio Astronomy Service (RAS), the secondary allocation for Earth exploration-satellite (active) (EESS(a)) at 24.05-24.25 GHz and the Terrestrial Component of IMT at 24.25-27.5 GHz.

### 3.6.6 Protection of adjacent passive bands

The 24.1-24.15 GHz band discussed here for WPT Beam use is within the 24.0-24.25 GHz band designated for industrial, scientific and medical (ISM) uses pursuant to RR No. **5.150**. Under the provisions of 15.13 « Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service ». 100 MHz below the possible WPT Beam frequency is the 23.6-24.0 GHz band that is allocated on a coprimary basis for Earth Exploration Satellite (passive) , Radio Astronomy, and Space Research (passive) and protected under the terms of RR No. **5.340** that states «All emissions are prohibited». Pursuant to 15.13 administrations that authorize ISM devices «shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service». Space Research (passive) is not a concern because it involves satellite-based receivers not pointing at Earth, but the potential of possible interference to Radio Astronomy and Earth Exploration Satellite (passive) is a concern and will be discussed below along with limits administrations could use to prevent harmful interference to these services.

### 3.6.7 Radio Astronomy

During an observation, a radio astronomy telescope points towards a celestial radio source at a specific right ascension and declination, corresponding with a specific azimuth and elevation at a certain moment in time. During this observation, the pointing direction of the telescope compensate for the rotation of the Earth. It can generally be assumed that interference from a terrestrial transmitter is received through the sidelobes of the radio astronomy antenna; however, many radio astronomy systems are capable of operating to 0 degree elevation.

Recommendation ITU-R RA.769 assumes that the interference is received in a sidelobe of the antenna pattern, i.e., at a level of 0 dBi at 19º from boresight (see also Recommendation ITU-R SA.509). It should be noted that a radio telescope is an antenna with an extremely high gain, typically in the order of 70-80 dBi. If interference is received via the main lobe of the antenna pattern, this high gain should also be considered, and as noted in Recommendation ITU-R RA.769, damage may result to radio astronomy receivers under such scenarios. However, Recommendation ITU-R RA.769 assumes that the chance that the interference is received by the main lobe of the antenna is low, and therefore uses the level of 0 dBi in the calculation of the levels of detrimental interference given in this Recommendation.

Depending on the relative location of the interferer and the telescope, the interference occurs in the near field or the far field of the telescope. The far field area, or Fraunhofer area, lies beyond a distance of 2D2/, where D is the diameter of the telescope and  the wavelength. For the RAS frequency band in 24 GHz, this distance is of the order of 400 km for a radio telescope of 50 metre diameter. While radio astronomy systems operating in this band have a range in telescope size and type, a diameter of 50 metre was considered representative of radio telescopes operating in the frequency range 22-24 GHz.

For the assumptions considered in Recommendation ITU-R RA.769, it is irrelevant whether the interferer is in the near field or in the far field of a radio telescope. The near field/far field issue is relevant only for studies that need to consider the signal path from the interfering transmitter to the receiving antenna.

The following are the radio astronomy service (RAS) system parameters for the threshold levels of interference detrimental to radio astronomy continuum observations for the 23.8 GHz band.

The interference protection criteria for RAS (Rec. ITU-R RA.769-2) is a threshold value given as -195 dBW received signal power for continuum measurements, This recommendation states “that administrations, in seeking to afford protection to particular radio astronomical observations, should take all practical steps to reduce all unwanted emissions falling within the band of the frequencies to be protected for radio astronomy to the absolute minimum.”

TABLE 17

Excerpt of RAS Protection Criteria

|  |  |  |
| --- | --- | --- |
| Parameter | Value continuum observations | Spectral-line observations |
| Centre frequency (1) *fc* (MHz) | 23 800 | 23 700 |
| Assumed bandwidth *f* (MHz) continuum observationsAssumed spectral line channel bandwidth  f (kHz) spectral-line observations | 400 | 250 |
| Minimum antenna noise temperature *TA* (K) | 15 | 35 |
| Receiver noise temperature *TR* (K) | 30 | 30 |
| **System sensitivity(2)  (noise fluctuations)** |
| Temperature *T* (mK) | 0.05 | 2.91 |
| Power spectral density *P* (dB(W/Hz)) | –271 | –254 |
| **Threshold interference levels(2) (3)** |
| Input power *PH* (dBW) | –195 | –210 |
| pfd *SH* *f* (dB(W/m2)) | –147 | –161 |
| Spectral pfd *SH* (dB(W/(m2 ⋅ Hz))) | –233 | –215 |
| Notes:1 Calculation of interference levels is based on the centre frequency shown in this column.2 An integration time of 2 000 s has been assumed ; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, −1.3, −2.8, −4.8 or −6.3 dB respectively. 3 The interference levels given are those which apply for measurements of the total power received by a single antenna. |

### 3.6.8 RAS regulation

For the WPT system in the 24.1-24.15 GHz band described here,, the nearby 23.6-24.0 GHz band, subject to footnote RRNo. **5.340**, with its RAS allocation is considered here.

### 3.6.9 RAS Discussion

The analysis in Section A2.3 of Annex 2 deals with use of segments of the 24.1-24.150 GHz ISM bands for Beam WPT. It is recognized in the Radio Regulations that radio astronomy receivers employ “exceptionally high sensitivity” (**29.1-4**). At the same time, radio astronomy observatories are often located in remote sites, with some degree of control over emissions near RAS stations (RR No. **29.6**). This fact affords additional options and protection of RAS operations from ISM transmitters in nearby bands, in conjunction with administrations taking practicable steps to allow such operation. Some of these steps and options are also detailed in Article **29** of the RR.

