CEPT ECC
Electronic Communications Committee

ECC Report 334

UWB radiodetermination applications in the frequency range 116-260 GHz

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0 EXECUTIVE SUMMARY

This Report considers coexistence of altogether eight proposed different UWB applications to incumbent Radio Services:

- Generic indoor surveillance radar (section 2.2.1);
- Radiodetermination systems for industry automation (RDI) (section 2.2.2);
- Short-range assist and surrounding monitoring for vehicles and autonomous systems (section 2.2.3);
- Ground based synthetic aperture radar (GBSAR) (section 2.2.4);
- Level probing radar (LPR) (section 2.2.5);
- Contour determination and acquisition (CDR) (section 2.2.6);
- Tank level probing radar (TLPR) (section 2.2.7);
- Radiodetermination systems for industry automation in shielded environments (RDI-S) (section 2.2.8).

The concept, the technical properties and deployment characteristics of these applications were communicated to CEPT with appropriate request for authorisation of use of spectrum in ETSI TR 103 498 [1]. For these applications, different candidate frequency bands in the frequency range from 116 GHz up to 260 GHz have been defined (section 2.2 and section 3.1) and investigated in MCL-based deterministic analyses.

It should be noted that the analyses in this Report do not cover generic EHF regulations for use by terrestrial services as authorised in one CEPT country. The studies performed when making these national regulations used different sharing criteria.

The following Radio Services, operating either in these candidate bands or adjacent to them, have been identified as possible victims of interference arising from the mentioned UWB applications (section 3.2):

- Radio Astronomy Service;
- Fixed Service;
- Earth Exploration Satellite Service (passive);
- Amateur Service;
- Mobile (not studied).

A detailed graphical overview of the band assignments to these Radio Services inside and nearby each investigated candidate band is given in section 3.3.

The evaluation of the maximum interference ranges for the different UWB applications under consideration for all terrestrial victims was carried out using an MCL deterministic approach by applying a worst-case interference scenario of one single interferer to one terrestrial victim receiver. All MCL calculations have been performed with line-of-sight (LOS) conditions (except for those interferers which are only located indoors) and without any natural shielding, like vegetation and other obstacles, located in the direct path from the interferer to the victim. It should be noted that as UWB is not defined as a radiocommunication service and there are a number of different UWB applications being studied in this Report, a degree of caution has been taken when looking at sharing impacts and criteria used. As a result, all calculated interference impacts represent the most conservative estimates, which in many real-life scenarios will be further reduced due to the aforementioned natural shielding mechanisms.

For the space-based victims, like EESS, the margins to the protection criteria, i.e. the maximum interference level in the victim receiver, have been also calculated in a single-entry scenario assuming worst-case conditions. In addition, a scenario where the aggregation of numerous interfering devices located in the satellite field of view on Earth's surface have been considered.

The calculations are provided in separate calculation sheets which are annexed to this Report. The results of these studies and the conclusions are provided in sections 4 to 8.

Finally, is worth to mention that the conducted calculations were supported by two specific actual measurement campaigns. In the first campaign the transmission attenuation of typical building materials has been evaluated in the frequency range 120-175 GHz (see ANNEX 2). This was necessary in order to determine reasonable values for the indoor to outdoor attenuation for all applications which are only used indoors, like RDI-S.

In the second measurement trial the reflection attenuation of a flat and smooth sand surface in different angles of incidence has been evaluated in the frequency range from 140 GHz up to 330 GHz (see ANNEX 3). The reflection attenuation of this ideal sand surface has been used in the study for level probing radar (LPR) and contour detection radar (CDR) as a worst-case reflection scenario.

The general outcome of this Report is summarised in the following Figure 1.

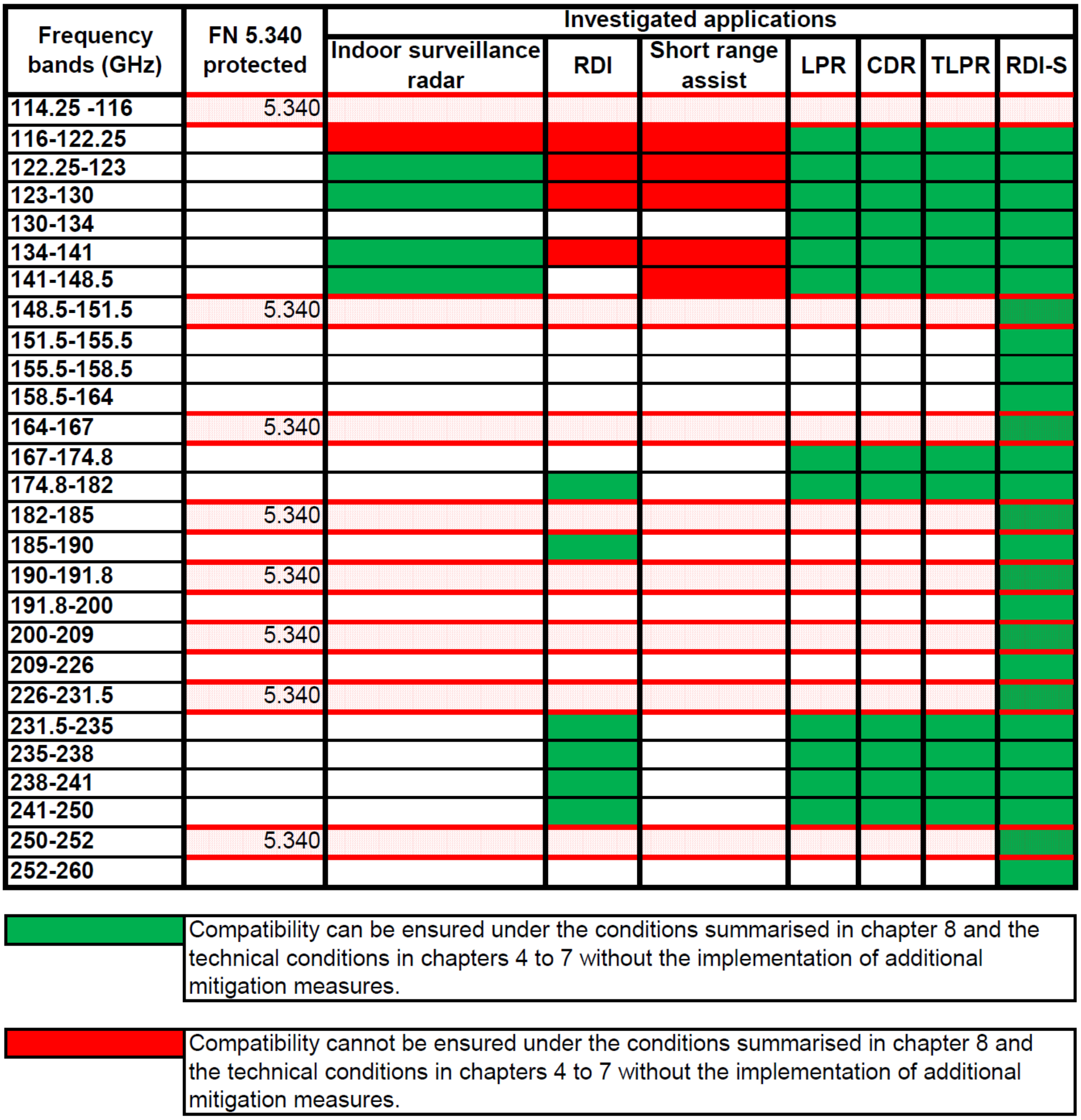


Figure 1: Compatibility situation between the investigated UWB-applications and all considered Radio Services

The application “short-range assist and surrounding monitoring for vehicles and autonomous systems” (section 2.2.3) was studied in the separate ECC Report 351 [72].

0.1 GENERIC INDOOR SURVEILLANCE RADAR

Generic indoor surveillance radar is used for measuring different physical parameters like presence, distance, velocity, or material properties of a target object. The obtained information is further processed and used for automation purposes within the home and building environment (smart home). The generic indoor surveillance radar application is intended for private use and has been divided into the two subcategories hand-held/mobile and fixed generic indoor use.

It is recommended that all fixed generic indoor surveillance radars should comply with the following (installation) requirements:

- Fixed generic indoor surveillance radars shall only be installed and operated inside buildings;
- Users and installers have to ensure that fixed generic indoor surveillance radars, although installed inside a building, do not perform a function outside the building structure, such as for example the detection of persons outside the building (e.g. through wall imaging);
- The provider is required to inform the users and installers of fixed generic indoor surveillance equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is recommended:

- For fixed generic indoor surveillance radars, the mean e.i.r.p. above 0° elevation shall be limited to 12 dBm (8 dB below the maximum mean e.i.r.p. of 20 dBm).

Table 1 and Table 2 show the proposed technical limitations under which the compatibility with the investigated Radio Services can be achieved.

Table 1: Proposed technical limitations for hand-held/mobile generic indoor surveillance devices in the candidate bands

Candidate frequency band	Maximum mean e.i.r.p (Note 1)	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p (Note 5)	Spectrum access and mitigation requirements (Note 3)	Minimum unwanted emissions attenuation (Note 4)
122.25 to 130 GHz	10 dBm	-20 dBm/MHz	20 dBm	$\sum T_{meas} \leq$ 400 ms within T_{obs} = 1 s is equivalent to a maximum duty cycle of 40%	20 dB
134 to 148.5 GHz	10 dBm	-20 dBm/MHz	20 dBm	$\sum T_{meas} \leq$ 400 ms within T_{obs} = 1 s is equivalent to a maximum duty cycle of 40%	20 dB

Note 1: Maximum mean e.i.r.p within the OFR (see Note 4) and during T_{meas} (time when transmission is on, see Figure 36).
Note 2: These limits should be measured with an RMS detector and averaging time of 1 ms.
Note 3: The maximum duty cycle is not included in the proposed maximum mean e.i.r.p and maximum mean e.i.r.p. spectral density values. Consequently, these values must be reduced by 4 dB when averaging over the observation time T_{obs} = 1 s because of the inclusion of the maximum duty cycle of 40%.
Note 4: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 5: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

Table 2: Proposed technical limitations for fixed generic indoor surveillance devices in the candidate bands

Candidate frequency band	Maximum mean e.i.r.p (Note 1)	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p (Note 5)	Spectrum access and mitigation requirements (Note 3)	Minimum unwanted emissions attenuation (Note 4)
122.25 to 130 GHz	20 dBm and 12 dBm > 0° elevation	-10 dBm/MHz and -18 dBm/MHz > 0° elevation	30 dBm and 22 dBm > 0° elevation	$\sum T_{meas} \leq$ 100 ms within T_{obs} = 1 s is equivalent to a maximum duty cycle of 10%	20 dB
134 to 148.5 GHz	20 dBm and 12 dBm > 0° elevation	-10 dBm/MHz and -18 dBm/MHz > 0° elevation	30 dBm and 22 dBm > 0° elevation	$\sum T_{meas} \leq$ 100 ms within T_{obs} = 1 s is equivalent to a maximum duty cycle of 10%	20 dB

Note 1: Maximum mean e.i.r.p within the OFR (see Note 4) and during T_{meas} (time when transmission is on, see Figure 36).
Note 2: These limits should be measured with an RMS detector and averaging time of 1 ms.
Note 3: The maximum duty cycle is not included in the proposed maximum mean e.i.r.p and maximum mean e.i.r.p. spectral density values. Consequently, these values must be reduced by 10 dB when averaging over the observation time T_{obs} = 1 s because of the inclusion of the maximum duty cycle of 10%.
Note 4: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 5: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

The lower portion, 116 to 122.25 GHz, of the whole candidate band 116 to 130 GHz has also been investigated. However, based on the results of this analysis compatibility between generic indoor surveillance radar sensors and EESS (passive) cannot be achieved in this portion of the band assuming the number of devices studied, and the power levels are given in Table 1 and Table 2.

For coexistence with RAS, the studies have concluded that:

- The separation distances in the lower frequency range 123 GHz to 158.5 GHz obtained in the single-entry study are for the fixed generic indoor surveillance radar devices 35.2 km for the outdoor consideration and 10.7 km for the indoor case. For the hand-held/mobile generic indoor surveillance equipment the separation distances are 19 km for the outdoor consideration and 1.6 km for the indoor case;
- For the fixed indoor equipment an installation requirement limiting the related mean e.i.r.p. to a maximal value of 12 dBm for elevation angles larger than 0° could be requested. In this case the separation distance would drop to 17.5 km for the outdoor consideration.

For the frequency bands 76 GHz to 116 GHz, 148.5 GHz to 151.5 GHz (adjacent frequency situation) compatibility can be achieved between both types of generic indoor surveillance radar equipment and RAS without the implementation of additional mitigation techniques. The separation distances obtained in the MCL calculations are all below 5 km.

Operational solutions to implement these separation distances were not studied in this Report.

0.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

RDI is an industrial and professional application used for measuring different physical parameters like presence, distance, velocity or material properties of a target object. The obtained information is further processed and used for industrial automation purposes.

The candidate bands 116 to 130 GHz and 134 to 141 GHz have been investigated. However, based on the results of this analysis compatibility between RDI and RAS cannot be achieved in these bands assuming the power levels given in Table 52 in section 4.2.1 without the implementation of additional mitigation techniques.

A graphical summary of all the candidate bands can be found in section 8.9.

Consequently, it is recommended that all RDI sensors should be limited to the bands 174.8 to 182 GHz, 185 to 190 GHz and 231.5 to 250 GHz and should comply with the following (installation) requirements:

- The operation of RDI sensors is envisaged for industrial purposes only;
- Installation and maintenance of RDI equipment shall be performed by professionally trained individuals only;
- RDI equipment shall not be marketed to private end customers;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- All outdoor RDI sensors under consideration shall be installed in heights from 0 m to 3 m above ground;
- In order to protect the Radio Astronomy Service, inside a radius of 20 km around the stations of NOEMA and IRAM 30 m, the installation and operation of RDI devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of RDI equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is recommended:

- For RDI devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

Table 3: European radio astronomy observatories operating in the frequency range 116 GHz to 260 GHz

Country/Administration	Observatory name and location	Geographic Latitude	Geographic Longitude
France	NOEMA, Plateau de Bure	44°38'02" N	05°54'28" E
Spain	IRAM 30 m, Pico Veleta	37°04'06" N	03°23'55" W

Table 4 shows the proposed technical limitations under which the compatibility with the investigated Radio Services can be achieved.

Table 4: Proposed technical limitations for RDI devices in the candidate bands

Candidate frequency band	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 3)	Minimum unwanted emissions attenuation (Note 1)
174.8 to 182 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
185 to 190 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
231.5 to 250 GHz	5%	-25.6 dBm/MHz	31 dBm	20 dB

Note 1: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The maximum duty cycle of 5% is already included in this mean e.i.r.p. value. Consequently, the given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

0.3 SHORT-RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

To perform different functionalities for driving assistance, cars are equipped with different types of radars that are integrated in specific positions onboard the vehicle. Front and corner radars are currently used for applications requiring long and medium range such as automatic cruise control, lane keep, lane change assist and automatic emergency braking. On the other hand, future applications, providing the vehicle with higher degree of autonomy, require short- and ultra-short-range radars for front-, side- and rear-view, such that 360° sensing is enabled. Those radars would allow to obtain a wide field of view (in elevation and azimuth) in the close proximity of the vehicle required for features like automated parking assistance.

For short-range assist and surrounding monitoring for vehicles and autonomous systems the candidate frequency bands 116 to 130 GHz, 134 to 141 GHz and 141 to 148.5 GHz have been studied. Based on the results of this analysis in none of the mentioned frequency ranges compatibility between short-range assist and the investigated Radio Services could be achieved under the technical assumptions used in the studies (see section 2.2.3.3 and Table 89). This conclusion has been initially drawn for a maximum e.i.r.p. of 47 dBm and has been further confirmed even with a decreased e.i.r.p. of 40 dBm and 26 dBm.

The following protection requirement has been assumed:

- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

Despite the fact that studies for the other relevant Radio Services, FS and Amateur, have not been conducted, it was considered sufficient at this time to conclude that , under the technical assumptions proposed by the industry (see Table 89) these UWB applications should not be authorised to operate in the investigated candidate bands (see section 2.2.3.2)

Further studies have been conducted which resulted in ECC Report 351 [72] in order to address the latest insight in the technical assumptions in bands adjacent to EESS (passive) bands.

0.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

Ground based synthetic aperture radar (GBSAR) is a professional application used to remotely monitor the displacements of thousands of points over a surface with a high accuracy. The displacement information is in general used to provide early warnings in case of deformation, having magnitude and rate indicative of hazardous instabilities of the monitored scenario. Such radars are used in order to improve the safety standard for a wide range of applications such as:

- Structural Health Monitoring (SHM);
- Slope Stability Monitoring;
- Tunnel Monitoring.

The conducted studies show that GBSAR, operated in the band 134 to 141 GHz, can achieve compatibility with the Earth Exploration Satellite Service (passive) if the maximum mean e.i.r.p. spectral density can be limited to -21.8 dBm/MHz in adjacent bands (unwanted emissions domain) allocated to this service. However, studies for the other relevant Radio Services, RAS, FS and Amateur, have not been conducted. A conclusion whether compatibility with these services can also be achieved cannot be drawn at this time.

0.5 LEVEL PROBING RADAR (LPR)

Level probing radar (LPR) is an industrial and professional application used in many industries to measure the distance to the surface of various materials and substances (mostly liquids and solids) and thus indirectly the amount of these goods in open-air areas or in tanks with non-attenuating shells (e.g. plastic tanks).

It is recommended that all level probing radars should comply with the following (installation) requirements:

- The operation of LPR sensors is envisaged for industrial purposes only;
- Installation and maintenance of LPR equipment shall be performed by professionally trained individuals only;
- LPR equipment shall not be marketed to private end customers;
- Level probing radars are required to be installed at a permanent fixed position pointing in a downwards direction towards the ground. The equipment shall not operate while being moved, or while inside a moving container;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- In order to protect the Radio Astronomy Service, inside a radius of 13 km around the stations of NOEMA and IRAM 30 m, the installation and operation of LPR devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of LPR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following two requirements are recommended:

- For LPR devices, the peak e.i.r.p. for elevations above 0° shall be limited to 0 dBm;
- For LPR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

Table 5 shows the proposed technical limitations under which the compatibility with the investigated Radio Services can be achieved without the implementation of additional mitigation techniques.

Table 5: Proposed technical limitations for LPR devices in the candidate bands

Candidate frequency band	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 3)	Minimum unwanted emissions attenuation (Note 1)
116 to 148.5 GHz	5%	-8.0 dBm/MHz	37 dBm	20 dB
167 to 182 GHz	5%	-6.0 dBm/MHz	37 dBm	20 dB
231.5 to 250 GHz	5%	-6.0 dBm/MHz	37 dBm	20 dB

Note 1: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The duty cycle of 5% is already included in this mean e.i.r.p. value. Consequently, the given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

0.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

Contour determination and acquisition radar sensors (CDR) are the most advanced sensors in the emerging field of bulk level measurement. These sensors are equipped to gather a plurality of distance values to different points located on the surface of the bulk material. These distance values can be used to form a digital representation of the bulk material surface or contour and can consequently be used to determine the volume or mass of material available in the current measurement scenario. It is recommended that all CDR sensors should comply with the following (installation) requirements:

- The operation of CDR sensors is envisaged for industrial purposes only;
- Installation and maintenance of CDR equipment shall be performed by professionally trained individuals only;
- CDR equipment shall not be marketed to private end customers;

- CDR equipment is required to be installed at a permanent fixed position. The equipment shall not operate while being moved;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- In order to protect the Radio Astronomy Service, inside a radius of 20 km around the stations of NOEMA and IRAM 30 m, the installation and operation of CDR devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of CDR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is recommended:

- For CDR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

0.6.1 Digital beamforming contour determination and acquisition sensors (DBF-CDR)

In addition to the installation and antenna requirements in section 0.6, applicable to all CDRs, the following condition is recommended for the subclass of DBF-CDR only:

- DBF-CDRs are required to be pointing vertically downwards towards the ground.

Table 6 shows the proposed technical limitations under which the compatibility of DBF-CDR equipment with the investigated Radio Services can be achieved without the implementation of additional mitigation techniques.

Table 6: Proposed technical limitations for DBF-CDR devices in the candidate bands

Candidate frequency band	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 3)	Minimum unwanted emissions attenuation (Note 1)
116 to 148.5 GHz	10%	-32.6 dBm/MHz	15 dBm	20 dB
167 to 182 GHz	10%	-29.0 dBm/MHz	15 dBm	20 dB
231.5 to 250 GHz	10%	-23.0 dBm/MHz	15 dBm	20 dB

Note 1: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The duty cycle of 10% is already included in this mean e.i.r.p. value. Consequently, the given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

0.6.2 Mechanical- and phased-array contour determination and acquisition sensors (M- and PA-CDR)

In addition to the installation and antenna requirements in section 0.6, applicable to all CDRs, the following conditions are recommended for the subclass of M-CDRs and PA-CDRs only:

- M-CDRs and PA-CDRs shall have a permanent spatially scanning behaviour of the antenna main beam direction at any time during operation;
- The maximum tilting angle of the antenna main beam direction in relation to the vertical axis towards the ground shall never exceed 60°;
- The peak e.i.r.p. for elevations above 0° shall be limited to 0 dBm.

Table 7 shows the recommended technical limitations under which the compatibility of M-CDR and PA-CDR equipment with the investigated Radio Services can be achieved without the implementation of additional mitigation techniques.

Table 7: Proposed technical limitations for M-CDR and PA-CDR devices in the candidate bands

Candidate frequency band	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 3)	Minimum unwanted emissions attenuation (Note 1)
116 to 148.5 GHz	10%	-12.0 dBm/MHz	28.6 dBm	20 dB
167 to 182 GHz	10%	-9.0 dBm/MHz	34.6 dBm	20 dB
231.5 to 250 GHz	10%	-6.0 dBm/MHz	37 dBm	20 dB

Note 1: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The duty cycle of 10% is already included in this mean e.i.r.p. value. Consequently, the given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

0.7 TANK LEVEL PROBING RADAR (TLPR)

Tank level probing radar (TLPR) is an industrial and professional application used in many different industries to determine the amount of a substance (mostly liquids and solids) inside shielded tanks or containers. It is recommended that all tank level probing radars should comply with the following (installation) requirements:

- The operation of TLPR sensors is envisaged for industrial purposes only;
- Installation and maintenance of TLPR equipment shall be performed by professionally trained individuals only;
- TLPR equipment shall not be marketed to private end customers;
- TLPRs shall be installed at a permanent fixed position at a closed metallic tank or concrete tank, or a similar enclosure structure made of comparable attenuating material;
- Flanges and attachments of the TLPR equipment shall provide the necessary microwave sealing by design;
- Sight glasses shall be coated with a microwave-proof coating when necessary (i.e. electrically conductive or microwave absorbing coating);
- Manholes or connection flanges attached to the tank shall be closed while the TLPR equipment is in operation to ensure a low-level leakage of the signal into the free space outside the tank;
- The provider is required to inform the users and installers of TLPR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is recommended:

- For TLPR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

Table 8 shows the proposed technical limitations under which the compatibility with all investigated Radio Services can be achieved without the implementation of additional mitigation techniques.

Table 8: Proposed technical limitations for TLPR devices in the candidate bands

Candidate frequency band	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 3)	Minimum unwanted emissions attenuation (Note 1)
116 to 148.5 GHz	100%	12 dBm/MHz	42 dBm	20 dB
167 to 182 GHz	100%	12 dBm/MHz	42 dBm	20 dB
231.5 to 250 GHz	100%	12 dBm/MHz	42 dBm	20 dB

Note 1: The operating frequency range (OFR) is defined over the 20 dB reduction of the intentional transmission (20 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions attenuation applies to the frequencies outside the OFR and is to be reduced from the maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

0.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

Radiodetermination devices for industry automation to be used indoor or in similarly shielded environments are potentially used in many different industries. All RDI-S sensors have in common that they are used to sense unique frequency dependent features in the wideband frequency response of target objects. One category are RDI-S systems for plastic extrusion thickness measurement. Covering a wide contiguous frequency bandwidth allows RDI-S applications to improve the range resolution and measurement precision. The operation of RDI-S sensors is envisaged for industrial purposes only.

The operation of RDI-S in the two frequency ranges 116-190 GHz and 190-260 GHz are proposed and the need of large bandwidths is considered in the Report. However, contiguous bands of more than 32.5 GHz could only be realised, if passive bands subject to RR No 5.340 would be used. RR No 5.340 prohibits any emission. However, ECC Plenary #52 decided that these bands should also be considered in the studies under the conditions described in section 2.4.1.

This Report includes compatibility studies, which are based on the assumption that a wide contiguous bandwidth was available and also provides the technical justification why the large bandwidths are needed and why no technical solutions, such as notching out some frequencies, exist to avoid emitting in the RR 5.340 bands.

It is noted that the performance of RDI-S radars in terms of thickness measurements is proportional to the bandwidth used (resolution ~1/BW). Further information concerning the technical performance capabilities and the wide bandwidth requirements of RDI-S devices can be found in section 2.4.3.3.

It is noted, that notching out ITU RR 5.340 bands is technically possible for some rare RDI-S applications with low performance requirements and slow measurement rates, for example by using specific higher sweep-slopes of the local oscillator or switched amplifiers. However, this could impact accuracy and is not acceptable for high performance RDI-S measurements like needed for the vast majority of applications.

It is recommended that all RDI-S sensors should comply with the following (installation) requirements:
- For RDI-S, the 10 dB contiguous bandwidth shall be equal to or higher than 35 GHz;
- The operation of RDI-S sensors is envisaged for industrial purposes only;
- Installation and maintenance of RDI-S equipment shall be performed by professionally trained individuals only;
- RDI-S equipment shall not be marketed to private end customers;
- Installers have to ensure that the device main beam is not pointing towards windows or other weak shielded parts of the shielded environment. The direction of main radiation shall be indicated on the device;

- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- Slow sweeping RDI-S devices with sweep slopes smaller than 2.5 GHz/ms shall notch out the frequency bands subject to the provision RR No. 5.340 [71] by at least 10 dB reduction in mean and peak power (i.e. limits in Table 9 for maximum mean e.i.r.p. spectral density and maximum peak e.i.r.p. reduced by 10 dB);
- In order to protect the Radio Astronomy Service, inside a radius of 13.2 km around the stations of NOEMA and IRAM 30 m the installation and operation of RDI-S devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of RDI-S equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is recommended:

- For RDI-S devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

Table 9 shows for all the bands in the frequency range 116 to 260 GHz, including RR 5.340 bands, the proposed technical limitations under which the compatibility with the investigated Radio Services can be achieved without the implementation of additional mitigation techniques. This table shall not be understood as an endorsement for the use of the passive RR 5.340 bands by RDI-S applications.

Table 9: Proposed technical limitations for RDI-S devices in the band 116 to 260 GHz

Candidate frequency range	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 4)	Unwanted emission limits (Note 1)
116 to 122.5 GHz	100%	-5 dBm/MHz	45 dBm	-15 dBm/MHz max. mean e.i.r.p. spectral density (Note 2) and 35 dBm max. peak e.i.r.p. (Note 4)
122.5 to 123 GHz	100%	-5 dBm/MHz	45 dBm	
123 to 130 GHz	100%	+10 dBm/MHz	60 dBm	
130 to 134 GHz	100%	-5 dBm/MHz	45 dBm	
134 to 141 GHz	100%	+10 dBm/MHz	60 dBm	
141 to 148.5 GHz	100%	-5 dBm/MHz	45 dBm	
148.5 to 151.5 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
151.5 to 158.5 GHz	100%	-5 dBm/MHz	45 dBm	
158.5 to 164 GHz	100%	-5 dBm/MHz	45 dBm	
164 to 167 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
167 to 174.5 GHz	100%	-5 dBm/MHz	45 dBm	
174.5 to 174.8 GHz	100%	-5 dBm/MHz	45 dBm	
174.8 to 182 GHz	100%	+10 dBm/MHz	60 dBm	
182 to 185 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
185 to 190 GHz	100%	-5 dBm/MHz	45 dBm	
190 to 191.8 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
191.8 to 200 GHz	100%	-5 dBm/MHz	45 dBm	
200 to 209 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
209 to 226 GHz	100%	-5 dBm/MHz	45 dBm	
226 to 231.5 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	

Candidate frequency range	Maximum duty cycle	Maximum mean e.i.r.p. spectral density (Note 2)	Maximum peak e.i.r.p. (Note 4)	Unwanted emission limits (Note 1)
231.5 to 235 GHz	100%	-5 dBm/MHz	45 dBm	
235 to 238 GHz	100%	-5 dBm/MHz	45 dBm	
238 to 241 GHz	100%	-5 dBm/MHz	45 dBm	
241 to 244 GHz	100%	-5 dBm/MHz	45 dBm	
244 to 246 GHz	100%	-5 dBm/MHz	45 dBm	
246 to 250 GHz	100%	-5 dBm/MHz	45 dBm	
250 to 252 GHz (Note 3)	100%	-15 dBm/MHz	35 dBm	
252 to 260 GHz	100%	-5 dBm/MHz	45 dBm	

Note 1: The operating frequency range (OFR) is defined over the 10 dB reduction of the intentional transmission (10 dB bandwidth) radiated by the equipment into the air and shall remain in the candidate frequency bands. The unwanted emissions limits apply to the frequencies outside OFR. The measurement bandwidth for the unwanted emissions domain is 1 MHz.
Note 2: The given maximum mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36) in 1 MHz resolution bandwidth of the measuring receiver.
Note 3: Sub-band protected by the provision ITU RR No. 5.340 [71].
Note 4: The maximum peak e.i.r.p. shall be measured/evaluated in 1 GHz bandwidth.