With respect to operation of WPT systems and impacts to RAS sites, it is assumed individual administrations employ such steps as are necessary and useful to allow operation in conformance with the Radio Regulations. While administrations generally do not limit the possible locations of ISM devices, US presently prohibits low power unlicensed transmitters/short-range devices in radio quiet zones that surround some radio astronomy facilities.

### 3.6.10 Earth Exploration-Satellite Service (EESS) Passive Sensors

Earth exploration satellite service (passive) operates in the 23.6-24 GHz frequency band and is allocated on a primary basis in all three ITU regions. ISM is allocated to the adjacent band above this EESS band. RR No. **5.340** indicates that all emissions are prohibited in the 23.6-24 GHz band.

Currently, the EESS (passive) operates at least three major types of passive sensors:

– Conical scanning sensors, which are designed to rotate at a fixed angle around the nadir direction.

– Cross-track nadir sensors, which are designed to rotate through the nadir direction and perpendicular to the orbital path.

– Fixed-pointing sensors, which have a static viewing geometry and are typically pointed nearby or on the spacecraft nadir vector.

### 3.6.101 General considerations for EESS

Passive sensors are used in the remote sensing of the Earth and its atmosphere by Earth exploration and meteorological satellites in certain frequency bands allocated to the Earth exploration-satellite service (EESS) (passive). The products of these passive sensor operations are used extensively in meteorology, climatology, and other disciplines for operational and scientific purposes. However, these sensors are sensitive to any emissions within their allocated band. Therefore, any RF emissions above a certain level may constitute interference to the passive sensors using those bands. In addition, it should be noted that passive sensors may not be able to differentiate the wanted signal from the interference and that interference may not be identifiable in the passive sensor products.

Referencing Recommendation ITU-R RS.1861, the table below provides the definitions of some of the technical and operational EESS parameters associated with passive sensors and their operation that are needed for the analysis in this report.

TABLE 18

Definitions of technical and operational EESS parameters for passive sensors

| Parameter | Definition |
| --- | --- |
| Sensor type | Several types of radiometers are possible depending on the technology of the radiometer: interferometric radiometer, fixed pointing, conical scan, nadir/cross-track scan, push-broom, limb scan radiometer |
| Altitude | The height above the mean sea level |
| Inclination | Angle between the equator and the plane of the orbit |
| Repeat period | The time for the footprint of the antenna beam to return to (approximately) the same geographic location |
| Number of beams | The number of beams is the number of Instantaneous Field of View (IFOV) on Earth from which data are acquired at one time |
| Antenna size | For real aperture radiometers, it is the diameter of the antenna reflector; For interferometric radiometers, it is the size of antenna array. |
| Maximum antenna gain | The maximum antenna gain (dBi) |
| −3 dB beamwidth | The −3 dB beamwidth, θ3dB, is defined as the angle between the two directions in which the radiation intensity is one-half the maximum value. |
| Instantaneous field of view (IFOV) | The instantaneous field of view (IFOV) for a real aperture system is the area over which the detector is sensitive to radiation, defined as the linear dimensions of the beam on the Earth corresponding to the −3 dB beamwidth. By knowing the altitude of the satellite, the dimension of the IFOV is calculated on the Earth’s surface at the boresight direction (or at the tangent point for limb sounding sensors): the IFOV is expressed in km × km representing the minor and major axis of the footprint.  |
| Off-nadir pointing angle | The angle between the nadir and the pointing direction. |
| Incidence angle at Earth | The angle between the pointing direction and the normal to the Earth’s surface.  |
| Sensor antenna pattern | Antenna gain as a function of off-axis angle. For interferometric radiometers, it is the pattern of synthetic beam. |
| Sensor integration time | The *sensor integration time* corresponds to the short period of time allocated for the radiative measurement of the instantaneous area of observation by the detector of a sensor |
| Channel bandwidth | The *channel bandwidth* is the range of frequencies around a centre frequency used by the passive sensor |

The EESS (passive) sensor parameters used in the calculations are shown below.

TABLE 19

Technical EESS parameters for passive sensors F1 to F6 in 24 GHz

| Sensor | F1 | F4 (Outer) | F4 (Nadir) | F5(Outer) | F5 (Nadir) | F6 |
| --- | --- | --- | --- | --- | --- | --- |
| Sensor Type | Conical scan | Mechanical nadir scan | Mechanical nadir scan | Mechanical nadir scan | Mechanical nadir scan | Conical scan |
| Frequency (GHz) | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 |
| Orbit altitude (km) | 817 | 833 | 833 | 824 | 824 | 835 |
| Off-nadir angle (°) | 44.5 | 48.3 | 0.0 | 52.7 | 0.0 | 53.3 |
| Antenna gain (dBi) | 40 | 34.4 | 34.4 | 30.4 | 30.4 | 40.8 |
| Incidence angle at footprint (°) | 52.3 | 57.6 | 0.0 | 64.0 | 0.0 | 65.1 |
| Angle from Ground to Sensor (°) | 37.7 | 32.4 | 90.0 | 26.0 | 90.0 | 24.9 |
| Slant path distance (km) | 1227.3 | 1379.0 | 833.0 | 1562.9 | 824.0 | 1621.5 |
| Effective antenna diameter[[1]](#footnote-2) (m) | 0.52 | 0.27 | 0.27 | 0.17 | 0.17 | 0.57 |
| –3 dB beamwidth (horizontal) (°) | 1.81 | 3.30 | 3.30 | 5.20 | 5.20 | 1.50 |
| –3 dB beamwidth (vertical) (°) | 1.81 | 3.30 | 3.30 | 5.20 | 5.20 | 1.50 |
| IFOV Area (km²) | 1880 | 9298 | 1847 | 35983 | 4395 | 3411 |