A graphical illustration of Table 9 can be found in Annex 10.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
3D	Three Dimensional
ADAS	Advanced Driver-Assistance Systems
ALMA	Atacama Large Millimeter/submillimeter Array
AS	Antenna System
AWS	Automatic Weather Station
BEL	Building Entry Loss
BW	Bandwidth
BWA	Broadband Wireless Access
CDF	Cumulative Distribution Function
CDR	Contour Detection Radar, Contour Determination and Acquisition Radar
CEPT	European Conference of Postal and Telecommunications Administrations
CEPT	European Conference of Postal and Telecommunications Administrations
CMOS	Complementary Metal Oxide Semiconductor
CO	Continuum Observation
CO2	Carbon Dioxide
CW	Continuous Wave
dB	deciBels
DBF-CDR	Digital Beamforming Contour Detection Radar
dBi	Antenna Gain in deciBels relative to an Isotropic Radiator
DUT	Device Under Test
ECA	European Common allocation
ECC	Electronic Communications Committee
ECO	European Communication Office
EESS	Earth Exploration Satellite Service
EFIS	ECO Frequency Information System
E.I.R.P.	Equivalent Isotropically Radiated Power
EMC	Electromagnetic Compatibility
EME	Earth-Moon-Earth
EN	European Norm

Abbreviation	Explanation
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUT	Equipment Under Test
DATV	Digital Amateur TV
FN	Footnote
FMCW	Frequency Modulated Continuous Wave
FS	Fixed Service
FSL	Free Space Loss
FSS	Fixed Satellite System
FWA	Fixed Wireless Access
GaAs	Gallium Arsenide
GaN	Gallium Nitride
GBSAR	Ground Base Synthetic Aperture Radar
GEMS	Georgia Tech Electronics and Micro-System Lab
GEO	Geosynchronous Orbit
GSO	Geostationary orbit
H_2O	Water (-vapour)
HD-GBSAR	High Definition - Ground Base Synthetic Aperture Radar
HDPE	High-Density Polyethylene
HEO	High Earth Orbit
HPBW	Half Power Beamwidth
I/N	Interferer to Noise Ratio
IARU	International Amateur Radio Union
ICI	Ice Cloud Imager
IF	Intermediate Frequency
IFOV	Instantaneous Field of View
IGN	Institut National de l'Information Géographique et Forestière
IRAM	Institut de Radioastronomie Millimétrique
ISM	Industrial, Scientific and Medical
ISS	Inter-Satellite Service
ITU	International Telecommunication Union

Abbreviation	Explanation
ITU-RR	International Telecommunication Union Radio Recommendation
ITU-RR FN	International Telecommunication Union Radio Recommendation Foot Note
LEO	Low Earth Orbit
LFMCW	Linear Frequency Continuous Wave
LOS	Line of Sight
LPR	Level Probing Radar
M-CDR	Mechanical Contour Detection Radar
MCL	Minimum Coupling Loss
MIMO	Multiple Input Multiple Output
mmW	Millimetre Wave
MS	Mobile Service
MSS	Mobile Satellite System
MWI	Microwave Imager
NDT	Non-Destructive Testing
NLOS	Non-Line of Sight
NOEMA	Northern Extended Millimeter Array
NWA	Network Analyzer
O_2	Oxygen
O_3	Ozone
OFDM	Orthogonal Frequency-Division Multiplexing
OFR	Operating Frequency Range
OOB, OoB	Out of Band
PA-CDR	Phased Array Contour Detection and Acquisition Radar
PCB	Printed Circuit Board
PE	Polyethylene
PEEK	Polyether Ether Ketone
PLL	Phase-Locked Loop
PP	Polypropylene
PP	Point-to-Point
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
RAS	Radio Astronomy Service
RBW	Resolution Bandwidth

Abbreviation	Explanation
RCS	Radar Cross Section
RDI	Radiodetermination Systems for Industry Automation
RDI-S	Radiodetermination Systems for Industry Automation in Shielded Environments
RF	Radio Frequency
RMS	Root Mean Square
RPE	Radiation Pattern Envelope
RR	ITU Radio Regulations
Rx	Receiver
SAE	Single Antenna element
SAR	Synthetic Aperture Radar
SCPI	Standard Commands for Programmable Instruments
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SHM	Structural Health Monitoring
SiGe	Silicon-germanium
SISO	Single Input Single Output
SLO	Spectral Line Observations
SNR	Signal to Noise Ratio
SRD	Short Range Device
SRdoc	System Reference Document, source ETSI
SRR	Short Range Radar
SRS	Space Research Service
TDMA	Time Division Multiple Access
TLPR	Tank Level Probing Radar
TR	Technical Report, source ETSI
TRL	Transmission Reflect Line
TTT	Transport and Traffic Telematics
Tx	Transmitter
USB	Universal Serial Bus
UWB	Ultra-Wideband
VBW	Video Bandwidth
VCO	Voltage Controlled Oscillator
VLBI	Very-Long Baseline Interferometry
WG FM	Working Group Frequency Management

Abbreviation	Explanation
WG SE	Working Group Spectrum Engineering
WP-3M	Working Party 3M of ITU
WRC	World Radiocommunication Conference
WR-n	Hollow Waveguide Classification

1 INTRODUCTION

This Report has been prepared based on the information given in ETSI TR 103 498 [1], to consider possibilities for designating radio frequency spectrum in the frequency range from 116 GHz to 260 GHz to allow operation of next generation radiodetermination applications. Such applications comprise novel sensors for:

- generic indoor surveillance tasks;
- industrial automation purposes (RDI);
- vehicle applications for short-range assist and in-vehicle surveillance;
- ground based synthetic aperture radar featuring structural health and stability monitoring (GBSAR);
- level probing and tank level probing measuring tasks (LPR and TLPR);
- contour detection and volumetric measurements (CDR);
- high-precision measurements in shielded industrial environments (RDI-S) e.g. for plastic pipe thickness determination and quality inspection.

With the increasing digitisation of industrial production processes an increase of especially industrial automation requirements is expected. More and more individualised products are expected of being fabricated in highly or fully automated lines which contain lots of compact and flexible production units. These units will contain sensors for both, supporting the production process itself and supporting reconfiguration and change.

Thickness measurements in the recently fast-growing field of extruded plastic pipes and quality inspection like roughness determination of surfaces highly benefit from covering a wide modulation bandwidth to achieve an excellent range resolution and high measurement precision.

All the sensor systems for industrial purposes have in common that they need to be small, to be easily mounted in all kinds of applications, easily operable and they have to reliably function in harsh and adverse production environments with an outstanding measurement accuracy. They further should be equipped with small or even already chip-integrated antennas. The capability of fulfilling the individual measuring task with very low transmit power goes along with the requirement of supporting short response times which enable the detection and tracking of fast movements within the observation area.

Future applications providing vehicles with higher degree of autonomy towards highly (level 4) or even fully autonomous driving (level 5) require short- and ultra-short-range radars for front, side and rear-view such that 360°-sensing for ambient traffic monitoring is enabled. Those radars would allow to obtain a wide field of view (in elevation and azimuth) in close proximity of the vehicle which is mandatory for enabling features like autonomous manoeuvring, parking and collision avoidance.

But not only the surroundings of a car will be subject to intensive observation through different kinds of sensors in future, also indoor radar applications will play an important role in the home automation market, for intrusion detection or the very challenging contactless vital sign tracking and observation of persons inside a building e.g. in a hospital setting.

An exact description of these individual UWB applications, including their application scenario, technical parameters, antenna data, the expected market size and the assumed interference scenarios can be found in section 2.

The above-mentioned measurement objectives are only achievable with new spectrum designations for the mentioned UWB applications in the range above 116 GHz where larger modulation bandwidths can be realised and the interference potential towards other spectrum users is lower due to the higher free space loss and tendentially higher atmospheric attenuation.

For all next generation radiodetermination applications, different candidate frequency bands in the frequency range from 116 GHz up to 260 GHz have been defined and investigated in MCL-based deterministic analyses. The information concerning the defined candidate bands and the band assignments to Radio Services can be found in section 3.

The following Radio Services, assigned to either these candidate bands or to adjacent frequency ranges, have been identified as possible victims of interference arising from the mentioned UWB applications:

- Radio Astronomy Service;
- Fixed Service;
- Earth Exploration Satellite Service (passive);
- Amateur Service.

The technical parameters and the protection requirements for these systems are comprehensively treated in section 3.5.

The individual calculations for each UWB application are provided in separate worksheets which are annexed to this Report. The results of these calculations are provided in section 4 for Radio Astronomy, section 5 for Fixed Service, section 6 for Earth Exploration Satellite Service (passive) and section 7 for Amateur Service.

Finally, the conclusions drawn from these calculations for each candidate band can be found in section 8 including a graphical illustration of the ascertained compatibility situation in section 8.9.

2 UWB RADIODETERMINATION APPLICATIONS AND TECHNOLOGY

2.1 CATEGORISATION OF APPLICATIONS UNDER CONSIDERATION

The radio determination applications under consideration in this Report have been categorised into three types A, B and C relating to their interference potential. This scheme has already been introduced in the ETSI TR 103 498 [1], which is the technical base for this Report.

Applications of type A are intended for sensors which may radiate into the open sky in any direction outside a shielded environment, building or housing and are therefore considered as most critical relating to the generation of harmful interference into other Radiocommunication Services. The following type A applications are identified and investigated:

- Generic indoor surveillance radar;
- Radiodetermination systems for industry automation (RDI);
- Short-range assist and surrounding monitoring for vehicles and autonomous systems[1];
- Ground Based Synthetic Aperture Radar (GBSAR).

Type B is intended for applications where the sensor always radiates in a downward direction towards the ground (and thus not directly into the open sky in an arbitrary direction) outside a shielded environment, building or housing. Type B applications are considered less critical relating to the generation of harmful interference compared to type A, as victim radio services usually do not appear in the direction of main radiation of type B sensors. The following two type B applications were identified and investigated:

- Level Probing Radar (LPR);
- Contour determination and acquisition radar (CDR).

Type C is intended for applications emitting inside a confined and shielded environment, building or housing. Because of radiating inside or into a shielded environment, type C applications are considered to be least critical because of the inherent signal attenuation of the application scenario. The following three type C applications were identified and investigated:

- Tank Level Probing Radar (TLPR);
- Radiodetermination systems for industry automation in shielded environments (RDI-S).

However, all above mentioned applications in all three categories A, B and C have their own and unique peculiarities, technical parameters and deployment scenarios which influence the interference mechanisms to other spectrum users. Furthermore, different frequency ranges have been identified as appropriate and requested for the different applications. Therefore, it was necessary to conduct compatibility studies for each individual application with respect to the existing Radiocommunication Services inside or adjacent to the requested frequency range.

While performing the studies for each individual application, it became clear that a categorisation of applications would also not be feasible for the subsequent spectrum regulation. Therefore, all mentioned applications have been treated separately and the categorisation into types A, B and C has furthermore been suspended in the performed studies.

[1] In ETSI TR 103 498 [1], this application is named "Side-view assist and ambient monitoring for vehicles and autonomous systems".

2.2 DESCRIPTION OF APPLICATIONS

2.2.1 Generic indoor surveillance Radar

2.2.1.1 Application scenario

Similar to the other categories of millimetre-wave radars, the frequency range 116-260 GHz enables applications with high range resolution and low form factors. This is especially interesting for two major application categories:

- Indoor mobile and hand-held applications, like surveillance radars for robots and autonomous household devices (e.g. dust cleaners) or short-range interaction movement detection (e.g. gesture or object recognition);
- Fixed indoor surveillance radars, e.g. for intrusion detection, detection of falling persons.

Common characteristics of these use cases are depending on the inherent small form factors enabled by high frequencies and short wavelengths, respectively. Given the inherent need for detecting motion and presence of individual persons, objects, limbs or fingers, digital beam forming with a high angular resolution could be used as well.

For all these applications, the privacy -preserving nature of the radar sensing is a fundamental property and such sensors are used to assess the situation in a volumetric space. The situation is assessed by detecting the overall presence of an object (e.g. human) or parts of, e.g. micro-motion caused by heartbeat, breathing, or assessing the physical characteristics – the contour or the movement-of the objects. Some use-cases may also encompass the differentiation of creatures or objects, like between animals and objects or even between different animals.

Indoor applications are plentiful in the context of smart home, smart building, smart factory, and e-health. In these “verticals”, there is a huge requirement for contactless monitoring of people, including people detection, tracking, counting and activity recognition or to provide functions to devices which work together with humans. This can be achieved by either illuminating a room with one or several radars depending on the room size and geometry or putting the function into a cooperative device (e.g. a robot). In the e-health vertical, monitoring the vital signs of persons in rooms, at their desk or workplace is gradually becoming a key technology to improve the well-being of people. In hospital or old people's homes, this is also useful for the vital signs monitoring of patients being alone in their room or in bed.

Overview on some planned common use cases:

- Vital sign tracking (heartbeat/breathing): for example, assessment of the physical well-being – e.g. in a hospital setting – of one or several persons in the scene. The presence and evolution of vital signs are detected by assessing micro-motion caused by heartbeat and/or breathing;
- Exit and/or entry monitoring: for example, determining the contour of persons in an access corridor (e.g. a door), and assessing whether the contour corresponds to an allowed entry and/or exit policy;
- Person identification and tracking: for example, by using the contour of the occupant(s), an accurate tracking in a scene can be performed, even with occupants in close proximity;
- Object protection purposes: for example, detection of forgotten objects (e.g. mobile phones) or detection of unwanted intrusion into the scene (e.g. protection of valuable items).

The fixed indoor operation is shielded by the building envelope for industrial and consumer applications. For high-resolution imaging further encapsulation of the measurement setup is possible. Typically, the direction of main radiation of the sensor is horizontal or tilted downwards below the horizontal direction. Only for the hand-held/mobile applications it could be the case that there are emissions above the horizon, but for such applications there are lower power levels possible.

2.2.1.2 Frequency ranges and application types

Generic indoor surveillance radar has been categorised as type A application (see section 2.1). The following frequency ranges are proposed to be considered for this type of application (see Table 33):

- 116 GHz to 130 GHz;
- 134 GHz to 141 GHz;
- 141 GHz to 148.5 GHz.

2.2.1.3 Technical parameters

Table 10 gives an overview of the technical parameters of the indoor surveillance applications which may be relevant for conducting the compatibility studies.

Table 10: Technical parameters of indoor surveillance radar

Parameter	Value	Notes
Modulation scheme	Different modulation schemes are currently possible: ▪ Frequency Modulated Continuous Wave (FMCW) ▪ Pulsed ▪ OFDM	
Operating frequency range (OFR)	116 GHz to 130 GHz 134 GHz to 141 GHz 141 GHz to 148.5 GHz	
Available modulation bandwidth	14 GHz, 7 GHz and 7.5 GHz	
Used modulation bandwidth	1, 2, 4, 7, 14 GHz	-20 dB bandwidth aligned in the OFR
Sweep-time	10 µs to 15 ms	for a single frequency sweep over entire modulation bandwidth
Duty cycle	Maximum 40% for hand-held and mobile applications, but with an activity factor of maximum 50% per day which is equivalent to an overall DC of 20%. 10% for the fixed applications.	
Conducted mean power	Up to 0 dBm	with 100% duty cycle
Detection ranges	Hand-held/mobile: 2 m to 3 m Fixed: 5 m to 10 m	
Maximum mean power (e.i.r.p.)	Hand-held/mobile: up to 10 dBm Fixed: up to 20 dBm	The lower power level for hand-held/mobile applications relates to the shorter detection ranges.
Maximum mean power spectral density dBm/MHz (e.i.r.p.)	Hand-held/mobile: up to -20 dBm/MHz Fixed: up to -10 dBm/MHz	For a bandwidth of 1 GHz

2.2.1.4 Antenna data

Table 11: Antenna parameters of indoor surveillance radar

Parameter	Value	Notes
Antenna gain	Hand-held and mobile: 10 dBi fixed: up to 20 dBi	For fixed indoor surveillance radars an antenna pattern featuring at least 8 dB sidelobe suppression above an elevation of larger than 0° in combination with an installation requirement for the main beam direction could be considered

The antenna gain for indoor surveillance radar is mainly use-case/application dependent. It is important to also consider the “volume” and “distance” to the target the radar is intended to observe.

2.2.1.5 Market size

The situation inside buildings is difficult to estimate. The number of devices depends on the success of IoT and home automation applications and the temporal deployment. Such indoor surveillance sensors will be part of a building automation or security system. For a worst-case estimation one sensor per room (living room, entrance hall, etc.) could be assumed. This could lead up to 5 sensors per house or up to 3 sensors per flat.

A similar assumption was made for the studies on UWB <10 GHz in ECC Report 64 [17]. But in these studies, both, radiocommunication and radiodetermination applications have been considered. In addition, it is considered that for some applications (e.g. for longer detection distance) other frequencies could be used (e.g. 57 to 64 GHz) and for some special applications there are specific studies in this report (like RDI-S and CDR). Therefore, the following device densities were considered for the studies for generic indoor surveillance radar applications (see Table 12).

Table 12: Assumed device densities

	Rural (devices/km²)	Suburban (devices/km²)	Dense Urban (devices/km²)
Total device density (100%)	50	500	5000
Hand-held/mobile (50%)	25	250	2500
Consumer fixed indoor (40%)	20	200	2000
Professional fixed indoor (10%)	5	50	500

2.2.1.6 Interference scenarios

Based on the assessed device densities and the technical parameters (see Table 13) and possible installation requirements for fixed professional applications the following parameters for the compatibility studies could be extracted. The specific installation requirements for fixed applications could later be considered in the ECC Regulation.

Table 13: Parameters for the MCL calculation, hand-held and mobile generic indoor surveillance radar equipment

Parameter	Value for hand-held/mobile
Operating frequency range (OFR)	116 GHz to 130 GHz 134 GHz to 141 GHz 141 GHz to 148.5 GHz

Parameter	Value for hand-held/mobile
Duty cycle	Max. 40% for hand-held and mobile application, but with and an activity factor of 50% per day. Total Tx on time per day: 20%
Maximum mean power (e.i.r.p.)	10 dBm
Antenna gain	10 dBi
Out-of-band (OoB) attenuation	-20 dB (minimum)
Device densities (per km²)	Is it assumed that: ▪ The dense urban values are used for the studies; ▪ The devices will be used in both frequency ranges (116-130 GHz and 134-148.5GHz) with the same device density. This would lead to a density of 1250 devices/km² for both frequency ranges.

Table 14: Parameters for the MCL calculation, fixed generic indoor surveillance radar equipment

Parameter	Value for fixed indoor
Operating frequency range (OFR)	116 GHz to 130 GHz 134 GHz to 141 GHz 141 GHz to 148.5 GHz
Duty cycle	10%
Maximum mean power (e.i.r.p.)	20 dBm
Antenna gain	20 dBi
Out-of-band (OoB) attenuation	-20 dB (minimum)
Device Density (per km²)	Is it assumed that: ▪ The dense urban values are used for the studies; ▪ The devices will be used in both frequency ranges (116-130 GHz and 134-148.5 GHz) with the same device density. This would lead to a density of 1250 devices/km² for both frequency ranges.

- Fixed indoor applications are looking in horizontal direction or are tilted downwards to the ground in order to reach a better coverage of the observed volume. This applies also to indoor robots. This could be considered by limiting the radiation above 0° elevation to 8 dB below the main beam emission which is equivalent to a maximum mean e.i.r.p. of 12 dBm above 0° elevation (see Table 14).
- For the EESS aggregation assessment, no consideration of lower device densities in rural or suburban regions are made. As worst-case assumption the dense urban value was considered for complete Europe.
- Only for hand-held and some mobile applications the main beam direction could be aligned directly towards the FS receiving antenna.
- For the interference scenario a device height of 1 m was assumed. This value is considered as an average of the typical application heights found in the field.
- The typical usage scenario (see Figure 2, Figure 3 and Figure 4) and the related alignment of the devices would further reduce the probability of interference to the victim receiver. This aspect, however, was not considered in the conducted MCL calculations.

Figure 2, Figure 3 and Figure 4 provide the schematic illustration and the geometry of the interference scenarios. The figures are quite comparable to the ones used in the RDI-S interference assessments.

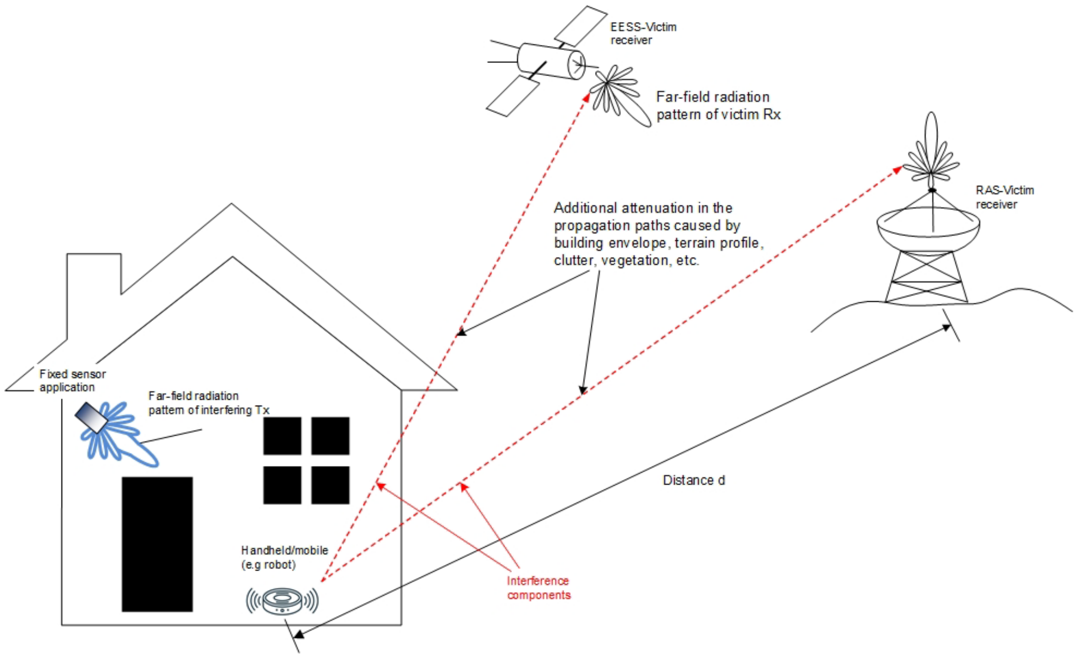


Figure 2: Interference scenario for generic indoor surveillance radars versus EESS (passive) and Radio Astronomy

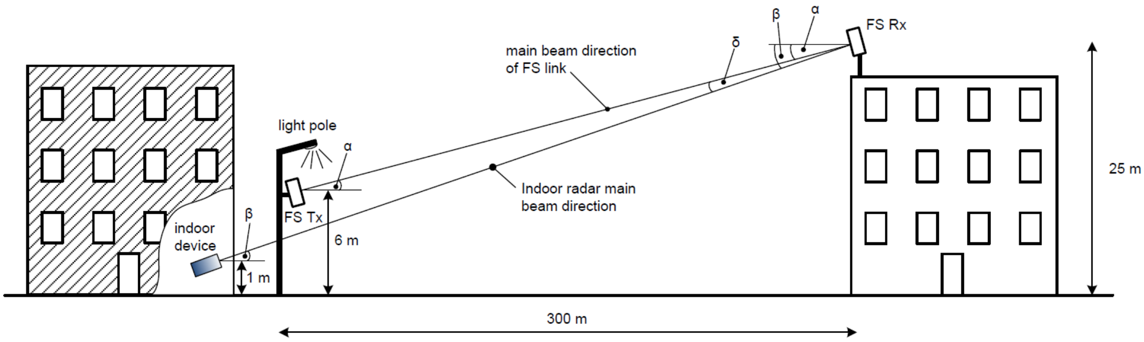


Figure 3: Interference scenario 1 for generic indoor surveillance radars versus Fixed Service

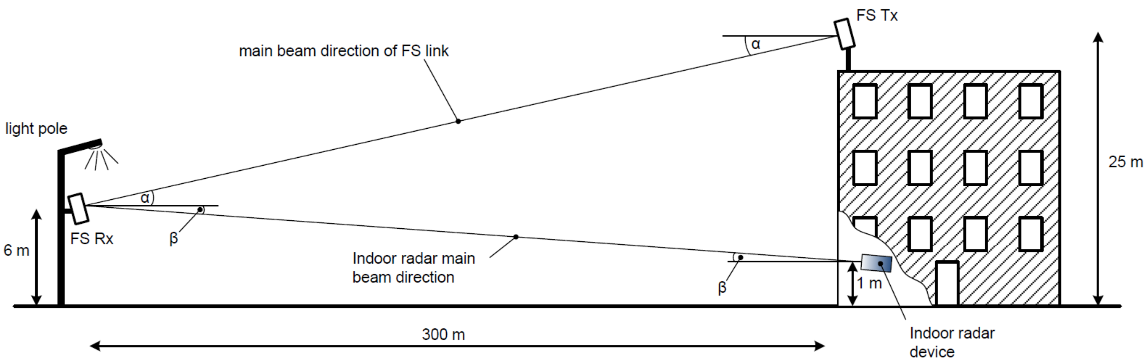


Figure 4: Interference scenario 2 for generic indoor surveillance radars versus Fixed Service

2.2.2 Radiodetermination systems for industry automation (RDI)

2.2.2.1 Application scenario

Radiodetermination sensors for automation purposes are used in many industries to measure different physical parameters like presence, distance, velocity or material properties of the target object. The obtained information is further processed and used for automation purposes. A typical conceptional measurement scenario for RDI devices in an industrial environment is illustrated in Figure 5.

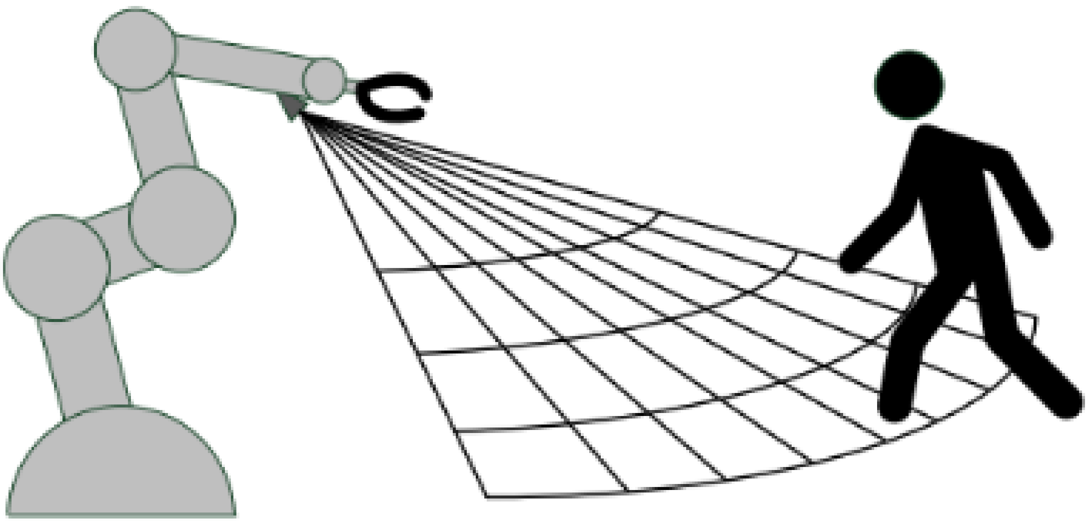


Figure 5: Conceptional RDI measurement scenario at an industrial robot in a production line

For RDI devices several measurement principles and modulation techniques can be applied such as FMCW or pulse-based Radar modulation schemes sometimes with doppler evaluation in order to extract the velocity information out of the received signal. A crucial advantage of Radar technology is that the RF signal travels at the speed of light, which enables real-time applications, and is nearly independent of ambient temperature, pressure and humidity and other adverse environmental conditions.

RDI sensors are expected to be installed in a variety of different industrial applications with automation background in order to gain information of different physical parameters of the measurement object. Such applications could be for example (non-exhaustive list):

- Position detection of components or workpieces as well as tools and machinery equipment in smart factory production lines;
- Presence and motion detection for collaborative robots in highly automated assembly lines for collision prevention and interaction with humans;
- Velocity measurement and positioning of transport containers/waggons during loading and unloading;
- Thickness measurement of products during fabrication process;
- Non-destructive in-line quality control of production goods.

It is worth mentioning that in many of these installations, RDI devices provide real-time and safety-critical information in order to protect humans, animals, technical equipment, machinery and the environment.

In other applications, an accurate monitoring of specific properties of the product, which can be measured with RDI sensors, helps to improve the quality of the end-product, and to conserve the environment by facilitating the efficient use of scarce natural resources by minimising the materials usage.

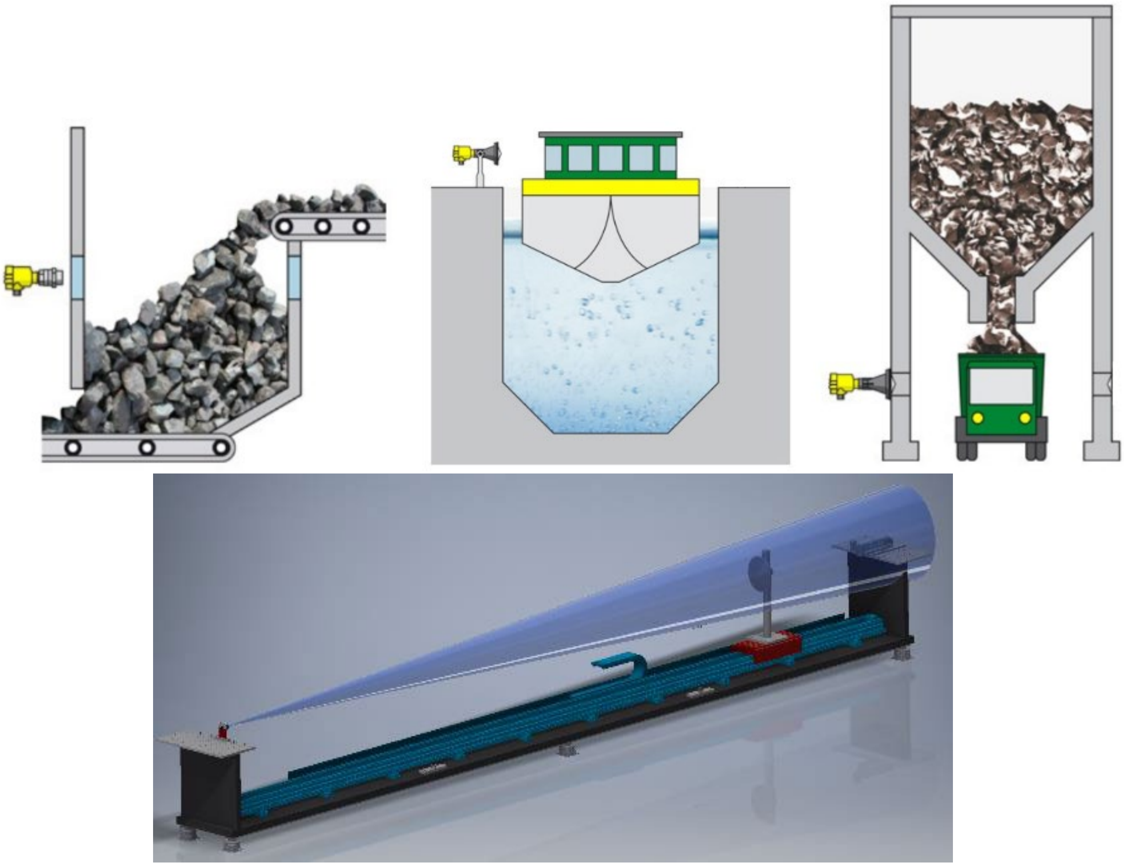


Figure 6: Typical examples of outdoor RDI installations

It is foreseen that RDI equipment in dedicated frequency bands within the range of 116 to 260 GHz is a strictly professional and industrial application. All RDI sensors are expected to be installed complying with the following installation requirements:

- Installers have to ensure that there are no obstacles in the main beam of the antenna in order to minimise unwanted reflections and scattering. This is of course not true for the measurement object itself whose physical parameters are being analysed;
- Installation and maintenance of RDI equipment shall be performed by professionally trained individuals only. RDI equipment shall not be marketed to private end consumers;
- As above mentioned, RDI sensors can be deployed in a variety of applications sensing a multiplicity of parameters. However, as the operation of these sensors is envisaged for industrial automation purposes, the installation heights are inherently limited to those which are actually used for the installations and objects which are being monitored for example in an automated production line;
- It is therefore expected that all outdoor RDI sensors under consideration will be installed in heights from 0 to 3 m above ground. In the considered interference scenarios, it is therefore proposed to use these figures.

2.2.2.2 *Frequency ranges and application types*

Radiodetermination for industry automation has been categorised as type A application (see section 2.1). The following frequency ranges are proposed to be considered for this type of application (see Table 33):

- 116 GHz to 130 GHz;
- 134 GHz to 141 GHz;
- 174.8 GHz to 182 GHz;
- 185 GHz to 190 GHz;
- 231.5 GHz to 250 GHz.

2.2.2.3 Technical parameters

Table 15 gives an overview of the technical parameters of radiodetermination devices which may be relevant for conducting the compatibility studies.

Table 15: Technical parameters of RDI devices

Parameter	Value	Notes
Modulation scheme	e.g. frequency modulated continuous wave (FMCW) or pulse-based modulation schemes	Combination of different OFRs possible
Operating frequency range (OFR)	116−130 GHz 134−141 GHz 174.8−182 GHz 185−190 GHz 231.5−250 GHz	
Available modulation bandwidth	14 GHz, 7 GHz, 7.2 GHz, 5 GHz, 18.5 GHz	
Used modulation bandwidth	up to 14 GHz up to 7 GHz up to 7.2 GHz up to 5 GHz up to18.5 GHz	-20 dB bandwidth
Sweeptime	10 µs to 5 ms	for a single frequency sweep over entire modulation bandwidth
Duty cycle	≤ 5%	
Conducted peak carrier power	up to -5 dBm	Maximum peak output power at antenna feeding point
Conducted mean power	-18 dBm	with 5% duty cycle and −5 dBm peak carrier power
Conducted mean power spectral density	-59.8 dBm/MHz	with 15 GHz modulation bandwidth and −18 dBm mean power
Maximum mean power spectral density (e.i.r.p.)	-23.8 dBm/MHz	calculated with 36 dBi maximum antenna gain

2.2.2.4 Antenna data

Especially for industry automation and industry automation applications in shielded environments often high gain antennas with small pencil beams and compact size are used to illuminate the measurement target with sufficient power to reach a large SNR, even with small radar targets. High gain antennas also limit the risk of interference with other systems because of the small beam width and a well-defined illumination area directed to the measurement target only.

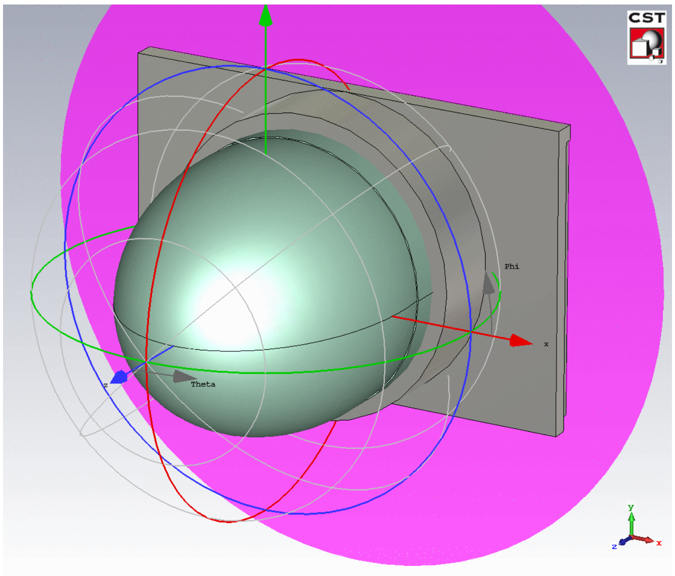


Figure 7: Typical high gain dielectric UWB antenna for industrial applications

In Figure 7 a model of a typical dielectric antenna is shown. The antenna consists of a ground plane (e.g. one side of the metallic sensor housing). The beam forming element is ellipsoidal shaped with 35 mm diameter that is fed in the second focal point.

In the model PTFE was chosen for the beam forming element material, but also PEEK, HPDE or other dielectrics are suitable, depending on the application's specific needs. The dielectric antenna has an external thread for assembly with the sensor itself. In this example, a standard design was chosen in order to assure a good compatibility between easy design and antenna performance in terms of directivity, HPBW and side lobe suppression.

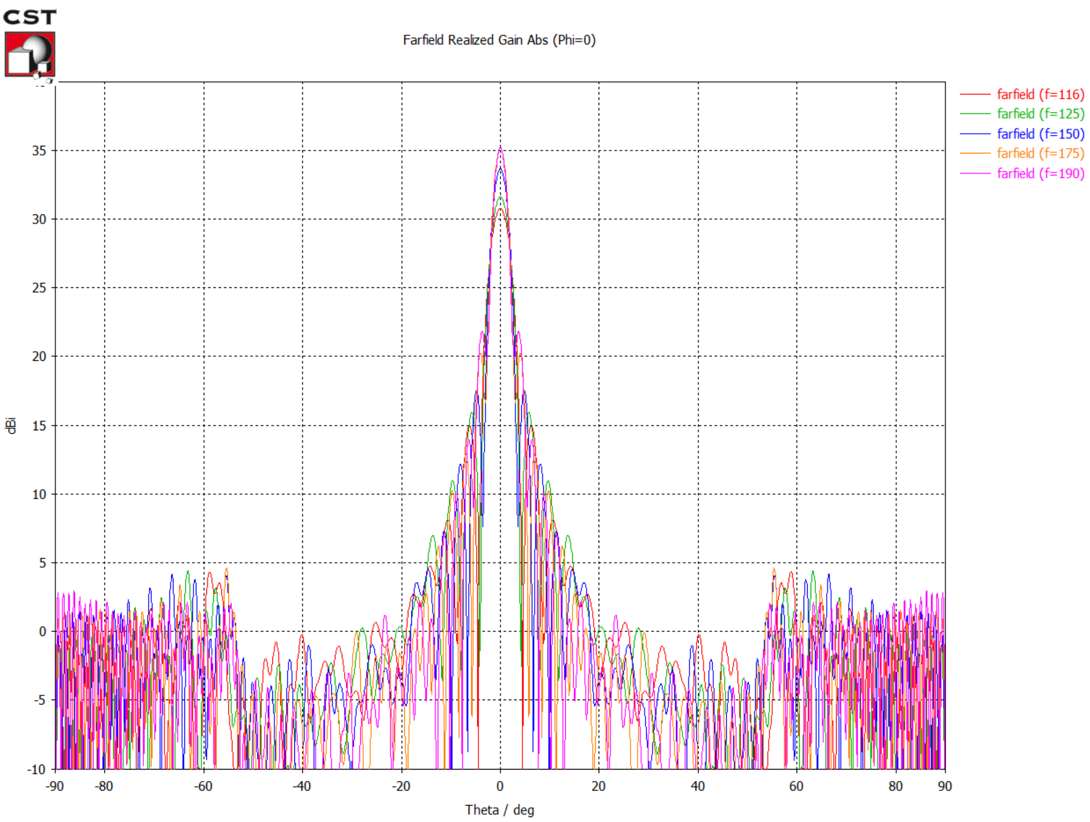


Figure 8: Antenna pattern in Φ=0° plane from 116 GHz to 190 GHz

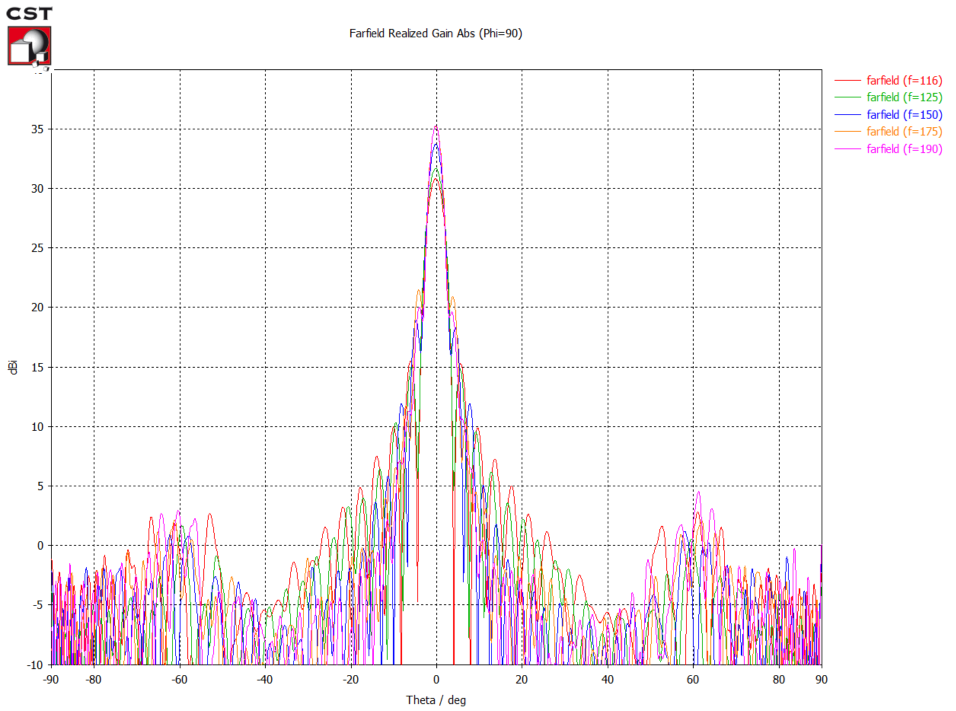


Figure 9: Antenna pattern in Φ=90° plane from 116 GHz to 190 GHz

For all simulations, a state-of-the-art 3D simulation tool with a time domain solver and a sufficiently fine mesh was used. Experience shows that simulation results usually exhibit a superior agreement with measurements of the real manufactured antennas even at those high frequencies.

In Figure 8 and Figure 9, the simulated antenna patterns in the two planes for frequencies from 116 GHz to 190 GHz is shown. The antenna gain in main beam direction varies from around 31 dBi to 36 dBi.

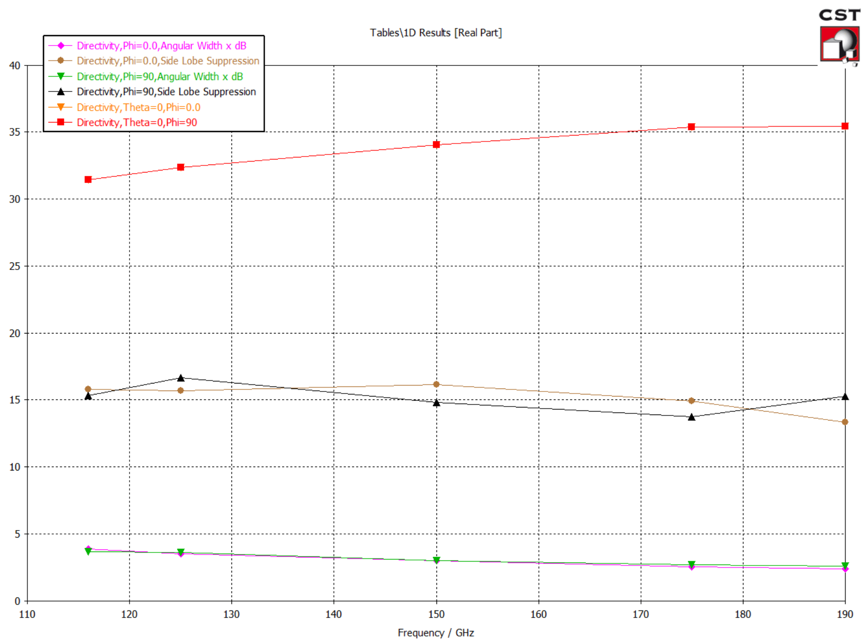


Figure 10: Directivity, HPBW and side lobe suppression for both planes from 116 GHz to 190 GHz

The antenna behaviour over frequency is depicted in Figure 10 in terms of directivity, HPBW (angular 3 dB beam width) and side lobe suppression in both planes.

Table 16: Antenna parameters for RDI devices

Parameter	Value	Notes
Antenna type	horn- and lens-horn antennas, dielectric lens antennas, planar antenna arrays or similar structures	application dependent
Antenna half power beam-width	between 2.3° and 3.9°	depends on individual antenna type/between open waveguide and high-gain antenna
Antenna gain	typically, 6 to 36 dBi	
Antenna polarisation	Linear or circular	

2.2.2.5 Market size

Table 17 shows the estimated market size[2] for RDI devices in open air applications throughout Europe subdivided for all proposed frequency bands 116−130 GHz, 134−141 GHz, 174.8−182 GHz, 185−190 GHz and 231.5−250 GHz. This rather rough estimation also considers a considerable growth within the first five years after market launch. Given the European land area of 10523000 km², this translates to the average density of 0.0152 RDI devices/km² in the band 116-130 GHz, 0.0076 devices/km² in the bands 134-141 GHz and 174.8-182 GHz and 0.0038 devices/km² in the bands 185-190 GHz and 231.5-250 GHz.

Table 17: Estimated sales figures and device densities of RDI devices

Parameter	Value
Worldwide accumulated number of RDI devices in the field 5 years after launch in all proposed frequency ranges	1000000
Fraction of devices sold for the European market in all bands	40%
Fraction of RDI devices sold in the band 116-130 GHz	40%
Fraction of RDI devices sold in the band 134−141 GHz	20%
Fraction of RDI devices sold in the band 174.8−182 GHz	20%
Fraction of RDI devices sold in the band 185-190 GHz	10%
Fraction of RDI devices sold in the band 231.5-250 GHz	10%
Accumulated number of RDI devices in the field in Europe 5 years after launch in the band 116-130 GHz	160000
Accumulated number of RDI devices in the field in Europe 5 years after launch in the band 134-141 GHz	80000
Accumulated number of RDI devices in the field in Europe 5 years after launch in the band 174.8-182 GHz	80000
Accumulated number of RDI devices in the field in Europe 5 years after launch in the band 185-190 GHz	40000
Accumulated number of RDI devices in the field in Europe 5 years after launch in the band 231.5-250 GHz	40000
European land area	10523000 km²

[2] Companies involved in this assessment: 2pi-Labs GmbH and VEGA Grieshaber KG.

Parameter	Value
Average density of RDI devices in Europe in the band 116-130 GHz	0.0152 devices/km²
Average density of RDI devices in Europe in the band 134-141 GHz	0.0076 devices/km²
Average density of RDI devices in Europe in the band 174.8-182 GHz	0.0076 devices/km²
Average density of RDI devices in Europe in the band 185-190 GHz	0.0038 devices/km²
Average density of RDI devices in Europe in the band 231.5-250 GHz	0.0038 devices/km²

It may be seen from the numbers given above, that the projected average density of RDI devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude certain cases, where multiple RDI devices could be used in very near proximity in an industrial plant for instance. But given their very low duty cycles and in addition to that the nevertheless unsynchronised nature of RDI devices, even in such cases, adverse aggregation effects may be considered highly unrealistic.

In order to implement the philosophy of worst-case simulations of RDI interference, no additional natural shielding, e.g. treated in Recommendation ITU-R P.2108-0 [25], is considered in the MCL calculations of this Report, i.e. all MCL calculations are performed for the worst-case of RDI being placed outdoors, with line-of-sight (LOS) conditions and without any natural shielding. As a result, all calculated interference impacts represent the most conservative estimates, which in many real-life scenarios will be further reduced due to aforementioned natural shielding.

2.2.2.6 Interference scenarios

In section 3.4, the possible interference scenarios are divided into the two broad categories:

- Interference over terrestrial line-of-sight (LOS) paths;
- Interference to spaceborne passive satellite receivers over LOS paths.

This categorisation also applies for radiodetermination sensors for industry automation.

Interference over terrestrial paths

The typical scenario in which an interference signal, originating from an automation sensor, propagates along a terrestrial path will be relevant when evaluating coexistence with the following victim services:

- Fixed Service (FS) links (PP and BWA);
- Fixed Satellite Service (FSS) earth station receivers;
- Terrestrial Radio Astronomy Service (RAS);
- Amateur Service receivers.

In this case, sensor installations might have an impact on the victim stations through direct emissions emitting in horizontal direction along the earth's surface. Due to the fact that radiodetermination sensors for industry automation are classified as type A applications they are not limited to certain antenna orientations and may therefore radiate in any direction. Thus, the case where the main beam direction of the sensor points exactly towards the antenna of the victim service should be considered as the worst-case. In contrast to that, it is suggested that the interference signal from the sensor application reaches the victim receiver by coupling over a sidelobe of the victim's receiving antenna. This concept is described for radio astronomy victims in Recommendation ITU-R RA.769-2 [9] where the gain of an isotropic radiator 0 dBi is assumed for the respective sidelobe gain. For the Amateur Service victims, a reduction of the main lobe receiving antenna gain of 20 dB due to this misalignment is suggested for the MCL calculations in the first instance.

This worst-case interference scenario along horizontal terrestrial paths utilised for the compatibility study for RAS and Amateur Service is illustrated in Figure 11 by means of an outdoor presence detector monitoring the presence of a vehicle for example during a loading process.

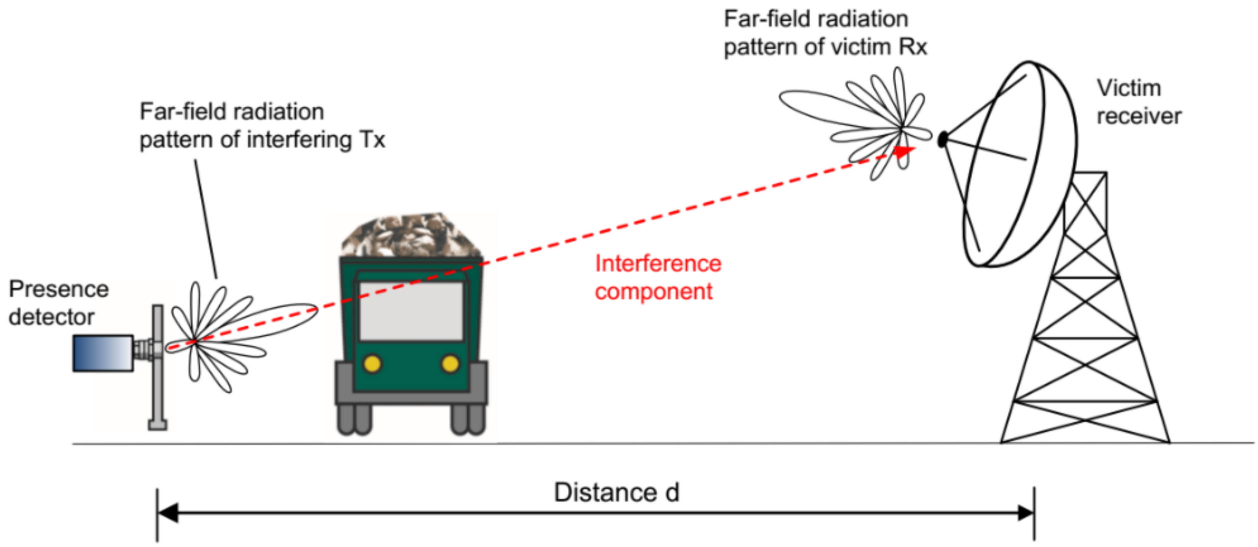


Figure 11: Worst-case interference scenario along horizontal terrestrial paths

For initial worst-case simulations also in this scenario it would be reasonable to assume direct line-of-sight (LOS) coupling between interferer and victim. This means that the free-space propagation model could be applied to model the propagation of the interfering signal over a flat path over the earth's surface without the presence of obstacles. This, in turn, makes it unnecessary to consider the heights of the sensor antenna and the victim station's antenna. However, this initial simplification could later be refined in the light of the calculated interference or impact range.

For example, if the calculated interference distance for a given coexistence case clearly exceeded the estimated radio horizon, this would mean that non-LOS propagation conditions predominate. This in turn would lead to the requirement to apply different propagation models and potentially an unavoidable reduction of the actual interference range.

For Fixed Service links however, dedicated interference scenarios have been developed where a Fixed Service transmitter attached to a light pole is linked with a receiver located on top of a building and vice versa (see Figure 12 and Figure 13).

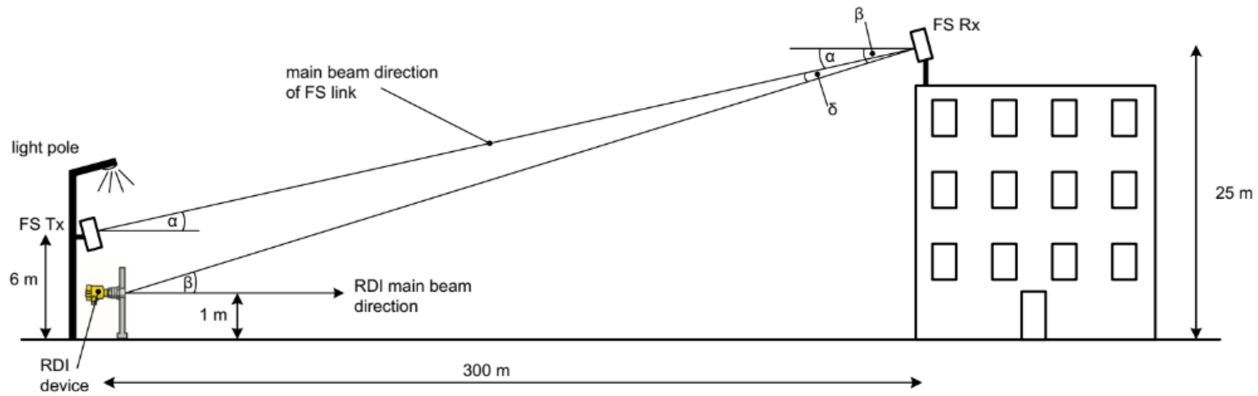


Figure 12: Light pole connected to a building by means of an FS link – FS Rx on building

In the first scenario (see Figure 12), the RDI device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. This constellation yields the smallest angle δ which describes the misalignment between the FS Rx main beam direction and the RDI device. The height of the RDI device above ground shall be 1 m. All RDI devices are expected to be placed between 0 and 3 m above ground (see section 2.2.2.1).

The angle δ becomes in the above example approximately 0.95° which results in approximately 38 dBi gain of the FS Rx antenna towards the RDI interferer.

In the second scenario (see Figure 13), the building rooftop is again connected to a light pole. In contrast to the first scenario, the locations of the FS Rx and the FS Tx are exchanged. The distance between the FS Rx and Tx is again 300 m and also the separation distance between the RDI device and the FS Rx is again 300 m resulting in an angle α+β which describes the misalignment between the FS Rx direction of main radiation and the location of the RDI device.

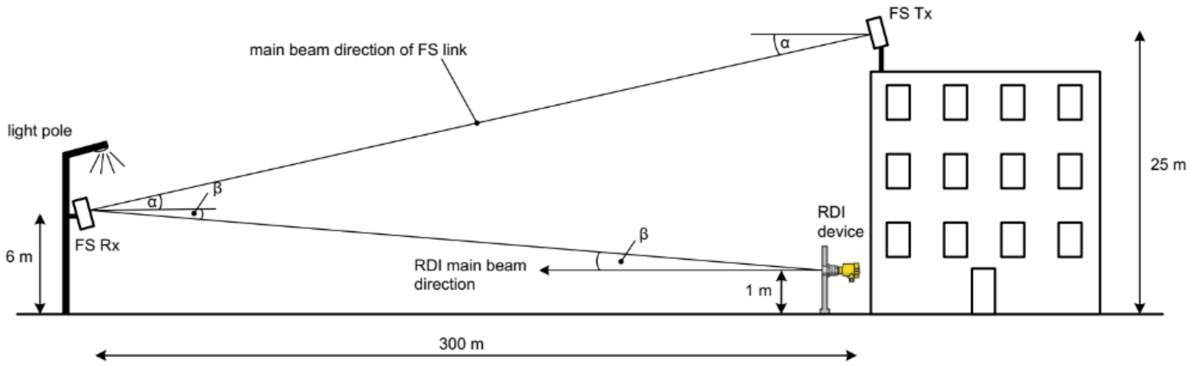


Figure 13: Light pole connected to a building by means of an FS link – FS Rx at light pole

For both scenarios, the following two cases can be distinguished:

- The RDI main beam points in horizontal direction (like indicated in Figure 12 and Figure 13);
- The RDI main beam points exactly towards the FS receiver.

Interference to EESS (passive) satellite receivers

In case of interference to satellite receivers, the relevant radiation direction would be in vertical plane above the sensor installation and the worst-case scenario could be described as an open-air sensor installation measuring vertically upwards.

Thus, the case where the main beam direction of the interfering transmit antenna points exactly towards the antenna of the victim service should be considered as the worst-case. Thus, also in this scenario the free-space propagation model could be applied assuming direct line-of-sight (LOS) conditions without obstacles between interferer and victim.

In contrast to the interference scenario over terrestrial paths, it is suggested that the interference signal from the sensor application reaches the victim satellite receiver by coupling over the main beam direction of the victim's receiving antenna.

Figure 14 shows a potential installation of a sensor application monitoring the placement of goods on a conveyor belt where the above described worst-case interference scenario would be reproduced.