TABLE 20

Technical EESS parameters for passive sensors F8 to F13 in 24 GHz

| Sensor | F8 | F9 (MWS) (Outer) | F9 (MWS) (Nadir) | F10 (MWI) | F11 (AMR) | F12 (MWR) | F13 |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sensor Type | Conical scan | Mechanical nadir scan | Mechanical nadir scan | Conical scan | Nadir | Nadir | Conical scan |
| Frequency (GHz) | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 |
| orbit altitude (km) | 699.6 | 833 | 833 | 833 | 1336 | 814.5 | 830 |
| Off-nadir angle (°) | 47.5 | 49 | 0.0 | 45.2 | 2.65 | 1.9 | 53.3 |
| Antenna gain (dBi) | 48.5 | 37 | 37 | 41.5 | 42.3 | 41 | 45.7 |
| Incidence angle at footprint (°) | 54.9 | 58.6 | 0.0 | 53.4 | 3.2 | 2.1 | 65.0 |
| Estimated Angle from Ground to Sensor (°) | 35.1 | 31.4 | 90.0 | 36.6 | 86.8 | 87.9 | 25.0 |
| Slant path distance (km) | 1114.3 | 1405.2 | 833.0 | 1273.6 | 1337.7 | 815.0 | 1609.9 |
| Antenna diameter (m) | 1.37 | 0.37 | 0.37 | 0.61 | 0.67 | 0.58 | 0.99 |
| -3dB beamwidth (horizontal) (°) | 0.75 | 2.80 | 2.80 | 1.70 | 1.40 | 1.80 | 1.00 |
| -3dB beamwidth (vertical) (°) | 0.75 | 2.80 | 2.80 | 1.70 | 1.40 | 1.80 | 1.00 |
| IFOV Area (km²) | 306 | 7153 | 1288 | 1802 | 855 | 491 | 1549 |

TABLE 21

Technical EESS parameters for passive sensors F14 to F18 in 24 GHz

| Sensor | F14 | F15 | F16 | F17 | F18 |
| --- | --- | --- | --- | --- | --- |
| Sensor Type | Conical scan | Conical scan | Conical scan | Fixed pointing | Conical scan |
| Frequency (GHz) | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 |
| orbit altitude (km) | 407 | 407 | 970 | 970 | 665.96 |
| Off-nadir angle (°) | 48.6 | 48.5 | 44 | 2.2 | 47.7 |
| Antenna gain (dBi) | 46.5 | 46.6 | 45 | 45 | 48.5 |
| Incidence angle at footprint (°) | 52.9 | 52.8 | 53.2 | 2.5 | 54.8 |
| Estimated Angle from Ground to Sensor (°) | 37.1 | 37.2 | 36.8 | 87.5 | 35.2 |
| Slant path distance (km) | 643.1 | 641.6 | 1461.7 | 970.8 | 1061.7 |
| Antenna diameter (m) | 1.09 | 1.10 | 0.92 | 0.92 | 1.37 |
| -3-dB beamwidth (horizontal) (°) | 0.80 | 0.85 | 1.12 | 1.12 | 0.65 |
| -3-dB beamwidth (vertical) (°) | 0.80 | 0.85 | 1.12 | 1.12 | 0.65 |
| IFOV Area (km²) | 106 | 122 | 933 | 216 | 264 |

### 3.6.12 EESS Protection Criteria

The EESS (passive) protection criteria are stated in Recommendation ITU-R RS.2017 (2012) “Performance and interference criteria for satellite passive remote sensing”

In *recommends* 5, the protection criteria should not be exceeded for more than a percentage of sensor viewing area. In the 24 GHz case, that percentage is 0.01%. The measurement area is a square on the Earth of 2 000 000 km2 unless otherwise justified. Therefore, the interference criteria of –166 dB(W/200 MHz) may not be exceeded in any 200 km2 area.

[Editor’s note: Views were expressed that the protection criteria in RS.2017 is given for all interference sources and cannot hence be used as such for a single application. It is also reminded that the corresponding EESS (passive) band 23.6-24 GHz was at stake during WRC-19 and has already seen most if not all of the interference allowance captured by another applications. The specification of the relevant EESS (passive) protection criteria applicable in this study will require additional consideration, in particular with WP7C.]

### 3.6.13 EESS (active)

The secondary allocation for EESS (active) at 24.05-24.25 GHz is subject to the terms of RR **5.150** which states “Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications.”

### 3.6.114Summary

[Editor’s note: The text below has not been discussed and agreed in WP 1A.]

[*Editor’s note: This section needs to be further reviewed with respect to the protection of the passive band from the unwanted emissions. Protection criteria and characteristics of incumbent services need to be confirmed with relevant Working Parties.*]

[The WPT ISM technology considered at this frequency involves a narrow band transmission which has a bandwidth occupying 0.04% of the centre frequency of 24 GHz ISM band. The maximum ISM emission bandwidth used is 10 MHz within the range of 24.1-24.15 GHz.

Annex 2 shows that the number of ISM devices that can be accommodated for each of the EESS (passive) sensors vary from a minimum device density of 67 per km2 to more than 350 000 devices per km2 averaged over the sensor’s field of view depending on each sensor characteristics. The analysis in Annex 2 shows that, for the case of indoor use of WPT beam power sources pointing in a downward direction, with OOB emissions specified by US ISM band limits, and a building entry loss varying between 3 dB and >40 dB will permit the use of an average of tens or more WPT beam devices per sq. km. without exceeding the protection limits of ITU-R RS.2017 for the worst case of each of the EESS (passive) sensors in ITU-R RS.1861. This analysis does not consider the contributions from other non-WPT sources that can affect the number of WPT devices that can operate in a km2, due to aggregate effects from all interfering sources, and makes a number of other assumptions related to building entry losses and predicted deployment density that are estimated and can also impact the results. Considering this, simplementing 24 GHz Beam WPT should consider measures limiting the geographic density of users and a means of ensuring that devices are used indoors, pointing downward to assure that the protection of allocated service required by **15.13** is met. The minimum average density calculated for the most vulnerable sensor is used to determine the level necessary toprotect EESS (passive).