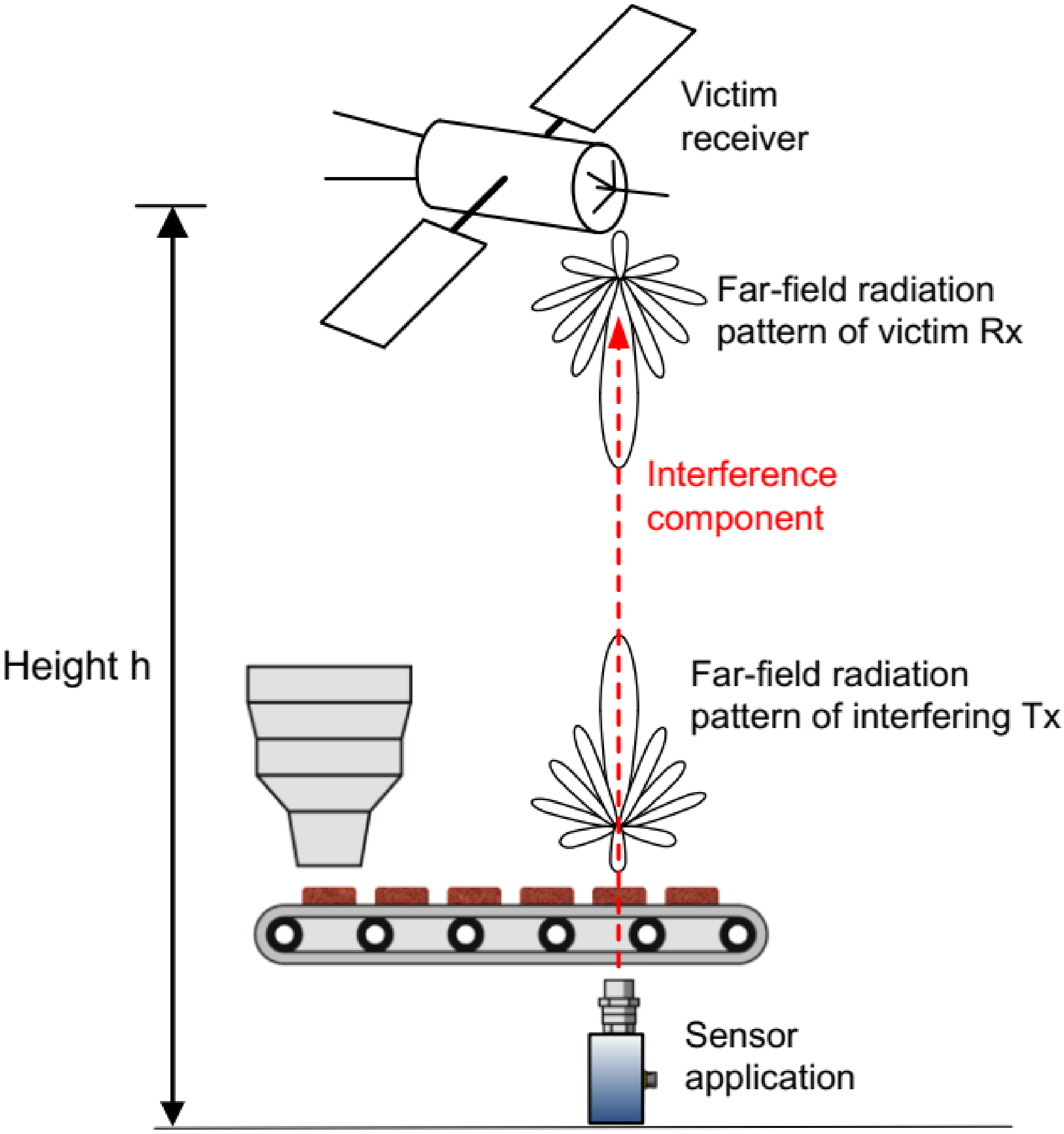


Figure 14: Worst-case interference scenario against EESS (passive) satellite receivers

Special conditions in aggregate interference scenarios

RDI devices can be arbitrarily aligned in the field depending on the measurement scenario. In aggregate interference scenarios, where many of these RDI devices can affect the victim, the usage of an average RDI antenna gain of 10 dBi towards the victim receiver was therefore assumed.

2.2.3 Short range assist and surrounding monitoring for vehicles and autonomous systems

2.2.3.1 Application scenario

To perform different functionalities for driving assistance, cars are equipped with different types of radars that are integrated in specific positions onboard the vehicle as shown in Figure 15. Front and corner radars are currently used for applications requiring long and medium range such as automatic cruise control, lane keep, lane change assist, automatic emergency braking, etc.

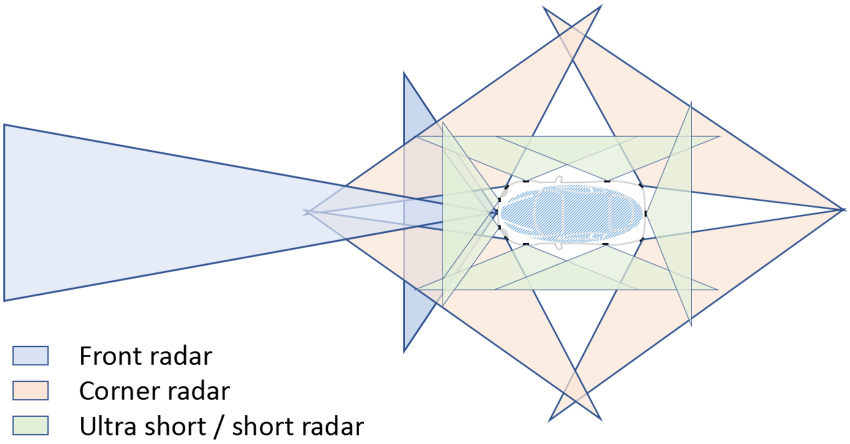


Figure 15: Short or ultra short-range car radar for short-range assist/monitoring

On the other hand, future applications providing the vehicle with higher degree of autonomy require short and ultra-short-range radars for front, side and rear-view (see green areas in Figure 15), such that 360° sensing is enabled. Those radars would allow to obtain a wide field of view (elevation and azimuth) in the close proximity of the vehicle and features like automated parking assistance or autonomous valet parking would be possible. To perform such features, the short-range detection radars should be capable to detect a wide range of objects different in nature to those traditionally detected for driving assistance radars (pedestrian, bicycles, vehicles, etc). Therefore, a wide range of target characteristics should be taken into account while assessing the technical parameters of the radars at this frequency range.

2.2.3.2 Frequency ranges and application types

Radar sensors for short-range assist and surrounding monitoring for vehicles and autonomous systems have been categorised as type A applications (see section 2.1). The following frequency ranges are proposed to be considered for this type of application (see Table 33):

- 116 GHz to 130 GHz;
- 134 GHz to 141 GHz;
- 141 GHz to 148.5 GHz.

2.2.3.3 Technical parameters

Radar products for automobile applications exist in the 24 GHz and 79 GHz frequency bands. No prototypes have been developed in frequency bands above 100 GHz; therefore, several hypotheses should be made to deduce radar characteristics at the bands considered in this Report. Table 18 provides general assumptions applicable to different type of radars that could be designed in these bands.

Table 18: General assumptions for automotive radars for short-range applications

Parameter	Value	Comment
Frequency bands	116-130 GHz 134-141 GHz 141-148.5 GHz	
Bandwidth	1, 2, 4, 7, 14 GHz	Depending on the required range resolution of the application
Required SNR	15 dB	Typical value in lower frequency bands
RCS	−30 dBm² to +10 dBm² (Note 1)	For different type of objects related to short-range assist application

Parameter	Value	Comment
Maximum antenna gain	10 dBi (SISO or MIMO) 19 dBi (beamforming)	For transmission and reception
Radar loss	6 dB	Overall IF signal handling loss
Noise figure	15 dB	Typical value in lower frequency bands
Antenna height	0.4-1 m above road	
Antenna azimuth -3 dB beamwidth	Tx/Rx: ± 70° (SISO or MIMO) Tx/Rx: ± 15° in case of beamforming	Equations according to Recommendation ITU-R M.2057 [24] (Note 2)
Antenna elevation -3 dB beamwidth	Tx/Rx: ± 30°, 60° (SISO or MIMO) Tx/Rx: ±5° in case of beamforming	Equations according to Recommendation ITU-R M.2057 [24] (Note 2)
Typical duty cycle	30-50%	
Conducted peak carrier power	up to +10 dBm (Note 3)	Maximum peak output power at antenna feeding point

Note 1: Analysis of RCS values should be further developed to ensure that small objects such as sidewalk edges, bushes and others are represented in the analysis
Note 2: Recommendation ITU-R M.2057 [24] is referenced here, even if it is only applicable to the frequency band 76 GHz-81 GHz.
Note 3: For the initial studies with EESS (passive), a maximum e.i.r.p. of 55 dBm was proposed by industry, subsequently decreased to 47 dBm.

Figure 16, Figure 17 and Figure 18 provide the results on required peak power for different targets (RCS) depending on the detection range.

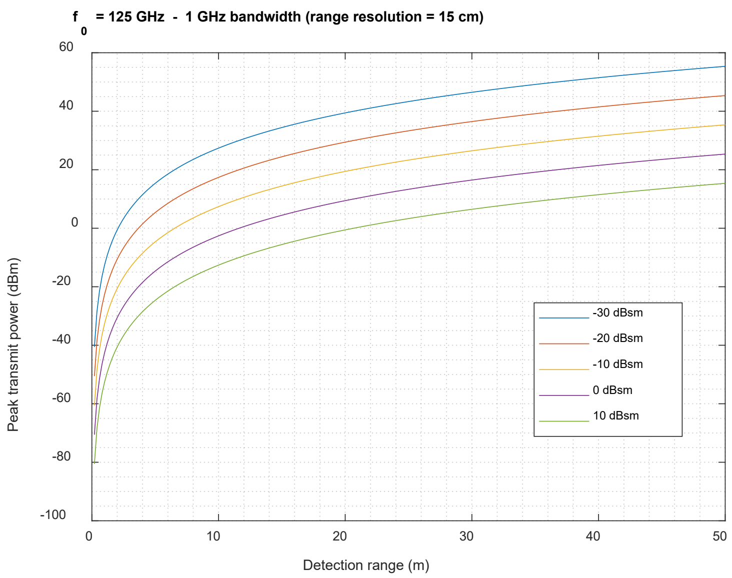


Figure 16: Maximum peak power vs detection distance for 1 GHz bandwidth radars

Using the same hypothesis on the link budgets for the two frequency bands considered, the order of magnitude obtained for central frequency of 125 GHz and 137.5 GHz are very similar. Consequently, the subsequent results are provided only for the 116-130 GHz frequency band.

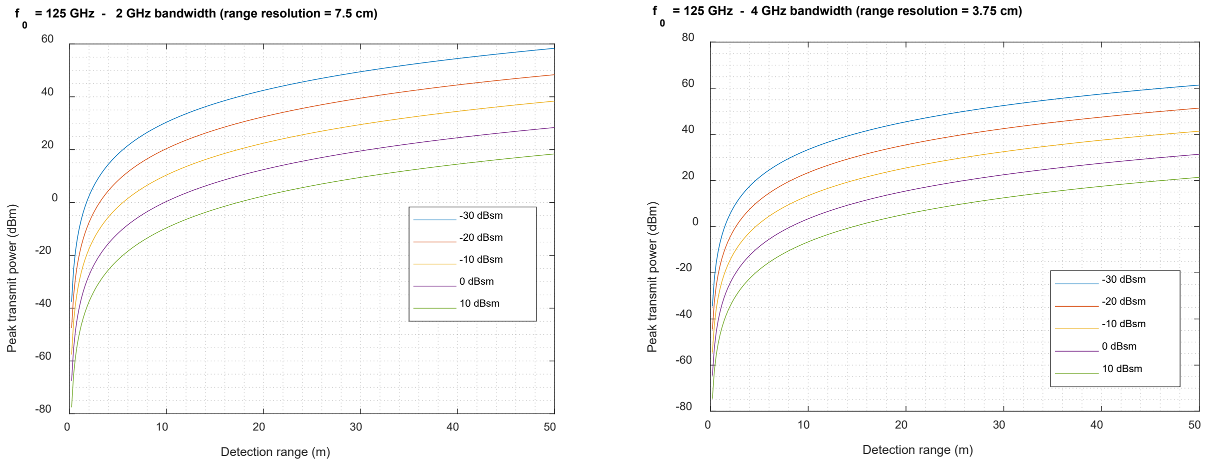


Figure 17: Maximum peak power vs detection distance for 2 and 4 GHz bandwidth radars

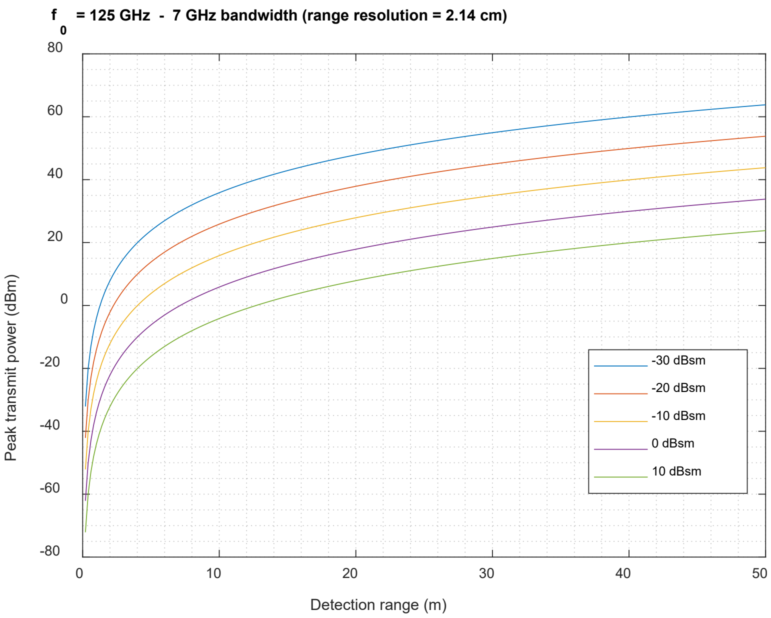


Figure 18: Maximum peak power vs. detection distance for 7 GHz bandwidth radars

Based on the previous results, it can be observed that for a fixed peak power level, the reduction in range is significant when a fine range resolution is required. This can be illustrated in Figure 19 in which 20 dBm peak power imply that a target of −10 dBm² is visible at around 20 m with a radar using 1 GHz bandwidth but the same target will be visible only at around 13 m for a 7 GHz radar. This is a consequence of the short duration of the pulse, which implies a reduction in the duty cycle that should be compensated by the peak power level. This effect is even more noticeable for targets with low RCS values (−20 dBm² or −30 dBm²), which are those that are more relevant for the application described in this section.

This analysis suggests that a peak power limitation is less suitable for radar applications in this band that an average power spectral density value, which is directly related to the used bandwidth, depending on the required range resolution. In addition, given the nature of radar signals, a mean power spectral density value would be more adapted to perform compatibility studies with other services.

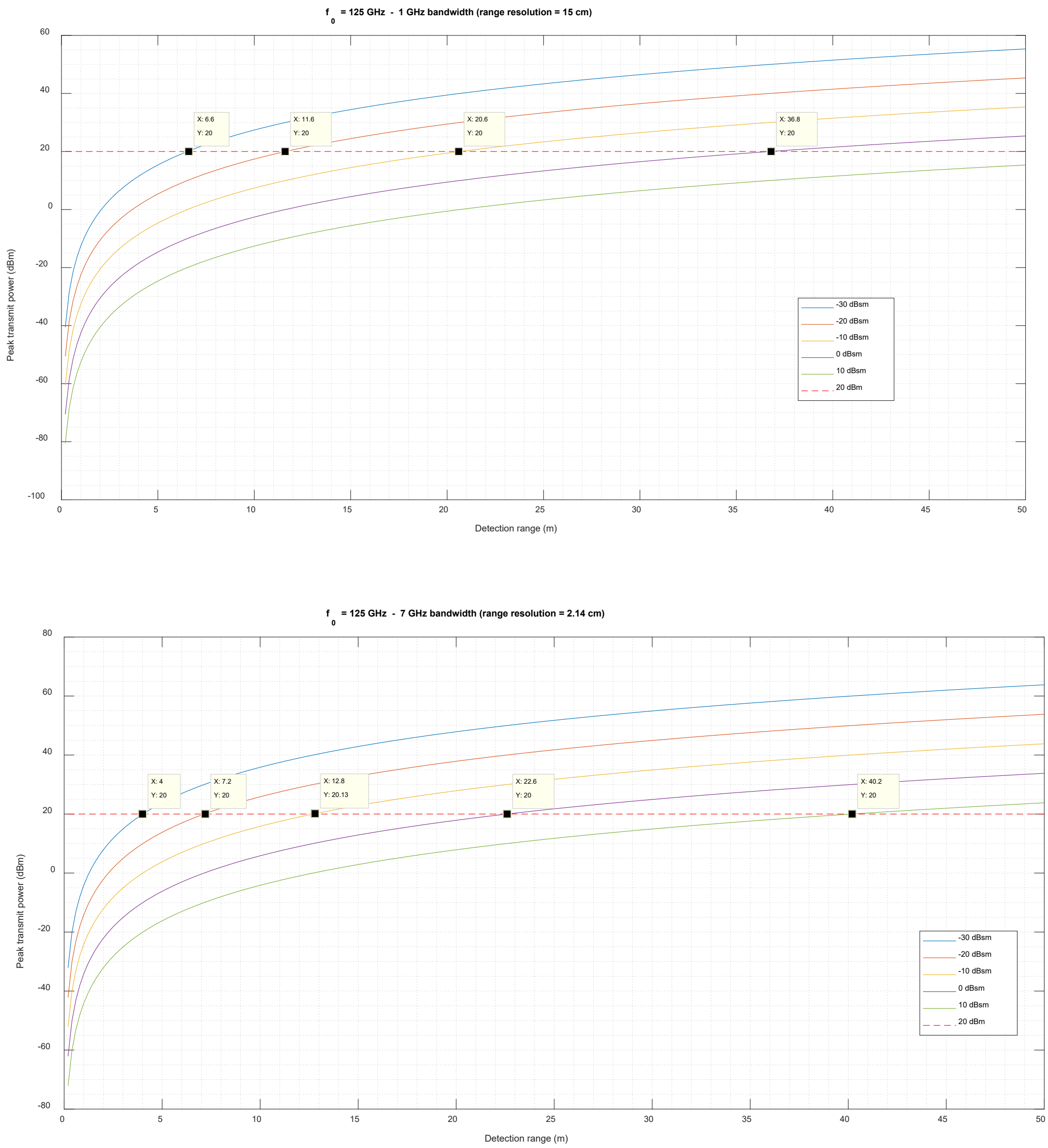


Figure 19: Required peak power for 1 GHz and 7 GHz bandwidth radars

Discussion on Design margin

The previous results do not take into account any margin to compensate for propagation effects such as rain fade or gas absorption which have a significant impact in the frequency bands analysed.

Since automotive radars do not implement power control mechanisms that would allow for increased power in the presence of rain; the power levels considered in this Report will be those estimated under clear sky conditions.

Discussion on Proposed mean power density limits

Different power limits could be applied to the frequency bands considered, depending on the sharing environment. For instance, in the 116-122 GHz band, the maximum power spectral density would be mainly limited by the coexistence with the EESS (passive). In the remaining bands, it will be the radio astronomy service that mainly drive the automotive radar power limitations.

Consequently, no specific values are proposed in this section for power density limitations; nevertheless, Figure 16, Figure 17 and Figure 18 provide information on the peak power values that would be necessary for different type of radars. The actual limitations would be derived from the subsequent sharing studies to be conducted.

It has however to be noted that for the initial compatibility studies with EESS (passive), a maximum e.i.r.p. of 55 dBm was proposed by industry, subsequently decreased to 47 dBm. This later 47 dBm value has been used as a reference for the studies in the present Report.

Additional calculations have also been performed with 40 dBm and 26 dBm maximum e.i.r.p.

2.2.3.4 Antenna data

The relevant antenna parameters, like maximum gain and azimuth and elevation -3 dB bandwidth for short-range assist and surrounding monitoring systems for vehicles and autonomous systems are included in Table 18 in section 2.2.3.3.

In the MIMO case, the Tx antennas are used with nearly omnidirectional patterns. Therefore, the beamwidth is the same as in the SISO case (SISO meaning single Tx antenna and single Rx antenna). The beamforming gain is achieved by receiver processing, which does not affect the e.i.r.p.

In the beamforming case, the Tx antennas are used jointly to create a directional beam that is narrower than the nearly omnidirectional beam of the individual elements, resulting in some array gain. The parameters of 19 dBi antenna gain and 3 dB azimuth and elevation beamwidth of 30° and 10°, as in the current version of the draft, are calculated exactly as per Recommendation ITU-R M.2057 (Note 2) [24], resulting in the following patterns.

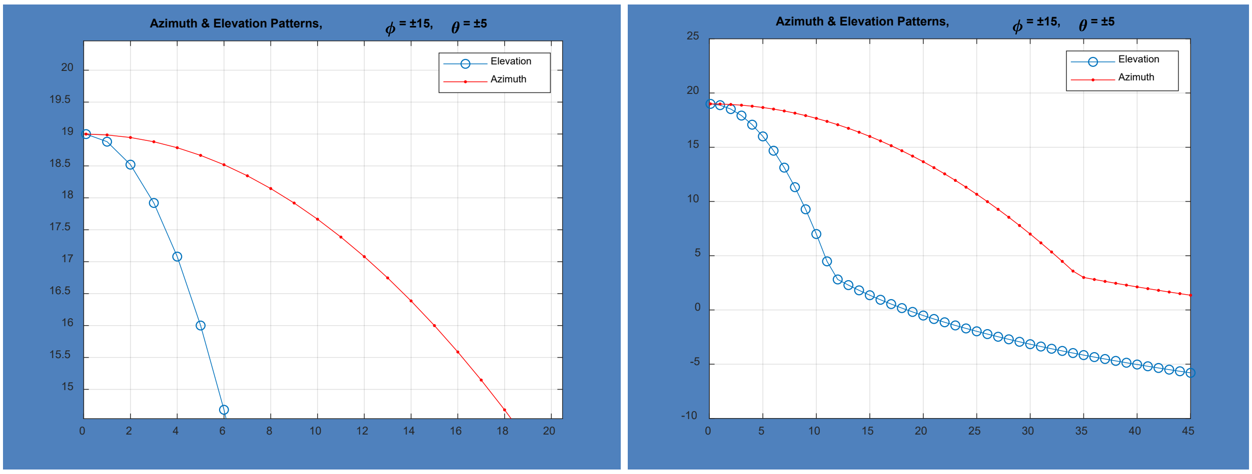


Figure 20: Antenna azimuth and elevation patterns for the beamforming case (calculated according to Recommendation ITU-R M.2057 (Note 2) [24]

2.2.3.5 Market size

Even though estimation of the market size is not provided in the ETSI TR 103 498 [1], it is expected that the number of vehicles equipped with this type of systems be smaller than those equipped with radars used for car safety and road safety. Indeed, the front radars or corner radars are often used by Advanced Driver-Assistance Systems (ADAS) to avoid collisions and accidents while driving; on the other hand, the short-range assist radars analysed in this section would be mainly deployed in vehicles with high level of autonomy.

2.2.3.6 Interference scenarios

Based on the applications identified in the European Common Allocation (ECA) Table contained in Table 34, the sharing scenarios between short-range and surrounding monitoring sensors for vehicles and existing services are described in Table 19.

Table 19: Sharing studies description

Interfered with service or application	Frequency bands
Earth Exploration Satellite Service (passive)	114.25-122.25 GHz (in-band) 148.5-151.5 GHz (adjacent band)
Non-specific SRDs	122.25-123 GHz
Radio Astronomy Service	123-130 GHz 130-134 GHz 134-141 GHz 141-148.5 GHz
Fixed Service	130-134 GHz 141-148.5 GHz
Amateur Service	122.25-123 GHz 134-141 GHz
Amateur-Satellite Service	122.25-123 GHz 134-141 GHz

2.2.4 Ground Based Synthetic Aperture Radar (GBSAR)

2.2.4.1 Application scenario

The use of a monitoring system based on the radar technology (GBSAR) is not new and allows to remotely monitor the displacements of thousands of points over a surface with a high accuracy and without the need of installing any reflector (see ECC Report 111 [60] and ECC Report 315 [61]). From a technical point of view, the measurement is performed by a high frequency LFMCW interferometry radar working as a rotating Synthetic Aperture Radar (Arc SAR). In practice, the radar continuously transmits LFMCW signals while it is rotating and moving along a circular trajectory (see Figure 21).

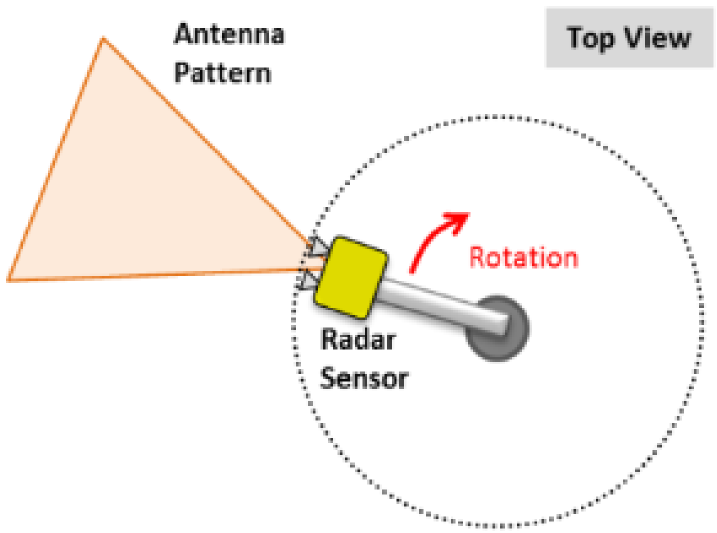


Figure 21: Arc SAR acquisition

GBSAR provides a bi-dimensional image of the monitored scenario; the two dimensions are determined by the range resolution and the angular resolution capability (see Figure 22).

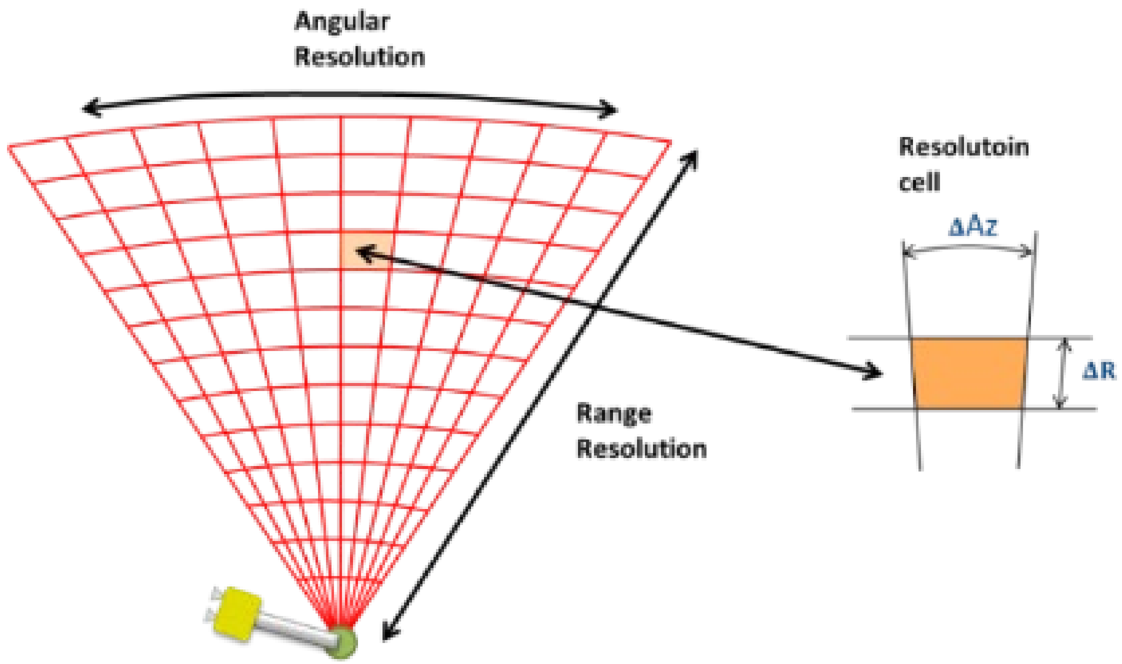


Figure 22: GBSAR spatial resolution

The range resolution ΔR is determined by the bandwidth of the emitted signal B ($\Delta R = c/2B$, where c is the speed of light); with a 7 GHz bandwidth, it is equal to about 2cm, whereas the angular resolution $\Delta \mathrm{Az}$ is around 8 mrad assuming a rotation radius of 25 cm. The combination of range and angular resolution allows the creation of a bi-dimensional image (see Figure 22), where each resolution cell is a measurement point providing a real-time displacement information with sub-millimetre accuracy thanks to the interferometric technique.

The system can perform an acquisition in less than a minute and provide as output a displacement heat-map of the monitored scenario. The displacement information is in general used to provide early warning in case of deformation having magnitude and rate indicative of hazardous instabilities of the monitored scenario. Therefore, this radar has the potential to be a perfect tool to improve the safety standard for a wide range of applications such as:

- Structural Health Monitoring (SHM);
- Slope Stability Monitoring;
- Tunnel Monitoring.

The above listed applications would significantly benefit by the availability of a very compact and portable system, providing at the same a very fine spatial resolution of the monitored scenario. Both compactness and high spatial resolution can be achieved by having a very large operating bandwidth located at very high frequency. Additional information concerning the mentioned applications and the typical usage of GBSAR are provided below.

Structural health monitoring

Monitoring of the deformation of civil structures such as buildings or other man-made structures to either assess stability of the structure, or to monitor for any instabilities induced over time by external causes, such as earthquake or underground construction taking place close to or directly under the monitored object.

GBSAR is installed in proximity of the structure to be monitored, at a distance D, (see Figure 23) and the vertical antenna radiation pattern boresight is pointed towards the middle of the building or structure to be monitored to maximise the vertical coverage. In order to optimise the monitoring performance, the distance D between GBSAR and the surveyed building shall be between 1 and 1.5 times the height of the building (ECC Report 315, annex 5 [61]).

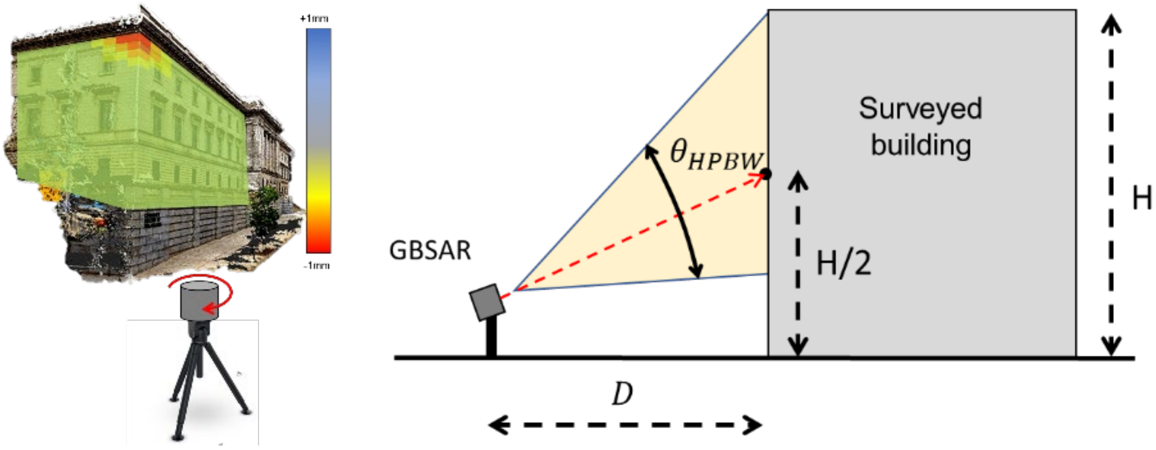


Figure 23: Building Monitoring scenario

Typical GBSAR application for structure monitoring consists of a short one-two days survey, installing the system nearby the structure to monitor and performing an acquisition every minute, therefore providing a new displacement measure every minute. For structure monitoring the maximum required horizontal field of view is of 180°, therefore considering the angular rotation speed of 10°/sec, GBSAR transmit around 18 seconds every minute, leading to an activity factor of about 30% during the survey period.

Slope stability monitoring

Monitoring of the ground superficial deformation of active quarry, open pit mines or natural landslide. For this use case GBSAR provides a maximum measurement distance of 800 m giving a real-time displacement measure of the monitored scenario every minute.

GBSAR is installed on a stable location with free line of sight of the slope to be monitored (see Figure 24). For this use case the GBSAR can offer a maximum measurement distance of 800 m providing a real-time displacement measure of the monitored scenario every minute. the vertical antenna radiation pattern boresight is pointed towards the middle of the slope to be monitored to maximise the vertical coverage.

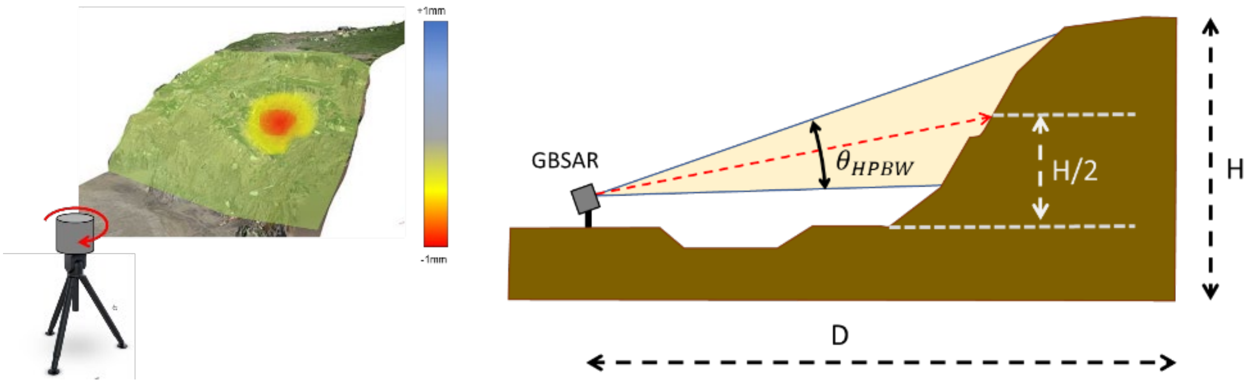


Figure 24: Slope Monitoring scenario

For slope monitoring applications, the GBSAR can be exploited for continuous or for time-discreet monitoring surveys: in the first case the system is permanently installed in front of the landslide/unstable slope, while in the second case it will be used as a nomadic system, performing several different surveys in different time-period. In the case of a time-discreet nomadic use, one survey would usually last for about 1-2 weeks with a time repetition interval of some months. The maximum required horizontal field of view for slope monitoring is 180°, therefore as for the structure monitoring case the activity factor during the survey period is around 30% (18 seconds every minute).

Tunnel monitoring

Monitoring of underground mines and tunnels under construction as a geotechnical tool for deformation measurement to provide early warning in case of surface deformation as precursor of an impending collapse.

GBSAR can be used for monitoring the front excavation face of tunnels under construction (see Figure 25) and underground mines wall (see Figure 26) as a geotechnical tool for deformation measurement to provide early warning in case of surface deformation as precursor of an impending collapse.

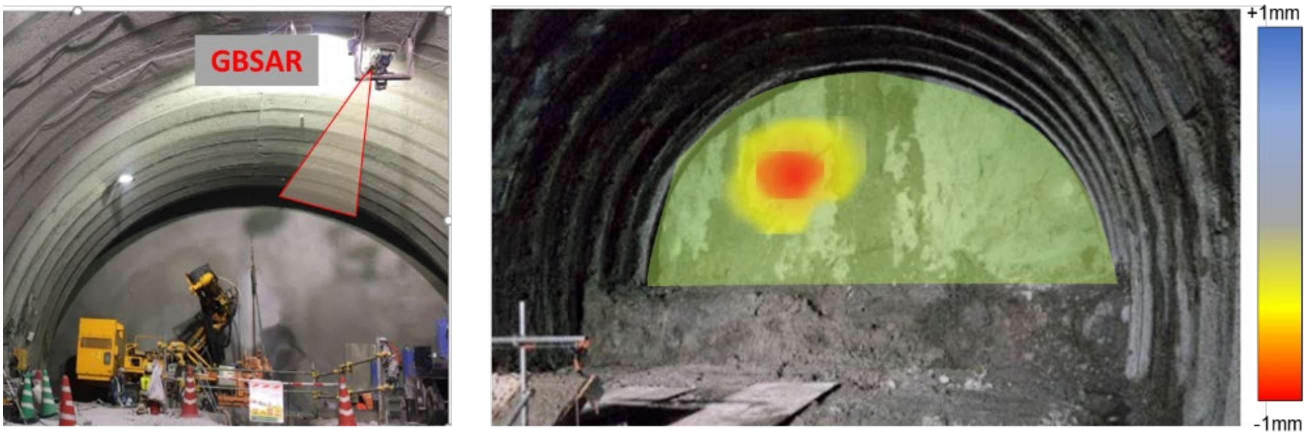


Figure 25: Tunnel in construction monitoring scenario

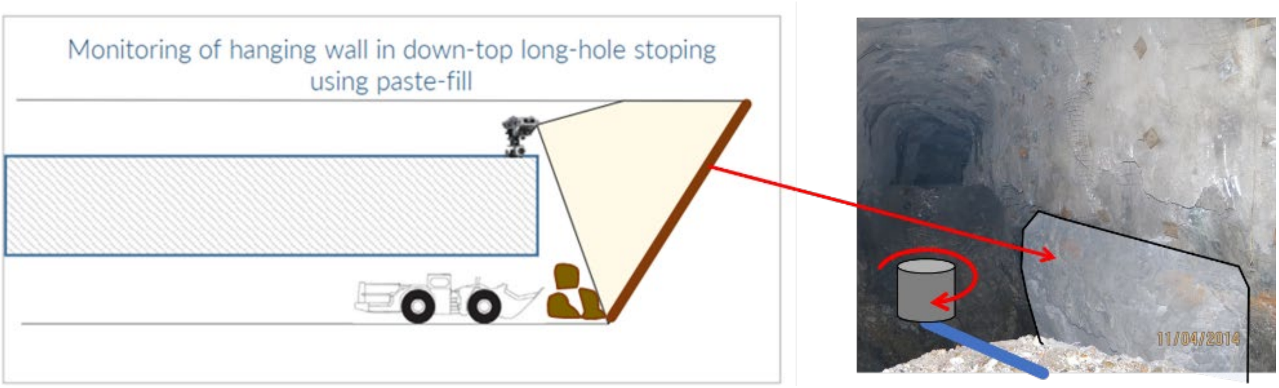


Figure 26: Underground mine monitoring scenario

For this applications GBSAR can be used either for continuous monitoring of unstable wall areas for a period from one day to several weeks, or for performing several surveys of various areas in different time-periods, where each survey lasts a few hours. In both cases the system is installed for the survey period close to the monitored area (<200 m). Given the sudden nature of the ground instability event in tunnel and underground mine environment, during the survey GBSAR performs an acquisition every 15 seconds with a field of view of 120°m, leading to an activity factor of 80% (12 seconds acquisition every 15 seconds).

2.2.4.2 Frequency ranges and application types

Ground Based Synthetic Aperture Radar (GBSAR) has been categorised as a type A application (see section 2.1). The following frequency range is proposed to be considered for this type of application (see Table 33):

- 134 GHz to 141 GHz.

2.2.4.3 Technical parameters

Table 20 provides an overview of GBSAR technical parameters to be considered for the compatibility studies.

Table 20: Technical parameters of GBSAR

Parameter	Value	Notes
Modulation scheme	Linear Frequency Modulated Continuous Wave (FMCW)	
Operating frequency range (OFR)	134-141 GHz	
Modulation bandwidth	7 GHz	
Sweep time	500 µs to 5 ms	For a single frequency sweep over entire modulation bandwidth
Conducted peak carrier power	up to +24 dBm	Maximum saturated output power at antenna feeding point
Maximum e.i.r.p	48 dBm	
Maximum Power Spectral Density	9.55 dBm/MHz	
Antenna type	horn- and lens-horn antennas, planar antenna arrays	
Antenna horizontal -3 dB beamwidth	10°÷30°	
Antenna vertical -3 dB beamwidth	10°÷50°	
Antenna polarisation	Horizontal or Vertical	
Antenna rotation speed	10 deg/sec	During the acquisition the antenna is rotating
Out-of-band domain maximum e.i.r.p.	0 dBm	
Maximum emission in the spurious domain	▪ 54 dBm, for *f* within the bands 47-74 MHz, 87.5-118 MHz, 174-230 MHz, 470-862 MHz; ▪ -36 dBm, for 9 kHz ≤ *f* ≤ 1 GHz (except the above frequency bands); ▪ -30 dBm, for 1 GHz < *f* ≤ *Fupper*	

The GBSAR horizontal and vertical antenna pattern shall be modelled respectively with the equations (1) and (2). The antenna normalised radiation pattern expressed in dB is shown in Figure 27 and Figure 28. The main lobe three-dimensional pattern can be approximated by multiplying the horizontal and vertical pattern formula, in any case the antenna attenuation can't be lower than -20 dB.

$$P_H(\phi)\mathrm{dB} = \begin{cases} 20 \cdot \log_{10}(\cos(\phi)^{10}) & |\phi| < 30° \\ \mathrm{P_0} & |\phi| = 30° \\ \mathrm{P_0} - \dfrac{|\phi| - 30}{60} \cdot (\mathrm{P_0} + 20) & 30° < |\phi| < 90° \\ < -20 & 90° < |\phi| < 180° \end{cases} \tag{1}$$

$$P_V(\theta)\mathrm{dB} = \begin{cases} 20 \cdot \log_{10}(\cos(\theta)^{3.5}) & |\theta| < 30° \\ \mathrm{P_0} & |\theta| = 30° \\ \mathrm{P_1} - \dfrac{|\theta| - 30}{60} \cdot (\mathrm{P_1} + 20) & 30° < |\theta| < 90° \\ < -20 & 90° < |\theta| < 180° \end{cases} \tag{2}$$

Where:

- $P_0 = 20 \cdot \log_{10}(cos(30))^{10}$;
- $P_1 = 20 \cdot \log_{10}(cos(30))^{3.5}$;
- ϕ is the azimuth angle (0° is the antenna boresight);
- θ is the elevation angle (0° is the antenna boresight).

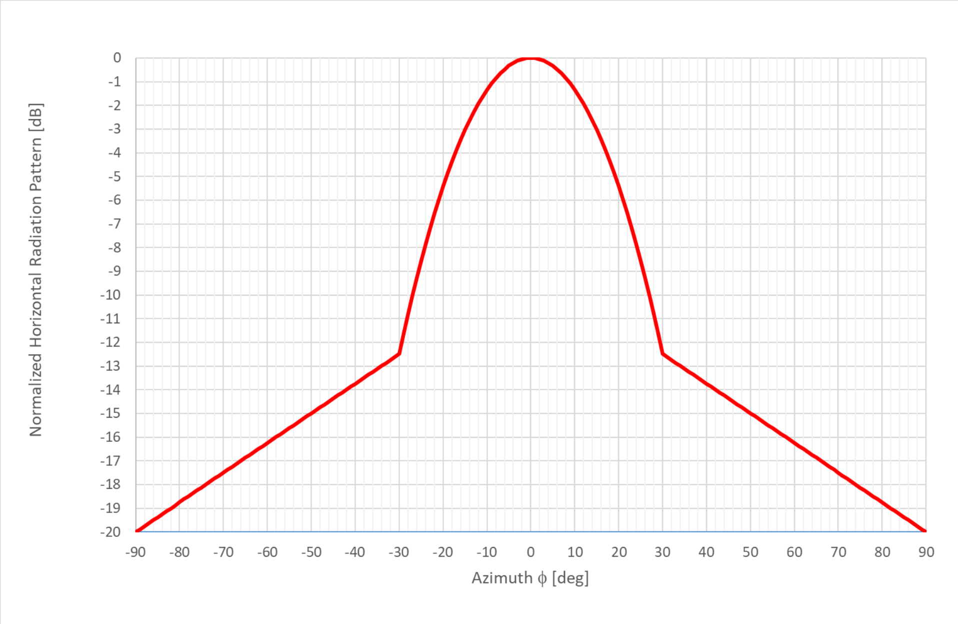


Figure 27: Representative Horizontal Radiation pattern of GBSAR

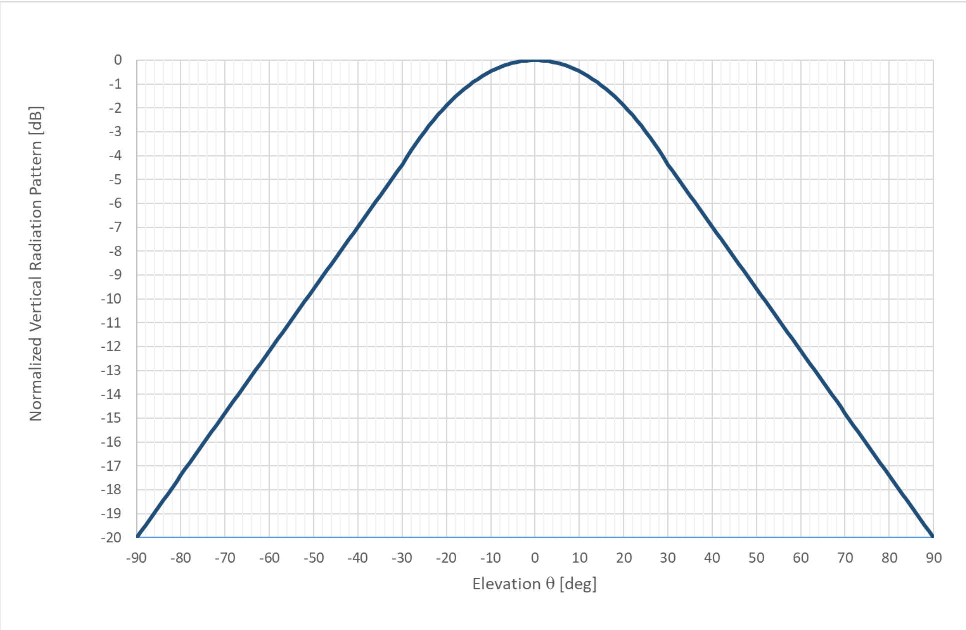


Figure 28: Representative Vertical Radiation pattern of GBSAR

2.2.4.4 Market size

ETSI TR 103 498 [1] does not give any figures for the market size for GBSAR. However, based on the market analysis performed in ECC Report 315 [61] for HD-GBSAR, it can be forecasted similar figures for the number of GBSAR deployed for Slope Monitoring and Tunnel Monitoring applications, and an order of magnitude higher number for GBSAR applied to Structural Health Monitoring (SHM). The higher number for SHM is justified by the increased compactness of the system allowed by the higher operating frequency, which fosters and makes more practical the deployment of the system for SHM applications. Table 21 reports an estimation of the GBSAR deployed units in the first 5 years divided for the three identified market segments.

For shared spectrum use considerations, the tunnel monitoring application can be excluded from further analysis because the systems would be deployed in an indoor environment with no risk of interference with services operating outdoor.

Given the European land area of 10523000 km², this translates to the average density of 0.000067 GBSAR devices/km² in the band 134-141 GHz operating outdoors.

Table 21: Estimated market size of GBSAR devices for the first five years after launch

Market Segment	Deployment Forecast (units)	Units per km²
Structural Health Monitoring	400	0.000038
Slope Monitoring	300	0.000029
Tunnel Monitoring	200	N.A.
Total operating outdoors (Structural Health + Slope)	700	0.000067

2.2.4.5 Interference scenarios

When considering the range of identified victim services (see section 3) and the GBSAR applications (see section 2.2.4.1), it may be suggested to divide the possible interference scenarios into two broad categories as proposed in section 3.4:

- Interference over terrestrial paths;
- Interference to EESS (passive) satellite receivers.

Interference over terrestrial paths

The scenario in which an interference signal, originating from GBSAR propagates along a terrestrial path is relevant when evaluating coexistence of GBSAR devices with the following victim services:

- Fixed Service (FS) operating in the adjacent band (130-134 GHz and 141-148 GHz);
- Terrestrial Radio Astronomy Service (RAS), active both in-band and in the adjacent band (123-158.5 GHz);
- Amateur Service receivers (in-band and out-of-band interference).

For Fixed Service links, the most likely worst-case interference scenarios are related to the urban environment, assuming the usage of GBSAR to monitor the stability of a building and the contemporary presence of FS point to point link, where a Fixed Service transmitter attached to a light pole is linked with a receiver located on top of a building and vice versa (see Figure 29 and Figure 30).

In the first scenario (see Figure 29), the GBSAR is monitoring the stability of a building located in close proximity of the FS Tx, thus in 300 m distance from the FS Rx. The worst-case condition is represented by the almost main beam to main beam interference between GBSAR and FS Rx.

In the second scenario (see Figure 30), the locations of FS Rx and Tx are exchanged and the interfered FS Rx is assumed to be between GBSAR and the monitored building. Such condition minimises the distance between GBSAR and FS Rx.

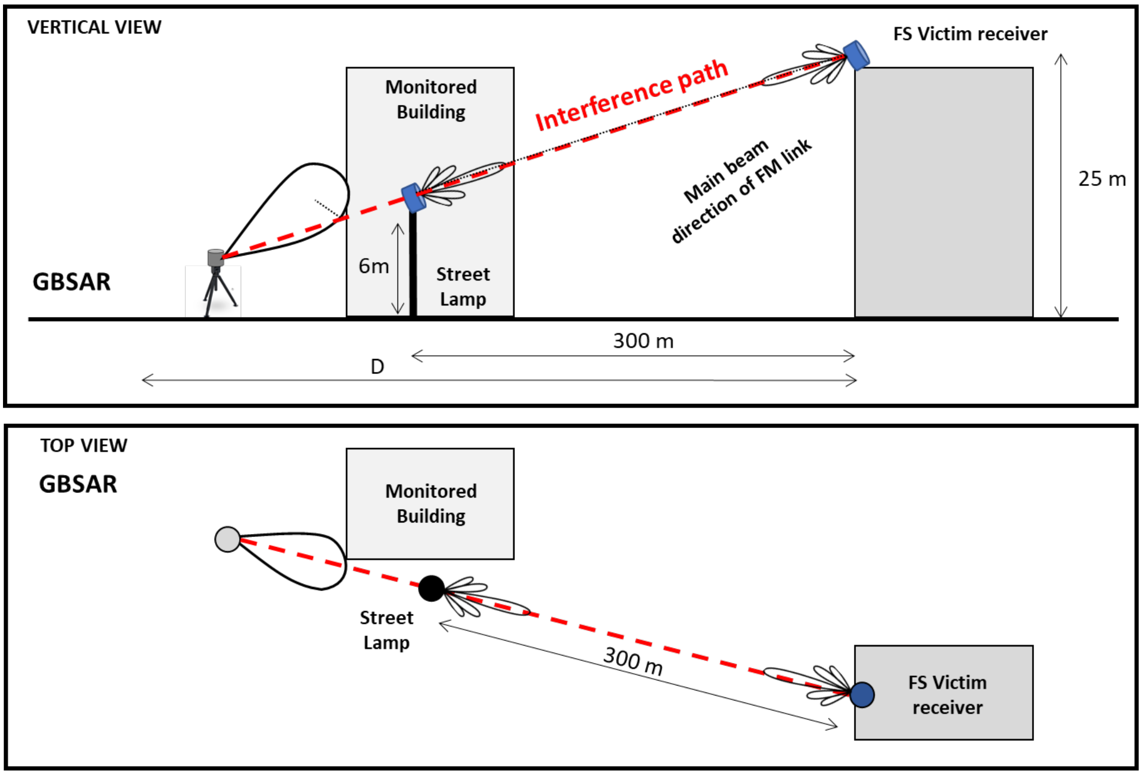


Figure 29: First GBSAR FS interference scenario (victim receiver on the building)

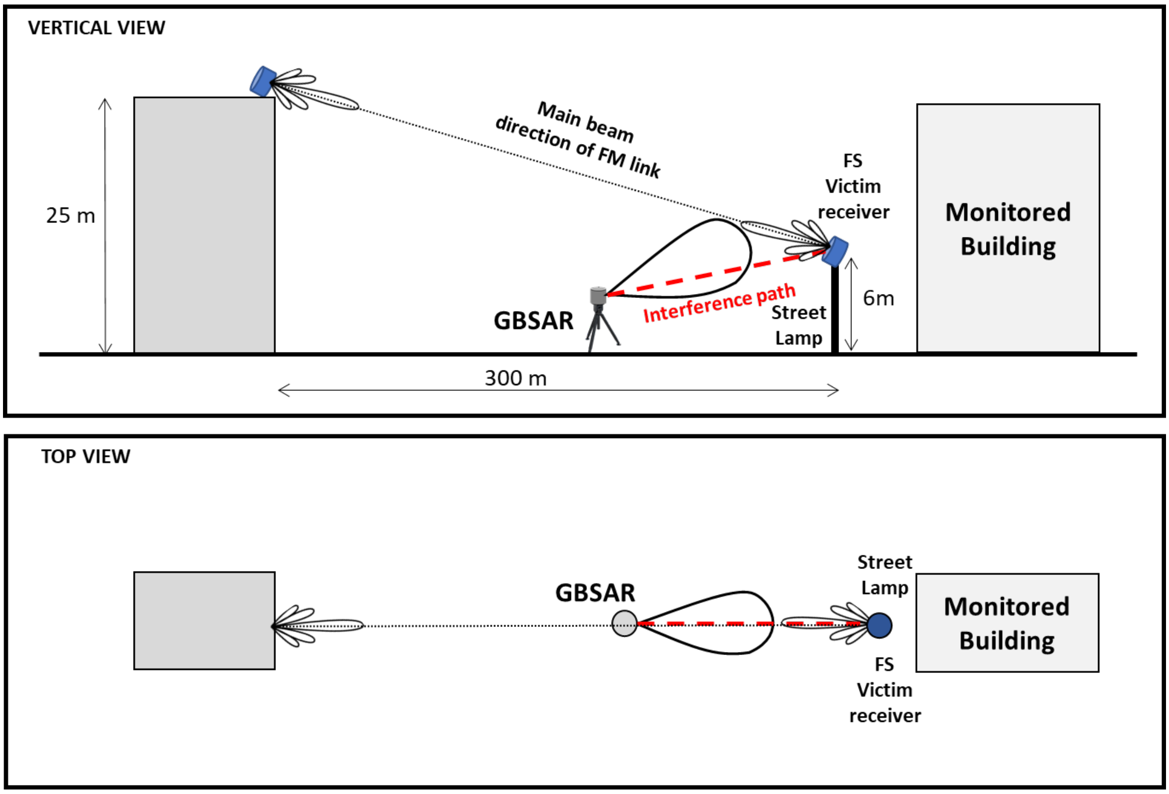


Figure 30: Second GBSAR FS interference scenario (victim receiver on the street lamp pole)

For both cases, the GBSAR is assumed the monitoring geometry of Figure 31, where GBSAR antenna is vertically pointed towards the geometric centre of the surveyed building to maximise the coverage of the monitored facade. For typical usage of GBSAR, it applies the same considerations reported in the ECC Report

315, annex 5 [61]), therefore in the sharing analysis the ratio between D1 and H1 shall be considered between 1.0 and 1.5, corresponding to a value of β ranging between 18.4° and 26.6°.

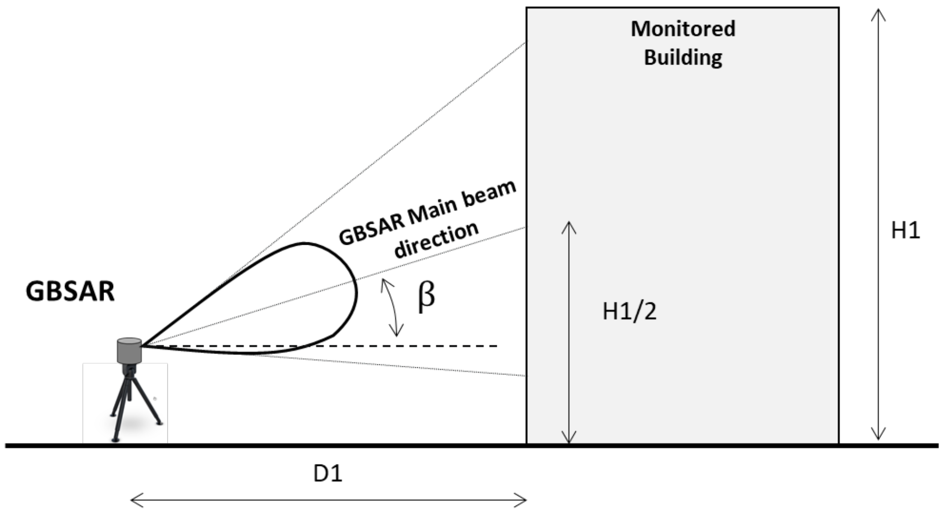


Figure 31: GBSAR acquisition geometry for SHM

The worst-case interference scenario along terrestrial paths utilised for the compatibility study for RAS and Amateur Service is illustrated in Figure 32. In such scenario GBSAR is monitoring the stability of slope with free LOS visibility with the victim receiver. For slope monitoring GBSAR antenna is assumed to be vertically pointed towards the centre of the monitored slope and the ratio between the height of the slope H and the distance of GBSAR and slope D shall range between 1 and 5 (see ECC Report 315, annex 5 [61]), consequently the GBSAR vertical main beam direction β is comprised between 5.7° and 26.6°.

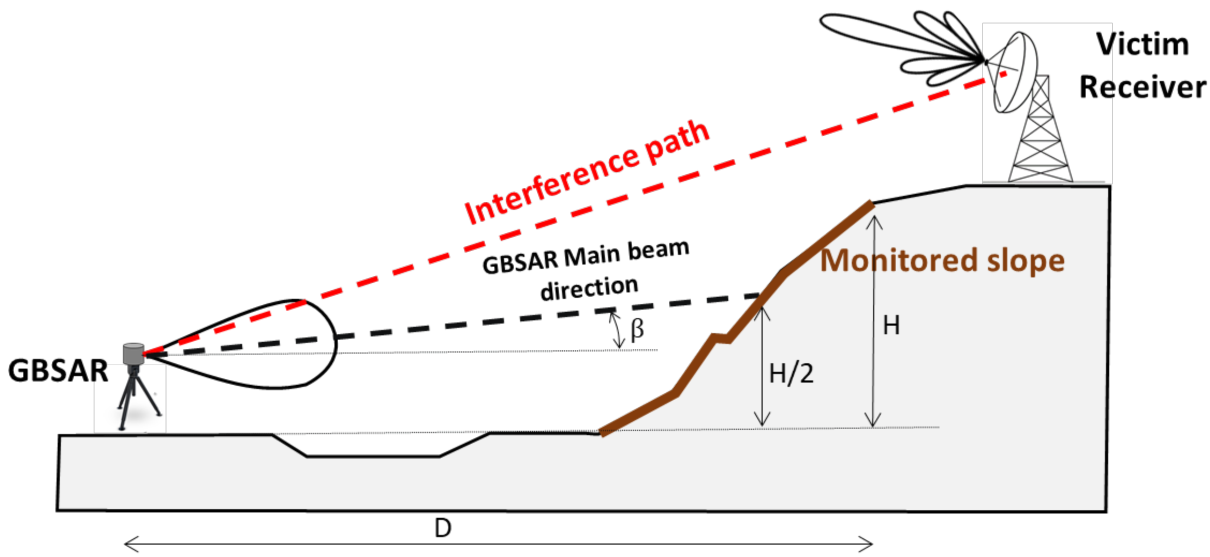


Figure 32: GBSAR interference scenario along terrestrial paht for RAS and Amateur Service

Interference to EESS (passive) satellite receivers

In case of interference to satellite receivers, the relevant radiation direction would be in vertical plane while GBSAR is either monitoring a building or a slope (see Figure 33).