For radio astronomy, the remote location and control of the radio environment for many sites affords protection of the receivers utilized, which are of “exceptionally high sensitivity”. In situations where WPT systems are expected to operate within the radio horizon of radio astronomy systems, administrations should take practicable steps to allow operation in conformance with the Radio Regulations. Some of these steps and options are also detailed in Article **29** of the RR.]

 …

Annex 2

Details of Impact Studies of Beam WPT on EESS(passive) , RAS and IMT

 in Study F

## A2.1 EESS (Passive) and Beam WPT

In the United States, beam WPT has been determined to be an ISM use of spectrum subject to the national 24 GHz ISM band limit established by FCC.[[2]](#footnote-3) For the case of transmitter power less than 500 W RF power, the out-of-band limit is a field strength of 25 μV/m at a measurement distance of 300 m and a measurement bandwidth of 1 MHz. Some administrations have created national requirements that devices for indoor only use have physical characteristics limiting their potential outdoor use, including the requirement that the device must be powered from electrical mains. Administrations could also require sensors in such devices to assure they are pointed downward.

### A2.1.1 Modelling impact of 24 GHz WPT beam devices on EESS (passive) sensors

In general, OOBE levels decrease as the frequency becomes separated from the carrier frequencies by multiples of the transmission half bandwidth. These transmissions are low in bandwidth compared to their separation from the nearby passive band. In this case the band separation is >100 MHz while the bandwidth of the WPT Beam emission is ≤ 10 MHz so the passive bands is more than 10 half bandwidths away. In this case ISM is only used indoor employing downward pointing antennas that transfer a large fraction of their transmitted power to the intended receiver. The antennas have multiple elements each with amplifiers and frequency synthesizers that derive the center frequency of transmissions from a reference frequency that is much lower. If the phase locked loop of the synthesizer has a bandwidth that is much smaller than the separation of the centre frequency from the nearby passive band, then the resulting emissions near centre frequency will have highly correlated phases over a bandwidth of less than 10 MHz over the various antenna elements and have uncorrelated phases over frequencies further from the centre frequency. This, in turn results in a highly focused beam at the centre frequency and a much more diffuse pattern with much lower gain at the frequencies more than 10 MHz from the center frequency.

It is noted that this is different than in the case of IMT MIMO antennas in the nearby IMT band. For the IMT case, out-of-band emissions are from both oscillator noise and the wideband IMT modulation and have greater out-of-band correlation between the signals in each antenna element. IMT emissions have much greater bandwidth because of complex information-carrying modulation which results in many correlated sidebands. In Beam WPT signal bandwidth is not an intentional design characteristic, but rather a byproduct of circuit noise in carrier frequency synthesis in the many individual antenna elements.

As a result, while the centre frequencies of each element are in phase and permit antenna beam focusing by changing the amplitude and phase of transmission from each element, for frequencies more than 10 MHz away from the centre frequency the phase noise of the emissions are uncorrelated, so their OOBE outside the 24-24.25 GHz ISM band do not focus, and the antenna array has little gain for such OOBE. This is illustrated below where the OOB emission pattern of a single antenna in an exemplary array is simulated using HFSS.

Figure A2.1

In-band and out-of-band radiation patterns



Figure A-2.2 shows the ISM device antenna gain towards selected EESS sensors for a fixed Earth to EESS elevation angle and for azimuth angles that vary between –180° to +180°.

Figure A2.2

Transmitter OOB Antenna Patterns versus Azimuth for Select Elevation Angles Matching
EESS Off-Nadir Angles

Tables A2.1 and A2.2 provide calculations to predict how much of this ISM device power reaches an EESS (passive) satellite of various types under assumption that all ISM transmitting units are indoors and are pointing downward. This is an upper-bound analysis to determine a geographic density of these devices that could be operated without adversely impacting the passive satellites. While a dynamic simulation would give a more precise result, the worst case here gives an upper bound for Beam WPT density.

The analysis provided in this document considers only direct-path propagation from the sidelobe and/or backlobe of the Beam WPT device to the main-beam of the passive remote sensor.

The calculations use the ITU-R P.2109 “Prediction of building entry loss” model that considers losses due to exterior building walls. As is shown in Figure A2.3 for high elevation angle paths to satellites the exterior wall may not be the only source of structural path loss. For a ceiling mounted transmitter all emissions reaching a satellite must pass through at least one interior floor construction before they reach the exterior wall. Depending on the satellite elevation angle and the distance of the transmitter from the exterior wall, more than one through the floor transit may be involved. There is no present recommendation for such path losses through interior floors, so it is not included in the calculation presented.

Figure A2.3

Impact of ceilings on high elevation angle paths in cases where WPT device is distant from exterior wall



In very high population density areas with multistory buildings this model is conservative in that it does not address the vertical loss a signal would have on high elevation angle paths if an emitter was several floors down from the building roof. Nor does it account for signal blockage by nearby buildings higher than the emitter that could block paths to the satellite as some elevation angles.

[Editor’s note: Views were expressed that the indirect path including in particular the reflections of the main beam emissions in its surrounding will also have to be considered.]