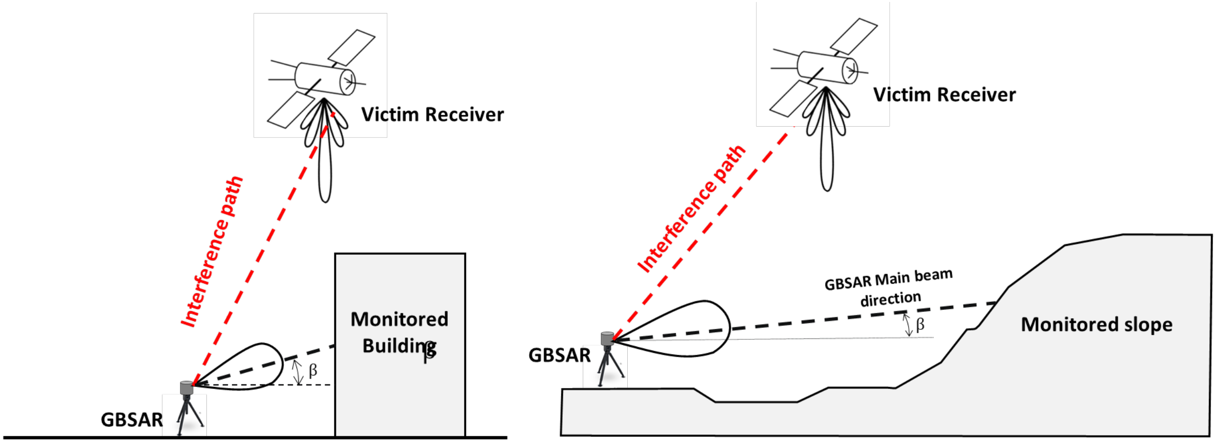


Figure 33: GBSAR interference scenario to EESS satellite receiver

2.2.5 Level Probing Radar (LPR)

2.2.5.1 Application scenario

Level Probing Radar (LPR) sensors are used in many industries to measure the distance to the surface of various materials and substances (mostly liquids and solids) and thus indirectly the amount of these goods in open-air areas or in tanks with non-attenuating shells (e.g. plastic tanks). A typical conceptional measurement scenario for LPR devices is illustrated in Figure 34.

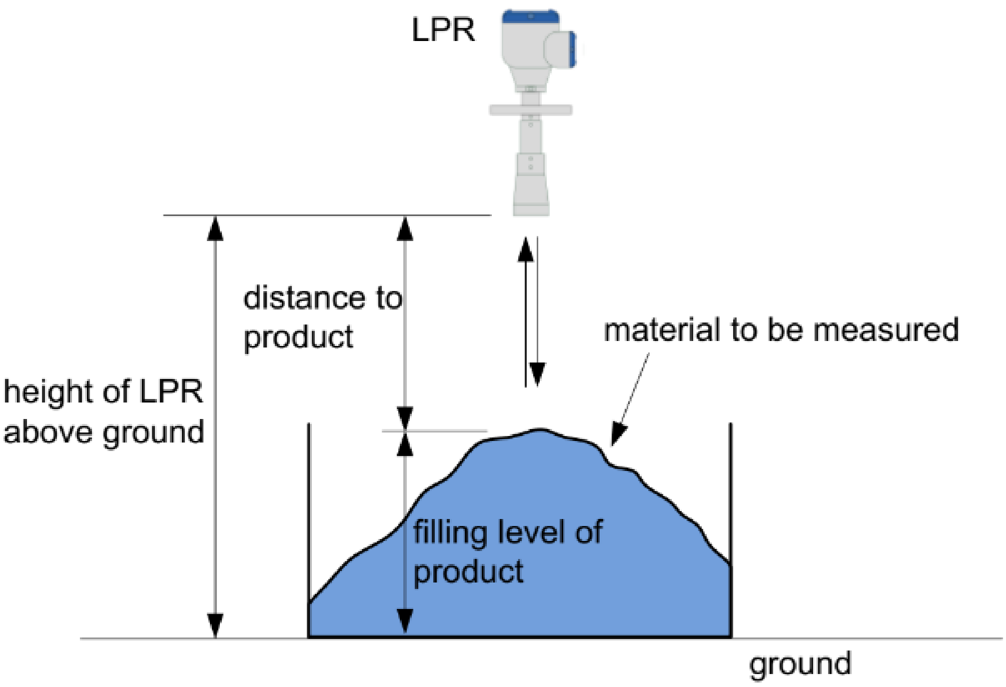


Figure 34: Conceptional LPR measurement scenario

The measurement principle of LPR devices is a time-of-flight method usually using an FMCW modulated Radar signal. Here, a frequency sweep over a defined bandwidth in a certain time is sent from the LPR antenna towards the material whose filling level has to be measured. The transmit signal is reflected at the surface of the respective material and received from the antenna again. The instantaneous frequency shift between the transmit signal and the received signal is proportional to the distance between the sensor and the surface and is evaluated for multiple reflections. A corresponding level signal can hence be calculated. The RF signal travels at the speed of light and is nearly independent of ambient temperature, pressure and humidity and other adverse environmental conditions.

Due to different physical or chemical properties of different liquids or solids, LPR sensors are installed in a large variety of different storage, processing or transportation environments including:

- open-air (level measurement of bulk solids heaps, piles, dams, pools, rivers, channels, flumes, etc.);
- non-metallic tanks (measurement in non-shielded environments like in containers made of plastic or glass).

In many of these installations, LPR devices provide real-time and safety-critical information in order to protect humans, technical equipment, machinery and the environment. Examples of such safety-critical open-air applications include:

- hydrological services (measurement of river or hydro dam levels, wave heights, tides, etc.);
- storing or processing of hazardous substances (level measurement of flammable and/or corrosive materials, acids, bases, etc.);
- storing solids in piles (measurement of levels of different materials such as sand, pebble stones, gravel, coal, pellets, wood chips, etc.).

In other applications, an accurate level measurement helps to improve the quality of the end-product, and to conserve the environment by facilitating the efficient use of scarce natural resources. Examples of such applications include:

- exact dosing of liquids in chemical or pharmaceutical plants;
- exact measurement of piles of solids (e.g. coal, iron ore, building materials like cement, etc.).

Typical examples of LPR installations are illustrated in Figure 35.

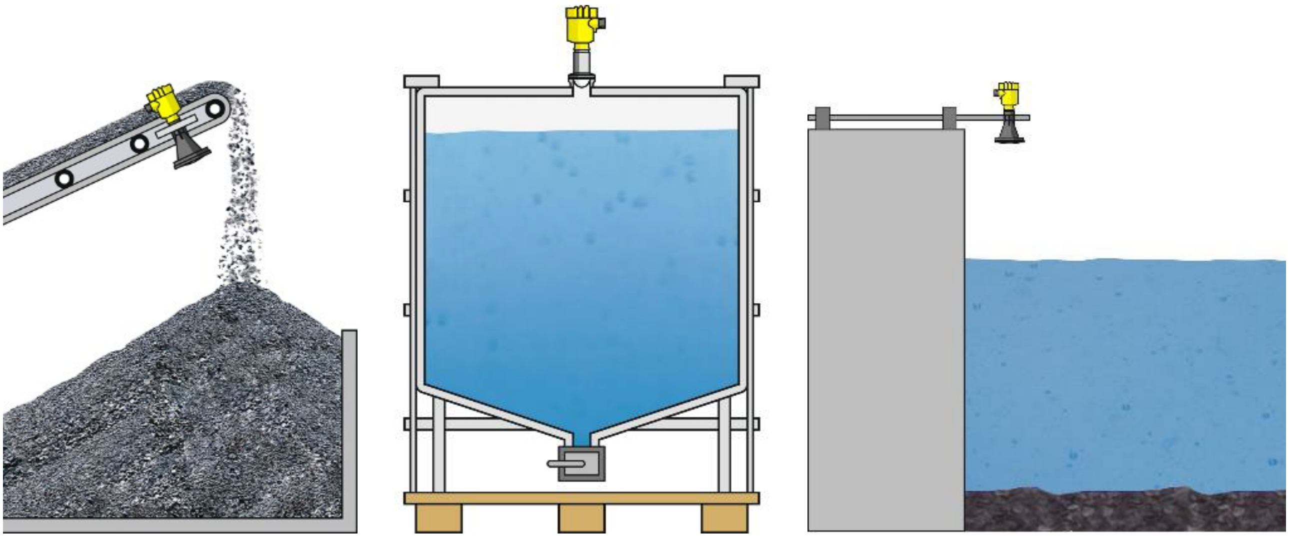


Figure 35: Typical examples of LPR installations

It is foreseen that LPR in dedicated frequency bands within the range 116 to 260 GHz is still a strictly professional and industrial application. All level probing radars are expected to be installed complying with the following installation requirements:

- Level probing radars are required to be installed at a permanent fixed position pointing in a downwards direction towards the ground;
- Installers have to ensure that there are no obstacles in the downwards radiating main beam of the antenna in order to minimise unwanted reflections;
- Installation and maintenance of LPR equipment shall be performed by professionally trained individuals only.

These installation requirements are well-established for LPRs already available on the market and operating in lower frequency ranges ETSI EN 302 729 [5].

In ECC Report 139, section 2.8 [4], an estimation of the installation above ground was given for LPRs in the lower frequency ranges 6 to 8.5 GHz, 24.05 to 26.5 GHz, 57 to 64 GHz and 75 to 85 GHz. There it was anticipated that 90% of all outdoor LPRs are installed 2 to 15 m above ground. Only 10% of all installations were predicted to be installed 15 to 50 m above ground. This estimation has proven true over the last years as observations of customer applications and especially of pre-set maximum measurement ranges of up-for-immediate-sale devices show. However, for LPR devices in higher frequency bands the maximum measurement ranges will drop due to higher free space attenuation and a lowered sensitivity of the receiver architecture.

It is therefore anticipated that 90% of all outdoor LPRs under consideration will be installed in heights from 0.5 to 5 m. The remaining 10% are expected in 5 to 10 m above ground. For aggregated interference scenarios it is therefore proposed to use these figures.

2.2.5.2 Frequency ranges and application types

Level Probing Radars (LPR) have been categorised as type B applications (see section 2.1). The following frequency ranges are proposed to be considered for this type of application (see Table 33):

- 116 GHz to 148.5 GHz;
- 167 GHz to 182 GHz;
- 231.5 GHz to 250 GHz.

2.2.5.3 Technical parameters

Table 22 gives an overview of the technical parameters of LPR devices which may be relevant for conducting the compatibility studies.

Table 22: Technical parameters of LPR equipment

Parameter	Value	Notes
Modulation scheme	Frequency Modulated Continuous Wave (FMCW)	
Operating frequency range (OFR)	116−148.5 GHz 167−182 GHz 231.5−250 GHz	
Available modulation bandwidth	32.5 GHz, 15 GHz and 18.5 GHz	
Used modulation bandwidth	Up to 32.5 GHz Up to 15 GHz Up to 18.5 GHz	-20 dB bandwidth
Sweeptime	500 µs to 5 ms	for a single frequency sweep over entire modulation bandwidth
Duty cycle	≤ 5%	
Conducted peak carrier power	Up to +5 dBm	Maximum saturated output power at antenna feeding point
Conducted mean power	-8 dBm	with 5% duty cycle and +5 dBm peak carrier power
Conducted mean power spectral density	-48 dBm/MHz	with 10 GHz modulation bandwidth and -8 dBm mean power
Maximum mean power spectral density (e.i.r.p.)	-8 dBm/MHz	calculated with 40 dBi antenna gain

Figure 36 shows a typical FMCW modulation scheme of an LPR device. A single or multiple frequency ramps are transmitted within one measurement burst with duration T_{meas} between the frequency boundaries f_L and f_H. The used modulation bandwidth is consequently $f_H - f_L$. Between individual measurement bursts, during the time T_{off}, the transmitter is switched off and no transmission occurs. The overall measurement cycle is denoted with $T_{meas_{cycle}}$.

The duty cycle is the ratio of active measurement periods (bursts, sweeps, scans) within the overall repetitive measurement cycle, i.e. $T_{meas}/T_{meas_{cycle}}$, provided that these time durations are constant during the designated observation period T_{obs}.

The time duration of a single frequency ramp over the entire used modulation bandwidth depends on several technical aspects and considerations. This time span is expected to take values between 500 µs and 5 ms.

In order to achieve an outstanding Radar resolution compared to LPR devices operating in lower frequency bands, a modulation bandwidth of not less than 10 GHz is required. The upper boundaries of a contiguous modulation bandwidth are equal to the available bandwidths in the individual requested frequency ranges which are 15 GHz and 18.5 GHz, respectively.

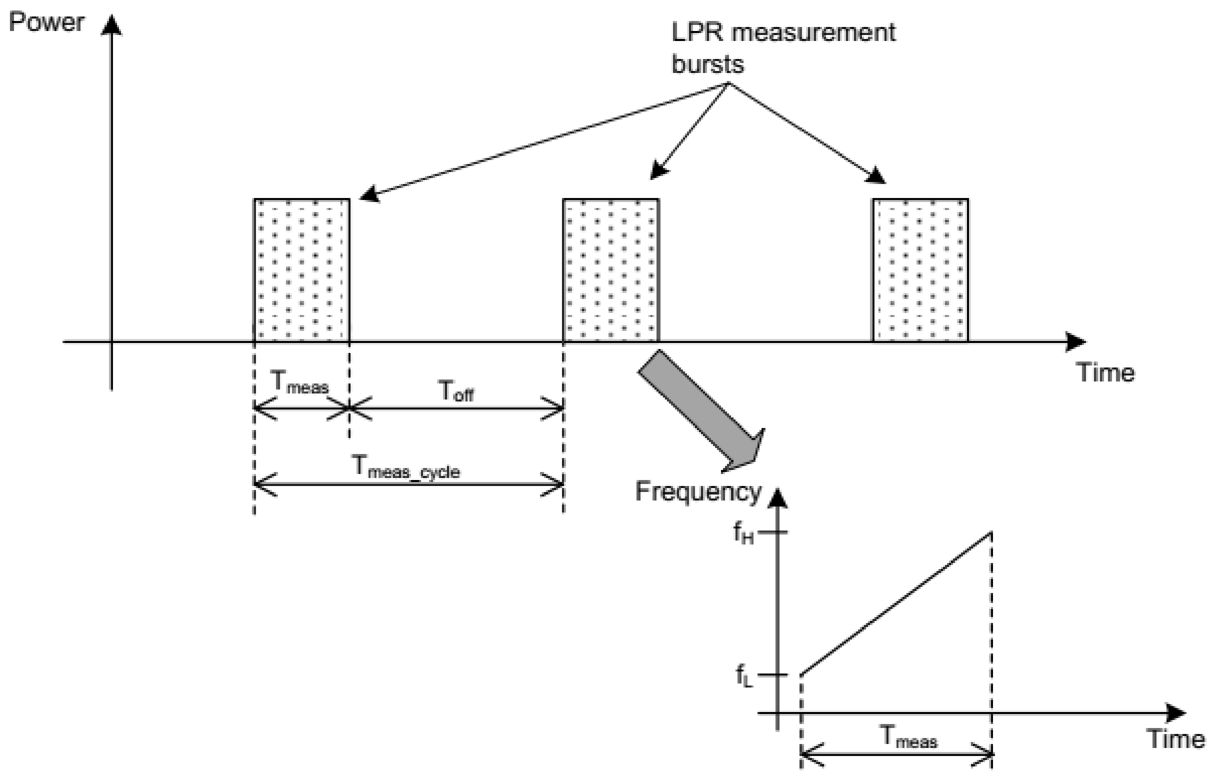


Figure 36: Typical modulation scheme of LPRs

The available saturated output power depends strongly on the used semiconductor technology and decreases with increasing frequency and is physically limited by Johnson's limit. A power amplifier survey [6], initiated in 2000 by the Georgia Tech Electronics and Micro-System Lab (GEMS) has shown that with conventional semiconductor technologies like CMOS, SiGe, GaAs, GaN, which can be envisaged to be used for LPR applications, a saturated output power of 10 dBm at frequencies around 200 GHz has proven possible also for cost-sensitive commercial applications in future. Taking into account inevitable losses from the individual RF output on-chip to the antenna feeding point, it can be assumed that a maximum saturated output power of 5 dBm will be available.

2.2.5.4 Antenna data

Table 23: Antenna parameters of LPR equipment

Parameter	Value	Notes
Antenna type	Horn- and lens-horn antennas, planar antenna arrays	Application dependent
Antenna half power beamwidth	4.3 to 5°	Depends on individual antenna type (see Annex 4)
Antenna gain	Typically up to 32 dBi	
Maximum antenna gain in angles >60°	−5 to 0 dBi	
Maximum antenna gain in angles 20°-30°	−3 to 4 dBi	
Antenna polarisation	Linear or circular	

More information on typical antenna parameters for LPR equipment is given in Annex 4.

2.2.5.5 Market size

ETSI TR 103 498 [1] does not give any figures for the market size for LPRs. However, a recently conducted assessment among several (T)LPR manufacturers yielded the expected sales figures given in Table 24 for the whole LPR market. This rather rough estimation also considers a considerable growth within the first five years after market launch. Given the European land area of 10523000 km², this translates to the average density of 0.0038 LPR devices/km² in the band 116-148.5 GHz, 0.0023 LPR devices/km² in the band 167-182 GHz and 0.0015 LPR devices/km² in the band 231.5-250 GHz.

Table 24: Estimated sales figures and device densities of LPR devices

Parameter	Value
Worldwide accumulated number of LPR devices in the field 5 years after launch in all proposed frequency ranges	200000
Fraction of devices sold for the European market in all bands	40%
Fraction of LPR devices sold in the band 116-148.5 GHz	50%
Fraction of LPR devices sold in the band 167-182 GHz	30%
Fraction of LPR devices sold in the band 231.5-250 GHz	20%
Accumulated number of LPR devices in the field in Europe 5 years after launch in the band 116-148.5 GHz	40000
Accumulated number of LPR devices in the field in Europe 5 years after launch in the band 167-182 GHz	24000
Accumulated number of LPR devices in the field in Europe 5 years after launch in the band 231.5-250 GHz	16000
European land area	10523000 km²
Average density of LPR devices in Europe in the band 116-148.5 GHz	0.0038 devices/km²
Average density of LPR devices in Europe in the band 167-182 GHz	0.0023 devices/km²
Average density of LPR devices in Europe in the band 231.5-250 GHz	0.0015 devices/km²

An additional re-assurance to the credibility of the provided estimates can be implemented by doubling the estimated mean device densities in Europe for the MCL calculations. This conservative overestimation emphasizes the worst-case approach of the compatibility studies.

It may be seen from the numbers given above, that the projected average density of LPR devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude certain cases, where multiple LPR devices could be used in very near proximity in an industrial plant for instance. But given their very low duty cycles and in addition to that the nevertheless unsynchronised nature of LPR devices, even in such cases, adverse aggregation effects may be considered unrealistic.

It should be further noted that it is expected that the majority proportion of LPRs will actually be installed indoors or at least inside roofed industrial areas or will have similar overhead structures reducing the level of emissions outside the installation.

Less than 10% of all LPR Installations are expected to be installed in an outdoor environment. In most cases the LPR equipment is used inside storage halls, roofed bunkers, silos and buildings. These fraction numbers were also used in ECC Report 139 [4] and haven't changed considerably since then.

The proposal for aggregated scenarios is thus as follows: 10% outdoor and 90% indoor use with an additional building attenuation. This shall be taken into account when performing a probabilistic analysis and aggregation effects.

However, in order to implement the philosophy of worst-case simulations of LPR interference, no additional natural shielding, e.g. treated in Recommendation ITU-R P.2108-0 [25], should be considered in the MCL calculations of this Report, i.e. all MCL calculations shall be performed for the worst-case of LPR being placed outdoors, with line-of-sight (LOS) conditions and without any natural shielding. As a result, all calculated interference impacts represent the most conservative estimates, which in many real-life scenarios will be further reduced due to aforementioned natural shielding.

2.2.5.6 Interference scenarios

When considering the range of identified victim services (see section 3), it may be suggested to divide the possible interference scenarios into two broad categories:
- Interference over terrestrial paths;
- Interference to EESS (passive) satellite receivers.

This approach has also been applied successfully in ECC Report 139 [4] for MCL calculations on terrestrial interference paths and space-based paths. In the present case of higher frequency bands there is no need to deviate from this approach.

Interference over terrestrial paths

The scenario in which an interference signal, originating from an LPR sensor, propagates along a terrestrial path is the most typical one. It will be relevant when evaluating coexistence of LPR devices with the following victim services:
- Fixed Service (FS) links (PP and BWA);
- Fixed Satellite Service (FSS) earth station receivers;
- Terrestrial Radio Astronomy Service (RAS);
- Amateur Service receivers.

In this case, LPR installations might have an impact on the victim stations through emissions emitting in horizontal direction along the earth's surface. The compatibility studies in this Report have considered two equally important components of such interference – emissions from the LPR antenna side lobes as well as the reflected signal power from the measured surface. The resulting interfering signal is then obtained by power summation of these two components (see Figure 37). Due to this worst-case approach, it is important that both components are also individually deduced from worst-case estimates.

As outlined in ECC Report 139 [4], it may also be in this case suggested that the reasonable worst-case interference scenario might be described as an LPR installed in an open-air environment over a slope of solid bulk material, such as sand.

There is a wide variety of bulk materials but only a few of them could be normally stored outdoors for the reasons of needing to protect from weather conditions, i.e. to prevent degradation on quality, purity and dryness.

Another important factor to consider here is the granularity of the solid bulk material. When the material is sufficiently fine to form a flat and smooth reflective surface (compared to the wavelength of radar signal), then the LPR’s antenna beam is reflected without scattering and will retain its original directive shape. When the material is coarser and forms an uneven surface (on the scale of the radar wavelength), the reflection will be diffuse and largely be scattered in all directions resulting in a dispersed signal rather than a selective reflection in just one direction.

In addition to that, the reflectivity of a radar signal is dependent on the dielectric constant and electromagnetic conductivity of the respective material.

A closer look at a wide range of outdoor bulk products leads to the conclusion that dry fine sand could be the worst-case material for the applications. It has a fine granular structure with particles' sizes from 0.1 to 0.5 mm and, being in effect a mixture of sand granules and air, the effective composite relative permittivity is around 2.38.

In fact, materials with better reflectivity have much coarser granularity, leading to the aforementioned case of uneven reflective surfaces.

An important characteristic of heaps consisting of fine solid bulk material is, that they all have a certain maximum angle of repose. For fine dry sand this characteristic angle is 33°. When wet sand is heaped, it could show larger angles of repose but also the shape gets usually much coarser which leads to scattering and lower e.i.r.p. of the reflected components. Reflection measurements on fine dry sand have been conducted in the frequency range from 140 GHz to 330 GHz for different angles of incidence. The results of this measurement campaign are shown in Annex 3. Further information on this topic can be found in ECC Report 139 ,annex 2 [4].

Hence, the worst-case interference scenario along horizontal terrestrial paths utilised for the compatibility study for RAS and Amateur Service is illustrated in Figure 37. It shows that both, the reflected component and the side-lobe component emitted by the LPR antenna directly, are taken into account by first calculating them separately and then performing an ideal mean power summation.

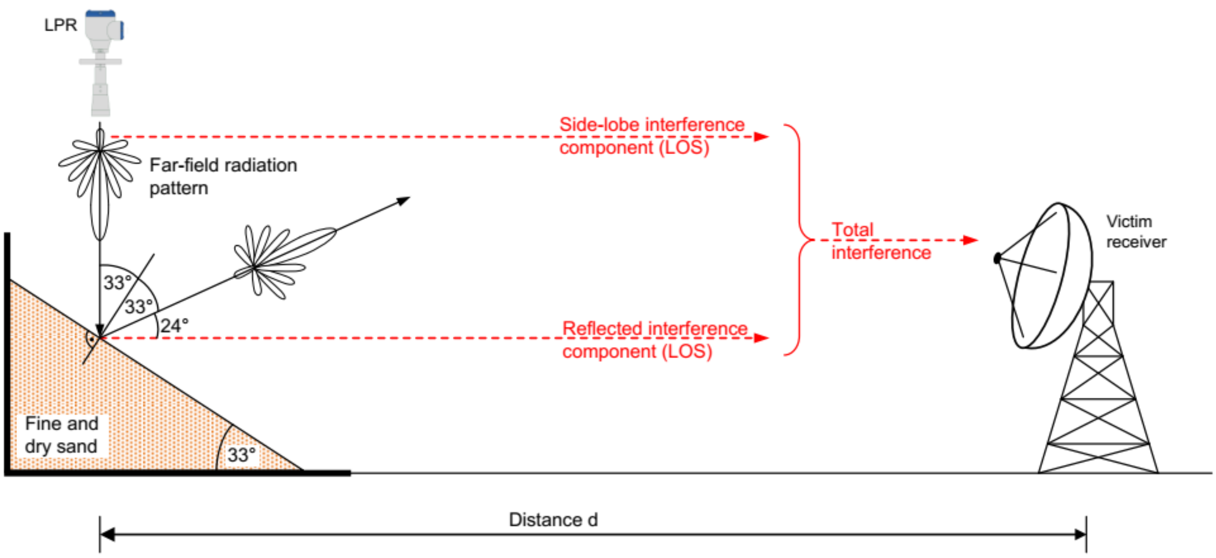


Figure 37: Worst-case interference scenario along horizontal terrestrial paths

It should also be mentioned that for initial worst-case simulations it would be reasonable to assume direct line-of-sight (LOS) coupling for both, the LPR reflected component and the side-lobe component towards the victim receiver. This means that the free-space propagation model could be applied to model the propagation of the interfering signal over a flat path over the earth's surface without the presence of obstacles. This, in turn, makes it unnecessary to consider the heights of the LPR antenna, the reflecting point and the victim station's antenna. However, this initial simplification could later be refined in the light of the calculated interference range.

For example, if the calculated interference distance for a given coexistence case clearly exceeded the estimated radio horizon, this would mean that non-LOS propagation conditions predominate. This in turn would lead to the requirement to apply different propagation models and potentially an unavoidable reduction of the actual interference range.

In this scenario it is very important whether LPR installations are located indoors or have any other similar roofed construction which attenuate both horizontal paths towards the victim receiver. As outlined in section 2.2.5.5 calculations shall assume that 90% of all LPRs are actually installed indoors. When performing a probabilistic analysis and aggregation effects an appropriate building attenuation shall be taken into account.

For Fixed Service links, dedicated interference scenarios have been developed describing a typical situation where a Fixed Service transmitter attached to a light pole is linked to a receiver located on top of a building and vice versa (see Figure 38 and Figure 39).

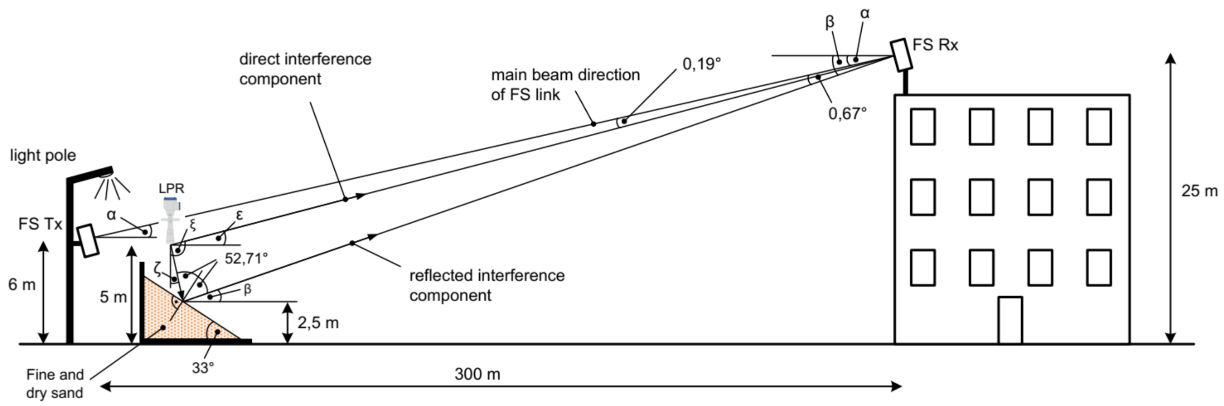


Figure 38: LPR secenario 1: Light pole connected to a building by means of an FS link – FS Rx on building

In the first scenario (see Figure 38) the LPR device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. The height of the LPR device above ground shall be 5 m. This means in fact that the LPR is located exactly 1 m below the FS Tx antenna.

In this scenario two interference components can be distinguished:

- Direct interference through emission over a sidelobe of the LPR antenna (angle ξ = 93.81°).
- Interference through emission over the reflected sidelobe of the LPR antenna (angle ζ = 19.71°) at the sand surface.

The reflection at the sand surface caused by a sidelobe of the LPR shall occur in 2.5 m height and under an angle ζ so that the reflected component is directly aligned towards the FS receiver on top of the building. All LPR devices are expected to be placed between 0.5 and 10 m above ground whereas the majority (90%) is expected to be placed in heights from 0.5 to 5 m (see section 2.2.5.1).

The two interference components are first calculated separately and then an ideal power summation is performed.