In the case considered the maximum WPT beam transmitter density under the above assumptions that is consistent with the ITU-R RS.2017 protection goals are shown in the table to be in the range of >67 to several thousand units per square kilometre, depending on which sensor from ITU-R RS.1861 is considered. As mentioned above this density would be larger in the case of areas with multistory buildings due to both attenuation from multiple levels above the transmitter and partial signal blockage of power that leaves a building at low elevation angles. However, there is presently no generally accepted building attenuation model for computing the increased attenuation at high elevation angles for such areas with many multilevel, multistory buildings. This model uses for the P.2109 building entry loss (BEL) estimation a mixture for 70% traditional buildings and 30% thermally-efficient buildings. For high device density areas with many multistory buildings this mixture will likely underestimate the fraction of Thermally Efficient buildings and therefore underestimate the maximum density of devices permitted.

TABLE A2.1

Sample Power budget for the Aggregate Usage of Beam WPT Devices for Sensor F18

| Sensor Type/Operator | Conical scanF-18 | Comments |
| --- | --- | --- |
| Sensor Orbit Altitude (km) | 665.96 | RS.1861, (term H) |
| Sensor Antenna Peak Gain (dBi) | 48.5 | RS.1861 |
| Off-nadir angle (°) | 47.7 | RS.1861, (term α) |
| Sensor Ground Area Instantaneous Field of View (IFOV) (km2) | 263.89 | RS.1861. Horizontal resolution = Hr = 14 kmVertical resolution = Vr = 24 km.IFOV (km2) = π×Hr×Vr/4 |
| Angle from ground towards Sensor (°) | 35.22 | RS.1861. Uses calculation for Incidence angle at footprint (°) = 90 - ASIN((Re +H)/Re)\*SIN(α)) |
| ISM out of band EIRP |  |  |
| The field strength level, E, of emissions which lie outside the 24 GHz band. Field strength limit (µV/m) per FCC 18.305 | 25 | FCC value used in the USA |
| Distance of Field strength limit (m). FCC 18.305 | 300 | FCC value used in the USA |
| EIRP (dBm) out of band per 1 MHz where V is the unit of measurement. | –27.27 | $$10log\_{10}\left(\frac{4π×E^{2}×r^{2}}{0.377×V^{2}}\right)$$ |
| Device EIRP (dB(W/MHz) | –57.27 | Conversion from dBm to dBW |
|  |  |  |
| Effective Device EIRP (dB(W/MHz)) | –57.27 | Adding antenna pattern reduction |
| **Losses** |
| Activity factor. Number of hours during the day where all ISM devices are active (hours/day) | 8 | Hours during the day where the ISM WPT device is active |
| Activity factor loss in dB | 4.77 | Activity factor loss =10\*log10(active hours / 24) active hours is 8 hours (dB) |
| Percent simultaneously active ISM devices during the active time (%) | 70 | This is the percent of all ISM WPT devices that are simultaneously active with EESS being interfered |
| Simultaneously active ISM devices factor, dB | 1.55 | Loss due to the fact that only a percent of devices is simultaneously active = 10xlog10(0.7) |
| Free Space Loss P.525 (dB) | 180.54 | Frees space loss at the centre of the IFOV. |
| Gaseous Loss P.676 (dB) | 0.71 | Gaseous loss using P.676 at the centre on the IFOV |
| Polarization mismatch loss (dB) | 3 | Polarization mismatch using P.619ISM device is assumed to have horizontal linear polarization. |
|  |  |  |
| Total Activity Adjustments (dB) | 6.32 | Total activity adjustment from the above (4.77+1.55) |
| **Calculations** |
| Total Interference at EESS dB(W/MHz)  | –199.79 | This is the level after all the adjustments at the EESS in MHz |
| Interference at EESS dB(W in 200 MHz)  | –176.79 | Convert to dB(W/200 MHz) |
|  |  |  |
| Statistical losses (dB) due to:* Device antenna OOB pattern and random azimuth angle of installation
* Building entry loss (P.2109)
* Clutter loss (P.2108)
 | 32.42 | Effective loss back calculated from Monte Carlo simulations.Loss value is picked based on available probability distribution for each sample and the interference from samples are added up until harmful interference is observed. The simulation is run several times to obtain an average number of interferers that cause harmful interference.Other probability distributions in addition to P.2108 and P.2109 used for sample selection:* Uniform probability 0-360 degrees for azimuth angle of device installation. Refer to antenna patterns of Fig. A2.2
* Equiprobable installation of devices in traditional and thermally-efficient buildings
 |
| Results for Number of Devices that would Exceed -166 dBW/200 MHz |  | This step we aggregate the ISM WPT device signal level at the sensor until the aggregate signal level is close to the protection criteria but does not exceed it. |
| Worst case (Lowest) Aggregated Number of ISM WPT Devices | 18,810 | This is the total number of devices that and be added without exceeding the EESS protection threshold level. |
| Device Density in one km2 (Device/IFOV Area)  | 71 | ISM WPT device density using the IFOV  |
| Device Density in one km2 (Devices Using 200 km2 Area)  | 94 | ISM WPT device density using the protection threshold area of 200 km2. |

[*Editor’s note: Views were expressed that the interference calculations being an aggregate to EESS (passive) receivers, the statistical elements (e.g. out of band antenna gain, P.2108,...) have to be taken in average and not in median. Further discussion was also invited on the WPT device deployment density, and the effects on the results.*]

## A2.2 Summary of Results

The tables below show the EESS (passive) sensors and of results of simulation indicating the number of ISM devices that might be allowed to operate simultaneously in the footprint of each passive sensor. The sensors in green are highlighted in this report.

Results for the number of ISM devices that could be accommodated for each EESS (passive) sensor using the assumptions of systems characteristics and operating conditions discussed above are shown in Table A2.2.

TABLE A2.2

Summary of Results per Sensor

| Sensor (RS.1861) | EESS antenna gain (dBi) | Elevation angle from ground to EESS sensor (deg) | EESS IFOV (km2) | Total ISM devices in IFOV (simulated ISM antenna gain reduction of the isotropic antenna randomized in azimuth angle) | Density using IFOV area (devices/km2) | ISM device density using 200 km2 area (devices/km2) |
| --- | --- | --- | --- | --- | --- | --- |
| **F1** | 40 | 37.74 | 1 880.2 | 248 577 | 132 | 1 243 |
| **F4 (Outer)** | 34.4 | 32.37 | 9 298.0 | 761,503 | 82 | 3 807 |
| **F4 (Nadir)** | 34.4 | 90.00 | 1 847.5 | > 70 million | >37 900 | >350 000 |
| **F5 (Outer)** | 30.4 | 26.02 | 35 982.7 | 2,162,096 | 60 | 10 810 |
| **F5 (Nadir)** | 30.4 | 90.00 | 4 394.6 | > 60 million | >13 600 | >300 000 |
| **F6** | 40.8 | 24.93 | 3 411.0 | 211 353 | 62 | 1 057 |
| **F8** | 48.5 | 35.09 | 306.3 | 22 552 | 73 | 113 |
| **F9 (MWS) (Outer)** | 37 | 31.42 | 7 153.4 | 424 454 | 59 | 2 122 |
| **F9 (MWS) (Nadir)** | 37 | 90.00 | 1 288.2 | > 60 million | > 46 500 | > 300 000 |
| **F10 (MWI)** | 41.5 | 36.65 | 1 801.7 | 163 443 | 91 | 817 |
| **F11 (AMR)** | 42.3 | 86.79 | 855.3 | 3 170 860 | 3 707 | 15 854 |
| **F12 (MWR)** | 41 | 87.86 | 490.9 | 2 801 872 | 5 708 | 14 009 |
| **F13** | 45.7 | 25.01 | 1 548.8 | 66 980 | 43 | 335 |
| **F14** | 46.5 | 37.06 | 106.0 | 13 751 | 130 | 69 |
| **F15** | 46.6 | 37.17 | 121.9 | 13 421 | 110 | 67 |
| **F16** | 45 | 36.83 | 933.1 | 98 636 | 106 | 493 |
| **F17** | 45 | 87.46 | 216.4 | 1 230 572 | 5 686 | 6 153 |
| **F18** | 48.5 | 35.22 | 263.9 | 18 810 | 71 | 94 |

The ISM device density that is possible without harmful interference to the listed EESS (passive) sensors ranges from >350 000 to 67 devices/km2 under the conservative assumptions and the building entry loss model given in P.2109 which considered only building wall loss and does not consider additional losses for high elevation angle paths in multistory buildings This analysis does not consider two issues that impact the maximum number of devices: the impact of aggregated interference to EESS (passive) from other sources such as IMT and the propagation modeling for urbanized areas with many devices being in multistory buildings. Administrations implementing 24 GHz Beam WPT should consider measures to address the conditions studied, such as limiting the geographic density of users and implementing an effective means of ensuring that devices are used indoors and pointing downward to assure that the protection of allocated service required by **15.13** is met.

Administration may also wish to consider the types of buildings used in their jurisdiction in urbanized areas with a possible high density of 24 GHz Beam WPT devices and consider how to model the BEL for high elevation angle OOBE in multistory buildings in such areas.

[*Editor’s note: Views were expressed that these conclusions are based on using the full EESS (passive) protection criteria to WPT. In addition, it should be stressed that all EESS (passive) sensors need to be protected from WPT emissions, hence meaning that the worst-case calculations should be taken for any conclusions. To this respect, already showing very low WPT densities in the Table above (e.g., 69 devices / km²) may argue for saying that WPT are not compatible with EESS (passive) at 24 GHz.*]

## A2.3 RAS and Beam WPT

This section reviews the impact of 24 GHz Beam WPT on RAS facilities in the 23.6-24.0 GHz band that are located nearby. The Beam WPT device is indoors and downward pointing as is shown in Figure A2.1. The out-of-band power in the direction of RAS facilities is not from the main beam of the device, but from the out-of-band radiation pattern of this multielement antenna which is much less focused. Table A2.3 shows that for distances of less than 1 km one Beam WPT device could cause interference. Beam WPT devices further away have a rapidly decreasing impact on RAS use because the total propagation loss as distances increase become the sum of a variety of propagation mechanisms and decreases with distance more rapidly than the free space attenuation of P.525.

Table A2.1 shows the path losses and net power reaching an RAS facility for the case of distances of 0.35km, 5km, 10km, 25km, and 50 km. Interference is possible from a single Beam WPT emitter at 0.35 km. But at a distance of 5 km, over 1000 emitters at that distance would be necessary before interference resulted.