In contrast to the first scenario the locations of FS Rx and Tx are exchanged in the second scenario (see Figure 39) and the LPR sensor shall be installed this time in the same height (6 m) as the FS Rx. The distance between FS Rx and FS Tx is again 300 m and also the separation distance between the LPR device and the FS Rx is again 300 m resulting in the lowest angle β, which yields in this example 0.67°.

In this scenario again the following two interference components can be distinguished:

- Direct interference through emission over a sidelobe of the LPR antenna (angle 90°).
- Interference through emission over the reflected sidelobe of the LPR antenna (angle ζ = 23.33°) at the sand surface.

The reflection at the sand surface caused by a sidelobe of the LPR shall occur again in 2.5 m height and under an angle ζ so that the reflected component is directly aligned towards the FS receiver attached to the light pole.

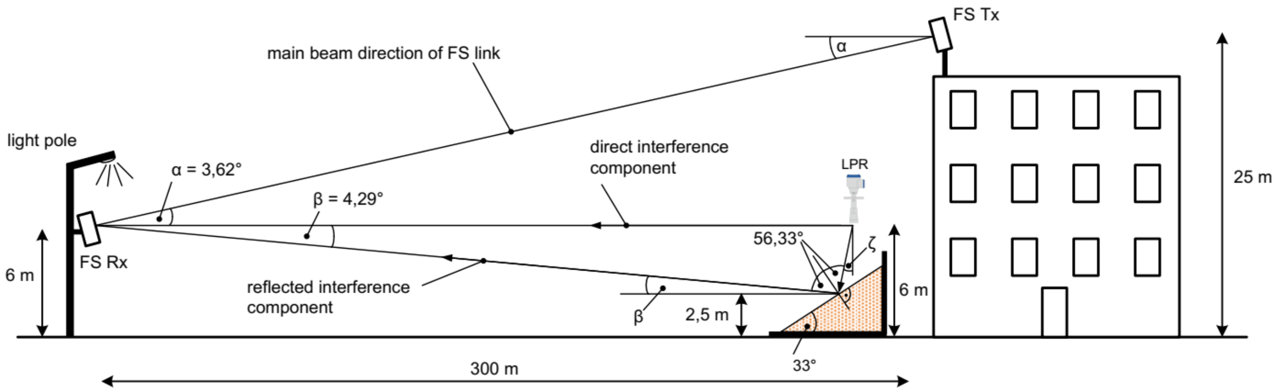


Figure 39: LPR scenario 2: Light pole connected to a building by means of an FS link – FS Rx at light pole

The two interference components are again calculated separately and then an ideal power summation is performed.

Interference to EESS (passive) satellite receivers

In case of interference to satellite receivers, the relevant radiation direction would be in vertical plane above the LPR installation and the worst-case scenario could be described as an open-air LPR installation over a calm (ripple-free) water surface. A calm water surface would produce a non-scattered reflection with a low reflection loss due to the high relative permittivity of water even in the higher frequency range above 116 GHz.

The studies in this Report should consider both, the direct radiation component from the LPR antenna's back-lobe as well as the reflected signal from the illuminated water surface in the vertical plane towards zenith, (see Figure 40). Like for the interference over terrestrial paths, both components are calculated separately and afterwards an ideal mean power summation is conducted to work out the total interference.

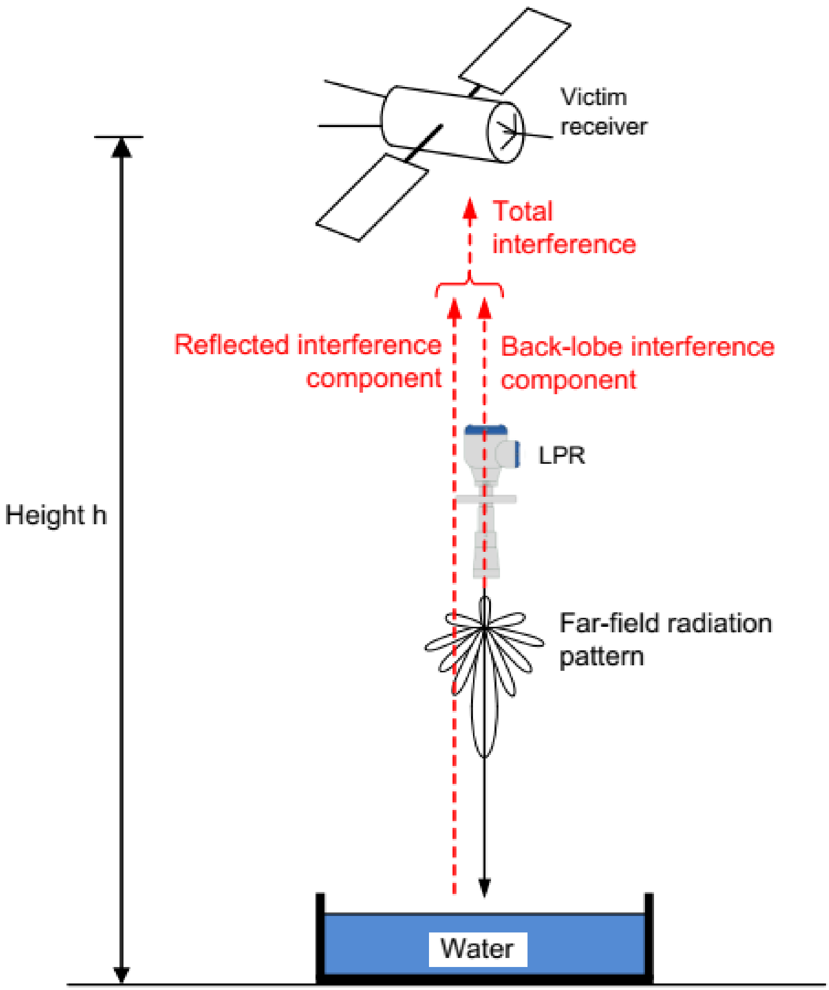


Figure 40: Worst-case interference scenario against EESS (passive) satellite receivers

In this scenario it is also very important whether LPR installations are located indoors or have any other similar roofed construction which attenuate the paths towards the sky. As outlined in section 2.2.5.5 calculations shall assume that 90% of all LPRs are actually installed indoors. When performing a probabilistic analysis and aggregation effects an appropriate building attenuation shall be taken into account.

2.2.6 Contour determination and acquisition

2.2.6.1 Application scenario

Contour determination and acquisition radar sensors (CDR) are the most advanced sensors in the emerging field of bulk level measurement. Level Probing Radar (LPR) sensors as shown in Figure 34 are equipped to measure a one-dimensional single distance to the uppermost position of a bulk level contour. Typically, this measured value does not represent a meaningful indication of the amount of material substantially available in the measurement application. In contrast, contour determination and acquisition sensors are equipped to gather a plurality of distance values to different points located on the surface of the bulk material. These values can be used to form a digital representation of the bulk material surface as illustrated in Figure 41. In addition, by means of digital calculation, dependent values based on the measured contour values can be calculated and provided by CDR sensors, e.g. volume or mass of material available in the current measurement scenario. In other applications it might also be of interest to identify dangerous conditions to protect humans, animals, the environment or material assets.

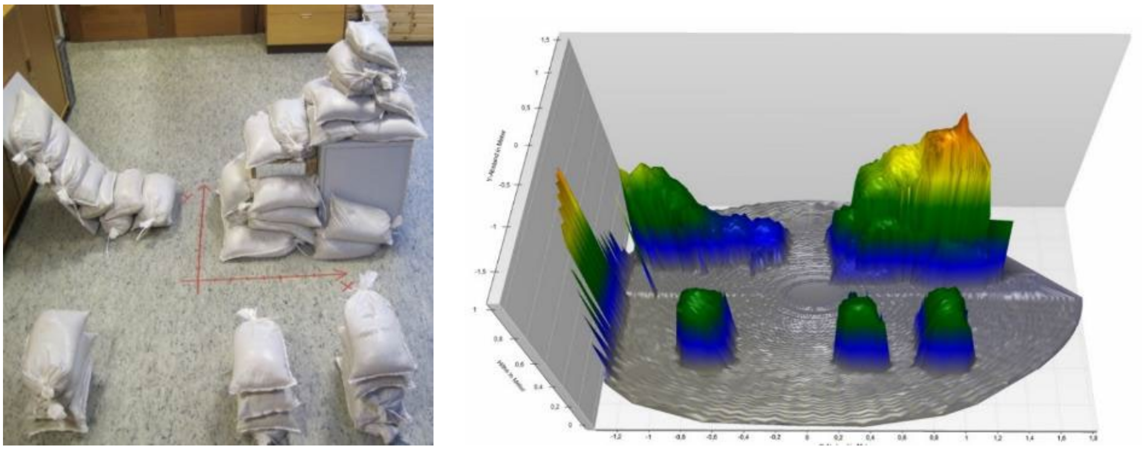


Figure 41: Imaging Radar systems for 3D visualising of arbitrary ground surfaces (contour determination)

The basic measurement principle of CDR sensors is a time-of-flight method by for example using an FMCW modulated radar signal like used for LPR radars (see section 2.2.5.3). In this case a frequency sweep over a defined bandwidth in a certain time is sent from the CDR-antenna towards the material whose contour values have to be measured. In addition-and in contrast to LPR or TLPR sensors-a CDR sensor is equipped to vary, control and register transmit and/or receive directions of the main lobe of the sensor antenna in order to get additional angular information regarding the location of an origin of a received signal. This variation of angular directions can be realised by mechanical tilting of a single antenna (M-CDR) and/or by electronic beam steering of multiple antenna elements forming a MIMO (multiple in multiple out) antenna. In case of electronic beam steering, as well time multiplexed operation of the multiple transmit antenna elements (DBF-CDR) as parallel operation of the transmit antenna elements (PA-CDR) will be feasible.

The emitted signal from the CDR sensor is reflected at the surface of the bulk material and received from the CDR antenna again. The instantaneous frequency shift between the transmit signal and the received signal is proportional to the distance between the sensor and the surface and is evaluated for multiple reflections. Taking additionally registered transmit and/or receive directions of the sensor antenna into account, a CDR can measure both distance to a reflection point of a bulk solid material's surface and elevation and azimuthal angle of a surface reflection point. Using multiple iterations, a CDR can measure multiple distance and angular positions of a plurality of different surface points a bulk material contour provides in an application.

As the used RF signal is nearly independent of ambient temperature, pressure and humidity and other adverse environmental conditions, robust and reliable measurement of bulk material surfaces and reliable calculation of volume and mass values can be achieved by using advanced CDR sensor technology.

2.2.6.2 Frequency ranges and application types

Systems for contour determination and acquisition have been categorised as type B applications (see section 2.1). The following frequency ranges are proposed to be considered for this type of application (see Table 33):

- 116 GHz to 148.5 GHz;
- 167 GHz to 182 GHz;
- 231.5 GHz to 250 GHz.

2.2.6.3 Technical parameters

Table 25 gives an overview of the technical parameters of CDR devices which may be relevant for conducting the compatibility studies.

Table 25: Technical parameters of CDR equipment

Parameter	Value	Notes
Modulation scheme	Frequency Modulated Continuous Wave (FMCW)	
Operating frequency range (OFR)	116-148.5 GHz 167−182 GHz 231.5−250 GHz	
Available modulation bandwidth	32.5 GHz, 15 GHz and 18.5 GHz	
Used modulation bandwidth	up to 32.5 GHz up to 15 GHz up to 18.5 GHz	-20 dB bandwidth
Sweeptime	50 µs to 5 ms	for a single frequency sweep over entire modulation bandwidth
Duty cycle	≤ 10%	
Conducted peak carrier power	up to +5 dBm	Maximum saturated output power at antenna feeding point
Conducted mean power	-5 dBm	with 10% duty cycle and +5 dBm peak carrier power
Conducted mean power spectral density	-46.8 dBm/MHz	with 15 GHz modulation bandwidth and -5 dBm mean power
Maximum mean power spectral density (e.i.r.p.)	-14.8 dBm/MHz	calculated with 32 dBi antenna gain

2.2.6.4 Antenna data

Table 26 and Table 27 show the antenna parameters of CDR devices subdivided into the three categories M−, PA− and DBF-CDRs.

Table 26: Antenna parameters of M-CDR equipment

Parameter	Value	Notes
Antenna type	mechanically tilted horn- and lens-horn antennas, planar antenna arrays, mechanically fixed horn- and lens-horn antennas, planar antenna arrays with electromagnetic deflection unit	application dependent
Antenna half power beamwidth	3° to 5°	depends on individual antenna type (see Annex 4)
Antenna gain	typically up to to 32 dBi	
Maximum antenna gain in angles >60°	−5 to 0 dBi	
Maximum antenna gain in angles 20°-30°	−3 to 4 dBi	
Antenna polarisation	Linear or circular	

Table 27: Antenna parameters of PA-CDR and DBF-CDR equipment

Parameter	Value	Notes
Antenna type	Antenna system (AS) consisting of multiple single antenna elements (SAE), realised by waveguide output arrays, filled waveguide output arrays, horn- and lens-horn arrays, planar antenna arrays	application dependent
PA-CDR: Antenna (AS) half power beamwidth	5° (no main lobe deviation) 11° (main lobe deviation of 60°)	Half power beamwidth of SAE not relevant as all elements are in parallel operation active
PA-CDR: Antenna gain of complete antenna system (AS)	typically up to 32 dBi	Antenna gain of SAE not relevant as all elements are in parallel operation active
DBF-CDR: Antenna element (SAE) half power beamwidth	120°	Half power beamwidth of AS not relevant as SAE's are activated one by one in TDMA mode
DBF-CDR: Antenna gain of single antenna element (SAE)	typically up to 10 dBi	Antenna gain of AS not relevant as SAE's are activated one by one in TDMA mode
Antenna polarisation	Linear or circular	

2.2.6.5 Market size

ETSI TR 103 498 [1] does not give any figures for the market size of CDRs. However, the results of a rough market prediction yielded the expected sales figures given in Table 28. This estimation also considers a market growth within the first five years after the first launch of the technology. Given the European land area of 10523000 km², this translates to the average density of 0.00019 CDR devices/km² in the band 116-148.5 GHz, 0.00011 CDR devices/km² in the band 167-182 GHz and 0.00008 CDR devices/km² in the band 231.5-250 GHz.

Table 28: Estimated sales figures and device densities of CDR devices

Parameter	Value
Worldwide accumulated number of CDR devices in the field 5 years after launch in all proposed frequency ranges	10000
Fraction of devices sold for the European market in all bands	40%
Fraction of CDR devices sold in the band 116-148.5 GHz	50%
Fraction of CDR devices sold in the band 167-182 GHz	30%
Fraction of CDR devices sold in the band 231.5-250 GHz	20%
Accumulated number of CDR devices in the field in Europe 5 years after launch in the band 116-148.5 GHz	2000
Accumulated number of CDR devices in the field in Europe 5 years after launch in the band 167-182 GHz	1200

Parameter	Value
Accumulated number of CDR devices in the field in Europe 5 years after launch in the band 231.5-250 GHz	800
European land area	10523000 km²
Average density of CDR devices in Europe in the band 116-148.5 GHz	0.00019 devices/km²
Average density of CDR devices in Europe in the band 167-182 GHz	0.00011 devices/km²
Average density of CDR devices in Europe in the band 231.5-250 GHz	0.00008 devices/km²

It may be seen from the numbers given above, that the projected average density of CDR devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude certain cases, where multiple CDR devices could be used in very near proximity in an industrial plant for instance. But given their very low duty cycles and in addition to that the nevertheless unsynchronised nature of CDR devices, even in such cases, adverse aggregation effects may be considered unrealistic.

It should be further noted that it is expected that the majority proportion of CDRs will actually be installed in some kind of roofed industrial areas or will have similar overhead structures reducing the level of emissions outside the installation. Thus, in most cases the CDR equipment is used inside storage halls, roofed bunkers, silos and buildings.

Like for level probing radars, in order to implement the philosophy of worst-case simulations of CDR interference, no additional natural shielding, e.g. treated in Recommendation ITU-R P.2108-0 [25], should be considered in the MCL calculations of this ECCReport, i.e. all MCL calculations shall be performed for the worst-case of CDR being placed outdoors, with line-of-sight (LOS) conditions and without any natural shielding. As a result, all calculated interference impacts represent the most conservative estimates, which in many real-life scenarios will be further reduced due to aforementioned natural shielding.

2.2.6.6 Interference scenarios

The possible interference scenarios for contour detection and acquisition systems could be divided in the known two broad categories:

- Interference over terrestrial paths
- Interference to EESS (passive) satellite receivers.
- This approach is similarly used for example for level probing radars (see section 2.2.5.6).

Interference over terrestrial paths

The scenario in which an interference signal, originating from a contour detection radar (CDR) sensor, propagates along a terrestrial path is the most typical one. It will be relevant when evaluating coexistence of CDR devices with the following victim services:

- Fixed Service (FS) links (PP and BWA),
- Fixed Satellite Service (FSS) earth station receivers,
- Terrestrial Radio Astronomy Service (RAS).
- Amateur Radio Service receivers

CDR installations might have an impact on the victim stations through emissions emitting in horizontal direction along the earth's surface. Altogether three different components of such interference could be identified for contour detection radars – emissions radiated over the antenna main beam, emissions from side lobes as well as the reflected signal from the measured surface. For M- and PA-CDR systems all three interference components apply as the direction of main radiation of the antenna is varied over time in order to consecutively sample the surface.

For DBF-CDR the direct path over the antenna main beam is no source of interference as the antenna is permanently aligned vertically downwards towards the surface whose contour is to be determined and the main beam direction doesn't change over time.

The resulting interfering signal is then obtained by power summation of the relevant components (see Figure 42 and Figure 43). Due to this approach, it is important that all components are also individually deduced from worst-case estimates.

As outlined in ECC Report 139 [4], it may also be in this case suggested that the reasonable worst-case interference scenario might be described as a CDR installed in an open-air environment over a heap of solid bulk material of fine and dry sand. The reasons why sand is chosen as a representative worst-case material are the same as for level probing radar and can be found ich section 2.2.5.6.

Hence, the worst-case interference scenario along horizontal terrestrial paths utilised for this compatibility study is illustrated in Figure 42. It shows that all three paths, the direct component, the side-lobe component and the reflected component emitted by M-CDRs and PA-CDRs, are taken into account by first calculating them separately and then performing an ideal power summation.

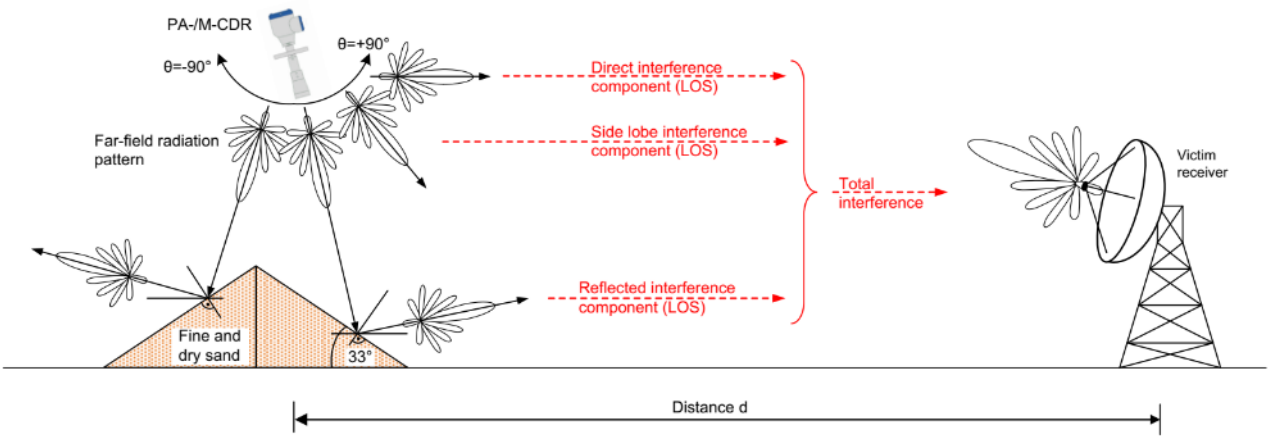


Figure 42: Worst-case interference scenario along horizontal terrestrial paths for PA- and M-CDR equipment

In this scenario it is assumed that the CDR is sampling the surface in 3° steps according to the assumed 3°-HPBW of the antenna in the whole half sphere from θ = 0° to +90° and Φ = 0° to 360°. Thus, altogether 3601 directions of the antenna main beam can be distinguished and are supposed to be measured in this scenario. In order to simplify this model and to follow the worst-case approach, it is assumed that in every direction a side lobe component and a reflected component reach the victim receiver, whereas the direct interference component is only relevant within a relatively small solid angle where the respective Rx-antenna of the victim receiver can be reached. This solid angle is estimated to be equivalent to approximately five directions of the CDR antenna main beam during a measurement cycle. This has to be taken into account when performing the single-entry mean power summation.

For the DBF-CDR the same terrestrial interference scenario as for level probing radars (see section 2.2.5.6 and Figure 43) with two interference components is used. This approach is valid, as in contrast to the M- and PA-CDR devices, the radiation pattern of the DBF-CDR system remains stationary while pointing in a downwards direction towards the surface to be sampled. However, the antenna properties, especially gain and HPBW, are different compared to the M- and PA-CDR as indicated in Table 26 and Table 27.

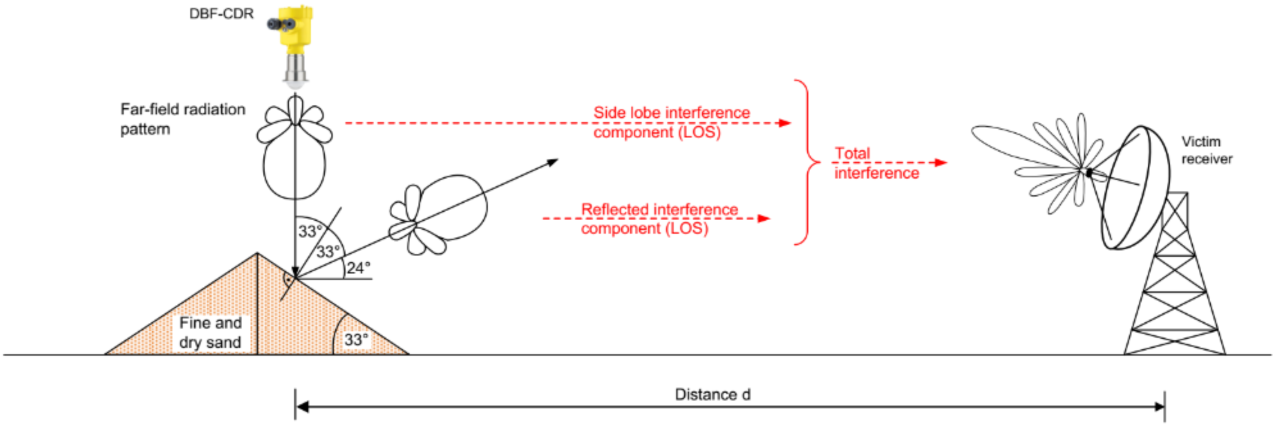


Figure 43: Worst-case interference scenario along horizontal terrestrial paths for DBF-CDR equipment

For Fixed Service links, altogether four dedicated interference scenarios have been developed where a Fixed Service transmitter attached to a light pole is linked to a receiver located on top of a building and vice versa (see Figure 44 to Figure 47 and Table 40).

For the DBF-CDR category the same interference scenarios as for LPR shall be used. The only difference are the antenna characteristics of both systems (see sections 2.2.5.4 and 2.2.6.4).

For the M-CDR and PA-CDR categories the scanning nature of the antenna has to be taken into account. For both categories the main beam direction is constantly changing and thus scanning the contour of the observed surface. For this study it is assumed that the whole half-space from -180° to 180° in azimuth and -90° to 0° in elevation is being scanned. Thus, the power of the M-/PA-CDR is spread or distributed over the large area of a half-space and most of the radiated power of the CDR device will never reach the victim receiver in a single-entry scenario. The spatial scanning function of the M- and PA-CDR devices can be interpreted for example as an additional duty cycle from the victim receiver's point of view. Alternatively, it could also be included in an average antenna gain when calculating the average interference power towards a potential victim in a long-term protection consideration.

Due to the mentioned circumstances above the long-term protection criteria is therefore not seen as the critical case concerning a FS victim receiver. In contrast to that it is expected that the time instants during the scan where either the main beam direction of the M-/PA-CDR is pointing horizontally towards the FS Rx or where the reflected interference component in main beam direction of the CDR device points exactly towards the FS Rx is much more critical. Those scenarios however should be estimated against the peak power criterion (see section 3.5.3.1 in the Report) because they occur only during a short period of the measurement cycle. For completeness however, both criteria, the long-term protection objective and the peak-power objective are considered.

In scenario 1 (see Figure 44) is assumed that the M-/PA-CDR device is tilted in the fashion that the reflected interference component exactly points towards the FS Rx and the M-/PA-CDR device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. The height of the CDR device above ground shall be 5 m which is identical compared to the LPR application (see section 3.2.6.6). The relevant angles under which both interference components are seen from the FS receiver are $\delta = 0.67°$ for the reflected component and $\varepsilon-\alpha = 0.19°$ for the direct component over a sidelobe.

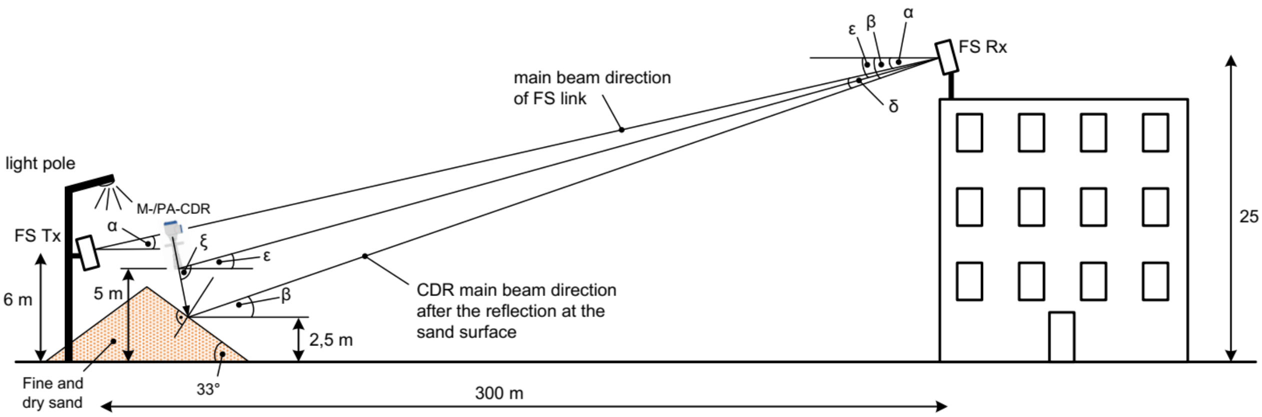


Figure 44: M-/PA-CDR scenario 1: Streetlamp post connected to a building by means of an FS link – FS Rx on building. Reflected interference component points directly to FS Rx.

In scenario 2 (see Figure 45) the locations of FS Rx and FS Tx are exchanged. Also in this scenario it is assumed that the M-/PA-CDR device is tilted in the fashion that the reflected interference component exactly points towards the FS Rx and the M-/PA-CDR device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. The height of the CDR device above ground shall be 6 m and the reflection at the sand surface shall occur in 2.5 m height.

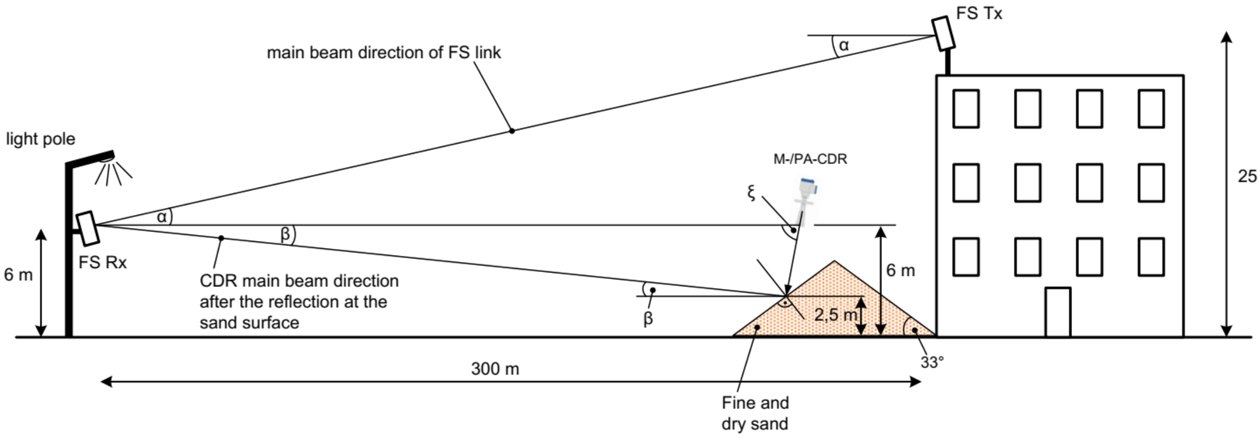


Figure 45: M-/PA-CDR scenario 2: Streetlamp post connected to a building by means of an FS link – FS Rx on light pole. Reflected interference component points directly to FS Rx.

In scenario 3 (see Figure 46) the CDR device is tilted to 90° so that the main beam direction points towards the FS Rx and not anymore to the sand surface. In this scenario only the direct component over the main beam direction is considered as there is no reflected component from the sand heap. There could be of course also in this scenario a reflected component from the flat ground. This component however is expected to be very weak due to the lower CDR antenna gain in this direction and due to the larger incidence angle off the FS Rx main beam direction and therefore neglected.