TABLE A2.3

Power budget for Beam WPT impact on Radio Astronomy

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Atmosphere conditions | Dry | Dry | Dry | Dry | Dry |
| **Threshold Input Power (dBW)** | **-195** | **-195** | **-195** | **-195** | **-195** |
| RAS Antenna Gain at Horizontal (dBi) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Observation Bandwidth (MHz) | 400.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| Threshold Input Spectral Power (dBW/MHz) RA.769-2 | -221 | -221 | -221 | -221 | -221 |
| **Distance from RAS Antenna (Km)** | **0.35** | **5.00** | **10.00** | **25.00** | **50.00** |
| ISM out of band EIRP |  |  |  |  |  |
| The field strength levels of emissions which lie outside the 24 GHz band. Field strength limit (uV/m) FCC 18.305 Field Strength Limits | 25 | 25 | 25 | 25 | 25 |
| Distance of Field strength limit (m) | 300 | 300 | 300 | 300 | 300 |
| EIRP (dBm) out of band per 1 MHz = 10\*log10(4\*pi\*E^2\*distance^2 / 0.377). Also see NTIA Technical Memorandum TM-10-469 Eq-59 | -27.27 | -27.27 | -27.27 | -27.27 | -27.27 |
| Device EIRP (dB(W/MHz) | -57.27 | -57.27 | -57.27 | -57.27 | -57.27 |
| **Losses** |   |   |   |   |   |
| Normalized Antenna Gain at Horizontal (Note that the device is ceiling-mounted and points downward) | -4 | -4 | -4 | -4 | -4 |
| Free Space Loss (dB) | 110.91 | 133.96 | 139.98 | 147.94 | 153.96 |
| Gaseous Loss (dB) | 0.00 | 0.07 | 0.14 | 0.35 | 0.70 |
| Polarization mismatch loss (dB) | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Clutter loss (P.2108 at 50%) (dB) | *26.18* | *33.00* | *33.00* | *33.00* | *33.00* |
| Building Entry Loss P.2109 (P=50%) - Traditional Buildings (dB) | *19.8* | *19.8* | *19.8* | *19.8* | *19.8* |
| Propagation by diffraction loss P.526-15 | *0.0* | *0.0* | *0.0* | *34.6* | *112.3* |
| **Total Losses** (dB) | 163.8 | 193.8 | 199.9 | 242.6 | 326.7 |
| **Calculations** |
| **Traditional Buildings** |   |   |   |   |   |
| Single Interferer level at RAS Antenna dB(W/MHz) for Traditional Buildings | -221.1 | -251.0 | -257.1 | -299.9 | -384.0 |
| Margin for Traditional Bldgs (dB) | 0.1 | 30.0 | 36.1 | 78.9 | 163.0 |
| **Number of Devices for Traditional Bldgs (dB) BEFORE exceeding RAS protection criteria** |  **1**  |  **1,007**  |  **4,092**  | **7.7E+07** | **2.0E+16** |

Due to this potential of harmful RAS interference, administrations that authorize the use of 24 GHz Beam WPT need to limit use of this technology near all 24 GHz RAS facilities similar to the way that they are limited in quiet zones. The exact distances of the necessary limitations depends greatly on the specific topography around the RAS facility since path loss at this frequency depends greatly on how obstructed the path is. For distances under 10 km, the propagation by diffraction given in P.526-15 can be ignored, but for greater distances it should be considered and has a large impact in preventing interference that might be predicted in a theoretical free space propagation environment.

Radio telescopes at 24 GHz are limited in number and usually in rural locations. Table A2.4 gives the estimated numbers on each continent. They are often sited in places where terrain blockage lessens their potential interference from intentional and unintentional emitters. While a few Beam WPT devices could in theory, result in interference to RAS observations within a few km in locations without terrain blockage, this can be avoided by administration that decide to permit 24 GHz Beam WPT under the provisions of 15.13 by forbidding use of the technology in area within a few km of 24 GHz radio telescopes and taking account of actual terrain.

TABLE A2.4

Summary of 24 GHz Radio Telescope Locations

|  |  |  |
| --- | --- | --- |
| **Continent** | **Number of 24 GHz Radio Telescopes** |  |
| North America | 10 |  |
| South America | 0 |  |
| Africa | 0 |  |
| Europe | 9 |  |
| Asia | 8 |  |
| Australia | 1 |  |
| Antarctica | 0 |  |
| **Total** | **28** |  |

## A2.4 Terrestrial Component of IMT (24.25-27.5 GHz)

The frequency band 24.25-27.5 GHz is identified by Res. **242** (REV.WRC-23) for the use of IMT worldwide and allocated to the mobile service on a primary basis. A blocking level of ‒86 dBm / 50 MHz[[3]](#footnote-4) for BS and ‒52.8 dBm / 50 MHz[[4]](#footnote-5) for UE can be used to assess the impact on IMT stations in the frequency band 24.25-27.5 GHz.

Table A2.5 shows the impact of 24.1-24.15 GHz Beam WPT on IMT UE in the 24 GHz IMT band. It can be seen that even at 10m separation there is no adverse out-of-band impact on the UE performance.

TABLE A2.5

Power budget for 24.25-27.5 IMT UE Impact

|  |  |  |
| --- | --- | --- |
| **Protection criteria used for IMT UE** |  |  |
| Atmosphere conditions | Dry | Dry |
| **Threshold Input Power (dBm)** | **-52.8** | **-52.8** |
| IMT BS Antenna Gain at Horizontal (dBi) | 0.00 | 0.00 |
| Observation Bandwidth (MHz) | 50.0 | 50.0 |
| Threshold Input Spectral Power (dBW/MHz) | -100 | -100 |
| **Distance from IMT UE Antenna (m)** | **10.00** | **50.00** |
| ISM out of band EIRP |   |   |
| The field strength levels of emissions which lie outside the 24 GHz band. Field strength limit (uV/m) FCC 18.305 Field Strength Limits | 25 | 25 |
| Distance of Field strength limit (m) | 300 | 300 |
| EIRP (dBm) out of band per 1 MHz = 10\*log10(4\*pi\*E^2\*distance^2 / 0.377). Also see NTIA Technical Memorandum TM-10-469 Eq-59 | -27.27 | -27.27 |
| Device EIRP (dB(W/MHz) | -57.27 | -57.27 |
| **Losses** |   |   |
| Normalized Antenna Gain at Horizontal (Note that the device is ceiling monted and points downward) | -4 | -4 |
| Free Space Loss (dB) | 79.98 | 93.96 |
| Gaseous Loss (dB) | 0.00 | 0.00 |
| Polarization mismatch loss (dB) | 3.0 | 3.0 |
| Clutter loss (P.2108 at 50%) (dB) | *0.00* | *6.01* |
| Building Entry Loss P.2109 (P=50%) - Traditional Buildings (dB) | *19.8* | *19.8* |
| **Total Losses** (dB) | 106.7 | 126.7 |
| **Calculations** |   |   |
| Single Interferer level at IMT UE Antenna dB(W/MHz) for Traditional Buildings | -164.0 | -184.0 |
| Margin for Traditional Bldgs (dB) | 64.2 | 84.2 |
| **Number of Devices for Traditional Bldgs (dB) BEFORE exceeding IMT UE protection criteria** | **3.E+06** | **3.E+08** |

Table A2.6 5 shows the impact of 24.1-24.15 GHz Beam WPT on IMT BS in the 24 GHz IMT band. Assuming an effective antenna gain at the BS of 0.0 dBi. It can be seen that even at 10m separation with path losses due only to free space propagation and building penetration loss a BS could operate without OOBE harmful interference even with more than 1000 24 GHz Bean WPT devices within this distance.

TABLE A2.6

Power budget for 24.25-27.5 IMT BS Impact

|  |  |  |
| --- | --- | --- |
| **Protection criteria used for IMT BS** |  |  |
| Atmosphere conditions | Dry | Dry |
| **Threshold Input Power (dBm)** | **-86** | **-86** |
| IMT BS Antenna Gain at Horizontal (dBi) | 0.00 | 0.00 |
| Observation Bandwidth (MHz) | 50.0 | 50.0 |
| Threshold Input Spectral Power (dBW/MHz) | -133 | -133 |
| **Distance from IMT BS Antenna (m)** | **10.00** | **50.00** |
| ISM out of band EIRP |   |   |
| The field strength levels of emissions which lie outside the 24 GHz band. Field strength limit (uV/m) FCC 18.305 Field Strength Limits | 25 | 25 |
| Distance of Field strength limit (m) | 300 | 300 |
| EIRP (dBm) out of band per 1 MHz = 10\*log10(4\*pi\*E^2\*distance^2 / 0.377). Also see NTIA Technical Memorandum TM-10-469 Eq-59 | -27.27 | -27.27 |
| Device EIRP (dB(W/MHz) | -57.27 | -57.27 |
| **Losses** |   |   |
| Normalized Antenna Gain at Horizontal (Note that the device is ceiling monted and points downward) | -4 | -4 |
| Free Space Loss (dB) | 79.98 | 93.96 |
| Gaseous Loss (dB) | 0.00 | 0.00 |
| Polarization mismatch loss (dB) | 3.0 | 3.0 |
| Clutter loss (P.2108 at 50%) (dB) | *0.00* | *6.01* |
| Building Entry Loss P.2109 (P=50%) - Traditional Buildings (dB) | *19.8* | *19.8* |
| **Total Losses** (dB) | 106.7 | 126.7 |
| **Calculations** |   |   |
| Single Interferer level at IMT BS Antenna dB(W/MHz) for Traditional Buildings | -164.0 | -184.0 |
| Margin for Traditional Bldgs (dB) | 31.0 | 51.0 |
| **Number of Devices for Traditional Bldgs (dB) BEFORE exceeding IMT BS protection criteria** |  **1,262**  |  **125,912**  |

References

[1] Recommendation ITU-R P.452-17, *Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at Frequencies above 0.7* (2021)

[2] Recommendation ITU-R P.525-4, *Calculation of free-space attenuation* (1978-1982-1994-2016-2019)

[3] Recommendation ITU-R P.676-12, *Attenuation by atmospheric gases and related effects* (Question ITU-R 201/3) (1990-1992-1995-1997-1999-2001-2005-2007-2009-2012-2013-2016-2019)

[4] Recommendation ITU-R P.2108-1, *Prediction of clutter loss* (2017-2021)

[5] Recommendation ITU-R P.2109-1, *Prediction of building entry loss* (2017-2019)

[6] Recommendation ITU-R RA.769, *Protection Criteria used for Radioastronomical Measurements*

[7] Recommendation ITU-R RA.1513-2, *Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis* (2015)

[8] Recommendation ITU-R RS.1861-1, *Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz* (Question ITU-R 243/7) (2010-2021)

[9] Recommendation ITU-R RS.2017-0, *Performance and interference criteria for satellite passive remote sensing* (2012)

[10] Recommendation ITU-R SM.2129, *Guidance on frequency ranges for operation of non-beam wireless power transmission systems for mobile and portable devices*

1. Calculated based on antenna gain and using 60% for antenna aperture efficiency per Recommendation ITU-R RS.1813. [↑](#footnote-ref-2)
2. The FCC discussed potential rule changes in ET Docket No. 19-226 that could affect their regulation of beam or “at-a-distance” WPT, including the possibility of moving such devices out of Part 18 of FCC rules covering ISM equipment. Changes in the OOB limits would impact the study results. [↑](#footnote-ref-3)
3. Calculation based on BS receiver blocking characteristics available in [3GPP TS 38.104 V18.4.0 (2023-12)](https://www.3gpp.org/ftp/Specs/archive/38_series/38.104/38104-i40.zip), “NR; Base Station (BS) radio transmission a “NR; Base Station (BS) radio transmission and reception”. See § 10.3.3 and § 10.5.2.3. [↑](#footnote-ref-4)
4. Calculation based on UE receiver blocking characteristics available in [3GPP TS 38.101-2 V18.4.0 (2023-12)](https://www.3gpp.org/ftp/Specs/archive/38_series/38.101-2/38101-2-i40.zip), “NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone”. See § 7.3.2.3 and § 7.6.2. [↑](#footnote-ref-5)