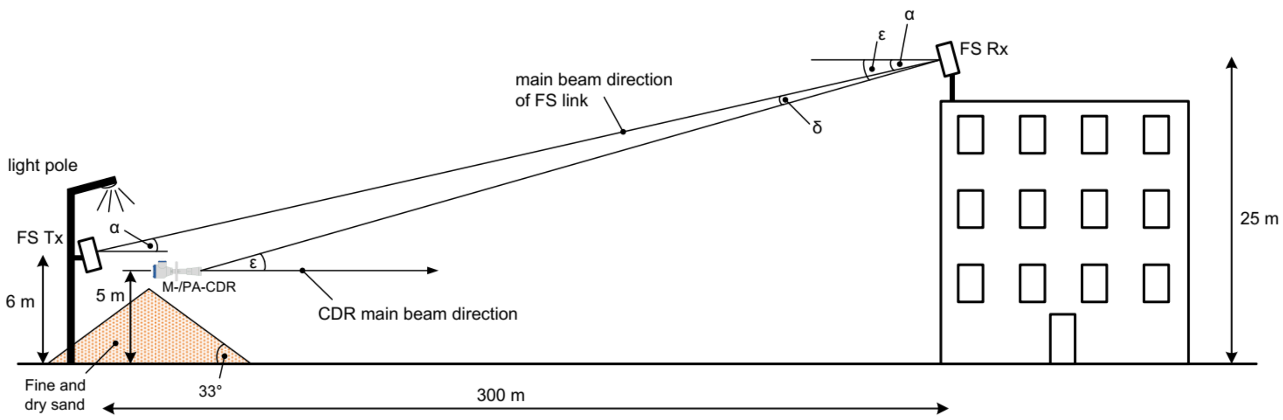


Figure 46: M-/PA-CDR scenario 3: Streetlamp post connected to a building by means of an FS link – FS Rx on building. Horizontal emission.

In scenario 4 (see Figure 47) the locations of FS Rx and FS Tx are exchanged again, and the CDR device is tilted again to 90° and mounted in 6 m height so that the main beam direction points towards the FS Rx attached to the light pole. Also in this scenario, only the direct component over the main beam direction is considered as there is no reflected component from the sand heap.

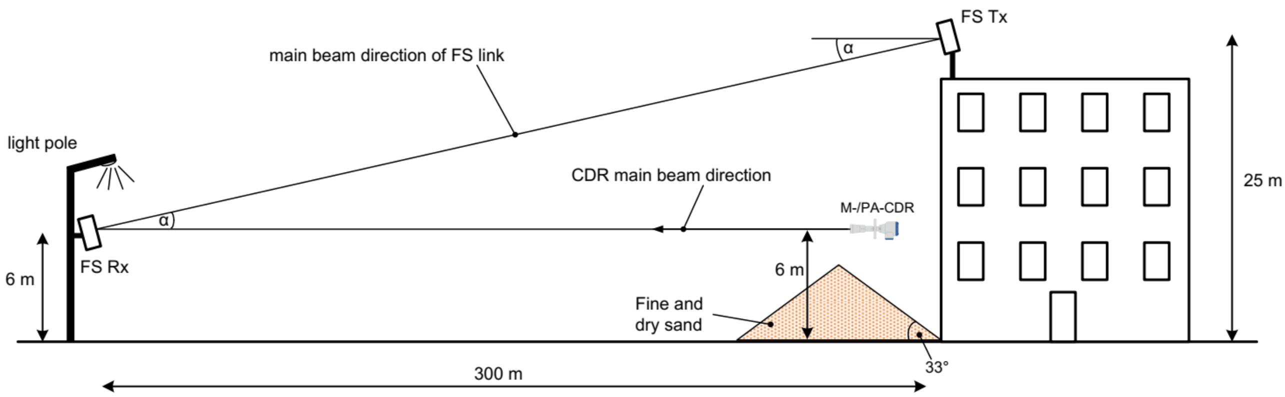


Figure 47: M-/PA-CDR scenario 4: Streetlamp post connected to a building by means of an FS link – FS Rx on light pole. Horizontal emission.

Interference to EESS (passive) satellite receivers

In case of interference to satellite receivers, the relevant radiation direction would be in vertical plane above the CDR installation (like for the level probing radar case) and the worst-case scenario could be described as an open-air CDR installation over a wet and flat sand surface. In contrast to level probing radars the measurement of a flat liquid surface is not a realistic use case for a contour detection radar. Despite the fact, that a flat surface is generally a very unlikely scenario for a CDR, it is not entirely impossible, however. At the planar sand surface there would also be a non-scattered reflection with a certain reflection loss. A conservative estimation of the relative permittivity of wet sand ranges between 6.5 and 9 for the frequency range between 300 MHz and 5 GHz. However, for frequencies above 116 GHz these figures are expected to be much lower. For the estimation of the reflected interference components a relative permittivity of $\varepsilon r = 8$ for the wet sand surface for frequencies beyond 116 GHz is assumed. This is equivalent to a reflection loss of 6.42 dB and is comparable to the reflection loss of a pure water surface at those high frequencies.

For M- and PA-CDR equipment the studies should consider both, the direct radiation component from the CDR antenna's back lobe and side lobes, as well as the reflected signal from the illuminated sand surface in the vertical plane towards zenith (see Figure 48). Provided that the CDR is again sampling the surface in 3° steps according to the 3°-HPBW of the antenna in the whole half sphere from $\theta = 0°$ to $+90°$ and $\Phi = 0°$ to $360°$, it is assumed that always a side lobe or the back lobe component reaches the victim receiver, no matter in which direction the main beam of the CDR antenna is actually pointing. On the contrary, the reflected interference component over the main beam of the antenna is only relevant within a relatively small solid angle. This solid angle is again estimated to be equivalent to approximately five directions of the CDR antenna main beam during one measurement cycle where the half sphere is sampled. This procedure is similar to the aforementioned approach used in the terrestrial interference case.

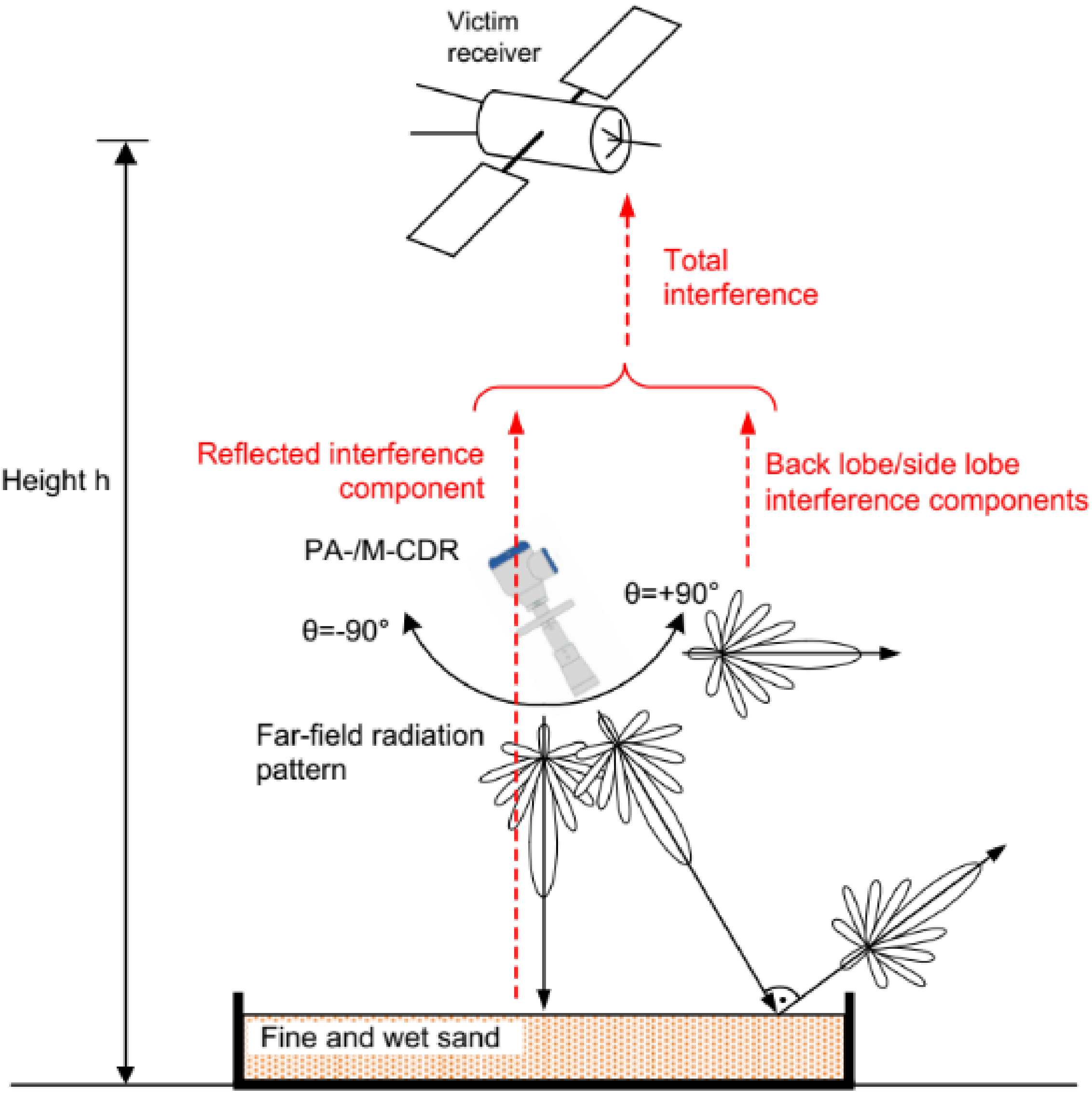


Figure 48: Worst-case interference scenario against EESS (passive) satellite receivers for M- and PA-CDR equipment

For the DBF-CDR device the interference scenario to EESS is the same as for level probing radar (see section 2.2.5.6 and Figure 49) with the only difference that the measurement object is not a water surface but also the mentioned flat surface of fine and wet sand. The reflection loss of both surfaces, however, is assumed to be identical taking a value of 6.42 dB as explained above.

The relevant reflected and back lobe interference components are again calculated separately and afterwards an ideal power summation is conducted to work out the total interference power.

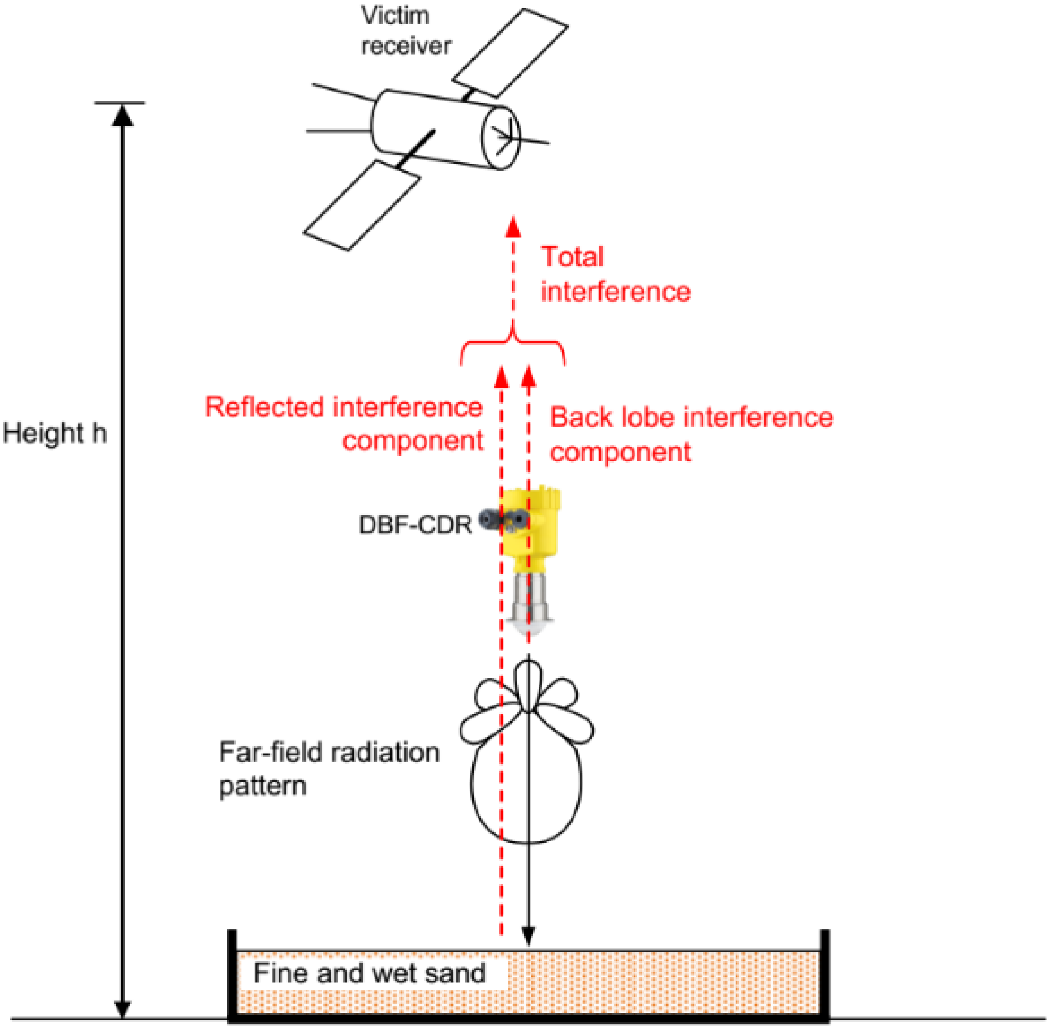


Figure 49: Worst-case interference scenario against EESS (passive) satellite receivers for DBF-CDR equipment

In all preceding interference scenarios, it is also very important whether CDR installations are located indoors or have any other similar roofed construction which attenuate the paths towards the sky or the terrestrial victims. As outlined in section 2.2.6.5 calculations shall assume that 90% of all CDRs are actually installed indoors, inside silos or tanks or below roofed environments. When performing a probabilistic analysis an appropriate building attenuation shall be taken into account.

2.2.7 Tank Level Probing Radar (TLPR)

2.2.7.1 Application scenario

Tank Level Probing Radar (TLPR) sensors are almost identical to Level Probing Radars (LPR) (see section 2.2.5) with the only exception that TLPRs are only allowed to be applied and radiate inside metallic tanks or containers consisting of a comparable attenuating material, e.g. concrete. The measurement principle is also identical to LPRs using a time-of-flight method with an FMCW modulated Radar signal. This principle is explained in more detail in section 2.2.5.

TLPRs are applied like LPRs in many industries to measure the distance to the surface of various materials and substances (mostly liquids and solids) inside closed containers and thus indirectly the amount of the filling product. A typical conceptional measurement scenario for Tank level Probing Radars is illustrated in Figure 50.

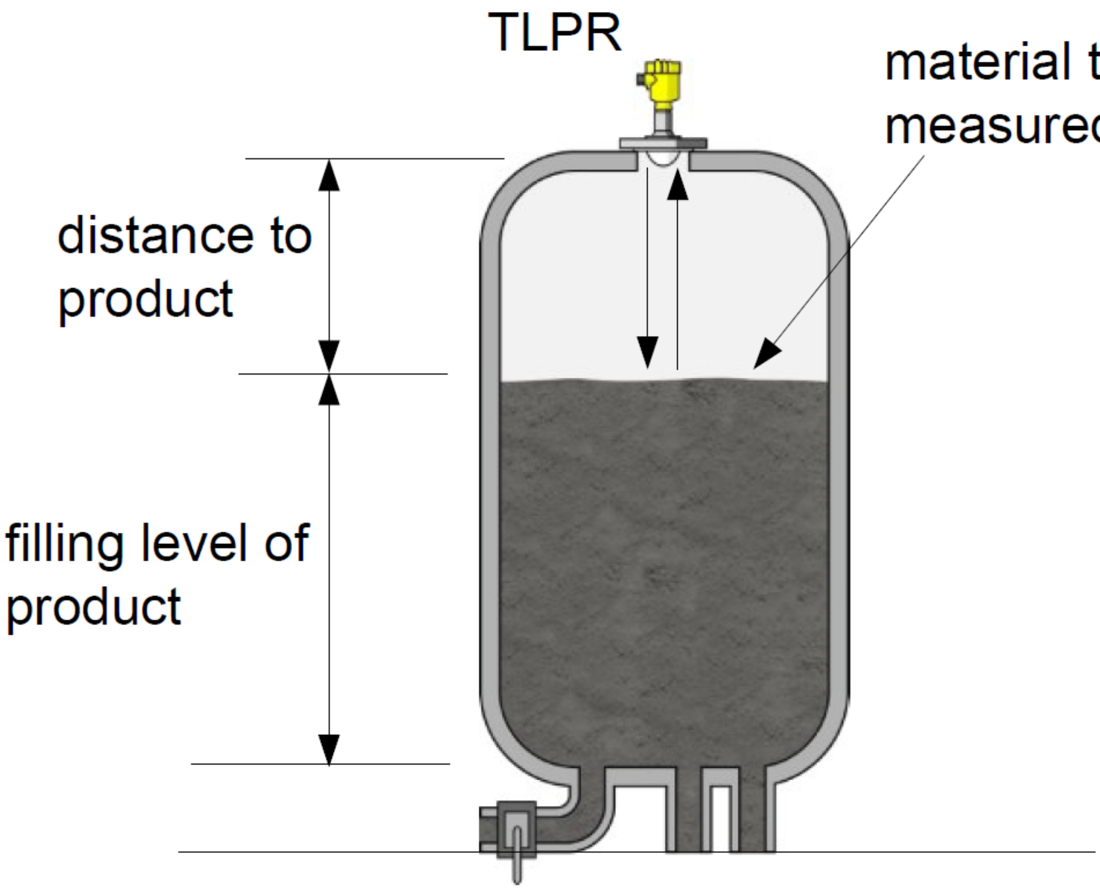


Figure 50: Tank Level Probing Radar for solids/liquids inside a metallic tank

Due to different physical or chemical properties of different liquids or solids, TLPR sensors are installed in a large variety of different storage, processing or transportation tanks.

In many of these installations, TLPR devices provide real-time and safety-critical information in order to protect humans, technical equipment, machinery and the environment. Examples of such safety-critical applications inside closed metallic tanks include:

- storing or processing of materials in very small containers (often used in the pharmaceutical industry);
- storing or processing of hazardous substances (level measurement of flammable and/or corrosive materials, acids and bases, poisonous liquids and other substances harmful to human's health);
- processing of materials under harsh environmental conditions (process pressure up to 400 bar and temperatures up to 250°C inside the reaction vessel).

In other applications, an accurate level measurement helps to improve the quality of the end-product, and to conserve the environment by facilitating the efficient use of scarce natural resources. Examples of such applications include:

- exact dosing of liquids and solids in chemical or pharmaceutical plants;
- monitoring of the exact filling level of custody transfer commodities in storage tanks during dispatch and billing (e.g. fuel oil and other refined petroleum-based products);
- level monitoring in chemical reaction vessels where an exact and constant filling level is crucial for the process.

Typical examples of LPR installations are illustrated in Figure 51.

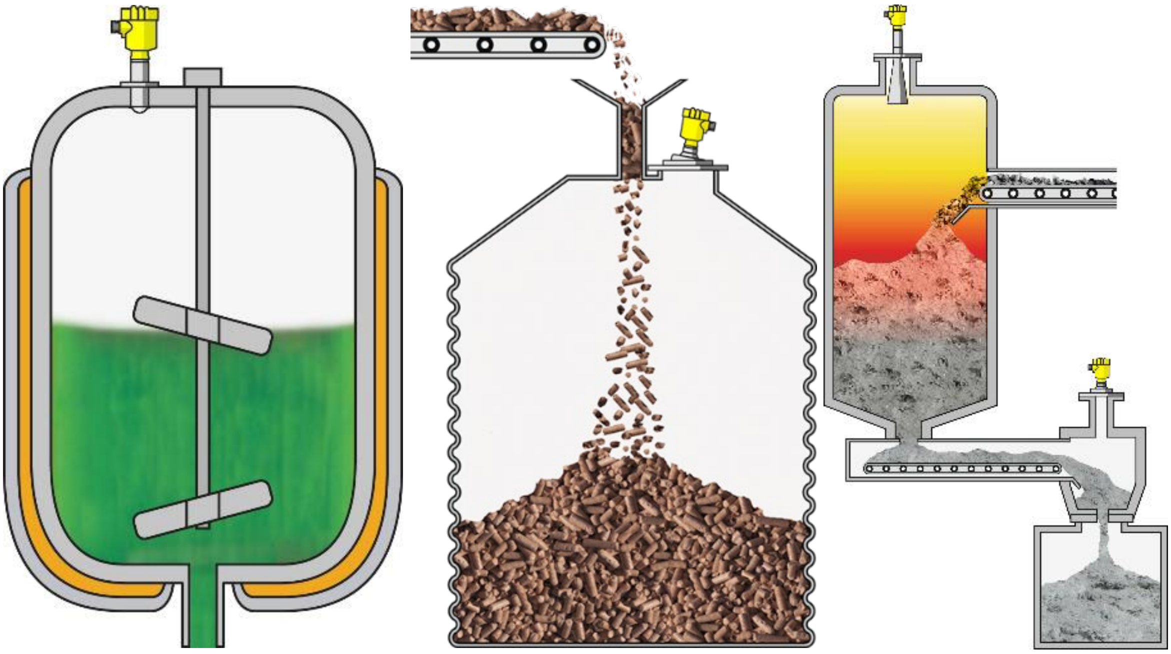


Figure 51: Typical examples of TLPR installations

It is foreseen that TLPR in dedicated frequency bands within the range 116 to 260 GHz is still a strictly professional and industrial application. All Tank Level Probing Radars are expected to be installed complying with the following installation requirements:

- TLPRs are required to be installed at a permanent fixed position at a closed metallic tank or reinforced concrete tank, or similar enclosure structure made of comparable attenuating material;
- flanges and attachments of the TLPR equipment shall provide the necessary microwave sealing by design;
- sight glasses shall be coated with a microwave proof coating when necessary (i.e. electrically conductive coating);
- manholes or connection flanges at the tank shall be closed to ensure a low-level leakage of the signal into the air outside the tank;
- whenever possible, mounting of the TLPR equipment shall be on top of the tank structure with the orientation of the antenna pointing in a downwards direction;
- installation and maintenance of the TLPR equipment shall be performed by professionally trained individuals only;
- the provider is required to inform the users and installers of TLPR equipment about the installation requirements and, if applicable, the additional special mounting instructions.

These installation requirements are well-established for TLPRs already available on the market and operating in lower frequency ranges and can be extracted from ETSI EN 302 372 V2.1.1, annex E [7].

2.2.7.2 Frequency ranges and application types

Tank Level Probing Radars have been categorised as type C applications (see section 2.1). The following frequency ranges have been requested for this type of application (see Table 33):

- 116 GHz to 148.5 GHz;
- 167 GHz to 182 GHz;
- 231.5 GHz to 250 GHz.

It is worth to mention here that these frequency bands coincide with those requested for Level Probing Radar (LPR) (see section 2.2.5).

2.2.7.3 Technical parameters

The technical parameters for TLPR equipment are identical to those for Level Probing Radar and can be found in section 2.2.5.3.

2.2.7.4 Antenna data

The maximum available antenna apertures for TLPR devices used for in-tank applications are usually smaller than for LPR devices. The reason for that is based on the fact that measurement distances in open air applications are often larger and thus the received echoes are smaller. Additionally, the reflection properties of certain products sometimes stored outdoors, e.g. some granules or powders with low relative dielectric constant, result in very weak and small echo signals. In such situations the highest available antenna gain is necessary in order to ensure a reliable measurement. A further reason is the fact that relatively small tank openings are also desired to be utilised for level measurements in certain cases. Therefore, the antenna should fit into the given and sometimes very small tank opening.

However, for simplicity the same antenna apertures shall be assumed for TLPR as for LPR (refer to section 2.2.5.4). This procedural method is accordant to the worst-case approach of this Report.

2.2.7.5 Market size

ETSI TR 103 498 [1] does not give any figures for the market size for TLPRs. However, a recently conducted assessment among several TLPR manufacturers yielded the expected sales figures depicted in Table 29. This estimation also considers a considerable growth within the first five years after market launch. Given the European land area of 10523000 km², this translates to the average density of 0.0057 TLPR devices/km² in the band 116-148.5 GHz, 0.0034 TLPR devices/km² in the band 167-182 GHz and 0.0023 TLPR devices/km² in the band 231.5-250 GHz.

Table 29: Estimated sales figures and device densities of TLPR devices

Parameter	Value
Worldwide accumulated number of TLPR devices in the field 5 years after launch in all proposed frequency ranges	300000
Fraction of devices sold for the European market in all bands	40%
Fraction of TLPR devices sold in the band 116-148.5 GHz	50%
Fraction of TLPR devices sold in the band 167-182 GHz	30%
Fraction of TLPR devices sold in the band 231.5-250 GHz	20%
Accumulated number of TLPR devices in the field in Europe 5 years after launch in the band 116-148.5 GHz	60000
Accumulated number of TLPR devices in the field in Europe 5 years after launch in the band 167-182 GHz	36000
Accumulated number of TLPR devices in the field in Europe 5 years after launch in the band 231.5-250 GHz	24000
European land area	10523000 km²
Average density of TLPR devices in Europe in the band 116-148.5 GHz	0.0057 devices/km²
Average density of TLPR devices in Europe in the band 167-182 GHz	0.0034 devices/km²
Average density of TLPR devices in Europe in the band 231.5-250 GHz	0.0023 devices/km²

An additional re-assurance to the credibility of the provided estimates can be implemented by doubling the estimated mean device densities in Europe for the MCL calculations. This conservative overestimation emphasizes the worst-case approach of the compatibility studies.

It may be seen from the numbers given above, that the projected average density of TLPR devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude certain cases, where multiple TLPR devices could be used in very near proximity in an industrial plant for instance. But given their very low duty cycles and in addition to that the nevertheless unsynchronised nature of TLPR devices, even in such cases, adverse aggregation effects may be considered unrealistic.

It should be further noted that it is expected that the majority proportion of TLPRs will actually be installed in tanks which are located indoors or at least in tanks located inside roofed industrial areas. Less than 10% of all tanks with an installed TLPR device are reckoned to be located in an outdoor environment.

Therefore, in addition to the shielding of the tank environment also the wall attenuation of the surrounding building can be taken into account in approximately 90% of all cases. However, due to the high shielding of the tank structures, the inclusion of an additional wall attenuation may be only of a minor consequence to the overall interference impact to other radio services. In order to underline the philosophy of worst-case simulations of TLPR interference, the wall attenuation is proposed not to be taken into account in the MCL calculations.

Likewise, no additional natural shielding should be considered in the MCL calculations of this ECCReport, i.e. all MCL calculations shall be performed for the worst-case of TLPR installed in a tank being placed outdoors, with line-of-sight (LOS) conditions and without any natural shielding. As a result, all calculated interference impacts represent the most conservative estimates, which in many real-life scenarios will be further reduced due to aforementioned natural and/or wall shielding.

2.2.7.6 Interference scenarios

The most common mounting scenario of a TLPR is by means of a flange or a screw-in fitting on a top of a tank with the antenna located inside the tank and pointing downwards towards the material to be measured (see Figure 50 or Figure 51). Generally, there are four sources of electromagnetic leakage which can be measured outside the tank (see ETSI EN 302 372 V2.1.1, annex G [7]).

a) Leakage from the TLPR enclosure including cabling and accessories. All leakage signals caused by this mechanism occur at frequencies well below the Radar frequency. They are usually covered by standard EMC tests.

b) Leakage of the Radar signal from a nonideally sealed mounting flange of the TLPR. Typically, this is the dominating part of the total leakage for the Radar frequency and its harmonics as there can be comparatively strong fields close to the antenna. If the flange gasket is not ideally sealed against electromagnetic radiation this leakage mechanism may occur.

c) Leakage through other flanges, sight glasses or screw-in fittings on the tank which are not properly sealed against electromagnetic leakage. The Radar signal will suffer from interreflection inside the tank especially in metallic tanks. It will additionally be scattered and, in the end, absorbed by the material inside the tank or the tank shell itself. Caused by this mechanism it is very likely that other tank openings, if present, can be a source of leakage. However, the bigger the tank the less leakage will in fact occur. This can be understood by a comparison of the areas of the flange gasket (as seen from inside the tank) with the total area of the inner tank shell.

d) Leakage through the tank wall. For a metal tank this effect is negligible as the attenuation through a metallic wall is nearly infinity. For a tank made of concrete, with or without reinforcement, the attenuation in the wall, according to experience, is incredibly high. This is explained by the thickness of the material and thus the high attenuation and in addition to that the natural moisture content inside the concrete.

According to experience with TLPR devices, the above-mentioned leakage mechanisms can be summarised in an overall frequency dependent mean tank shell attenuation. In order to conduct MCL calculations where the tank shell is considered as an additional attenuation it is proposed to use the extended building entry loss (BEL) model with probability P=0.5, an elevation angle of 0° and 100% thermally efficient buildings. This approach is considered to be very conservative having the above-mentioned installation requirements in mind and thus it follows the worst-case nature of MCL calculations.

The scenario of a tank located inside a building shall not be considered. For worst-case aggregation and probabilistic effects all tanks shall be located solely outdoors.

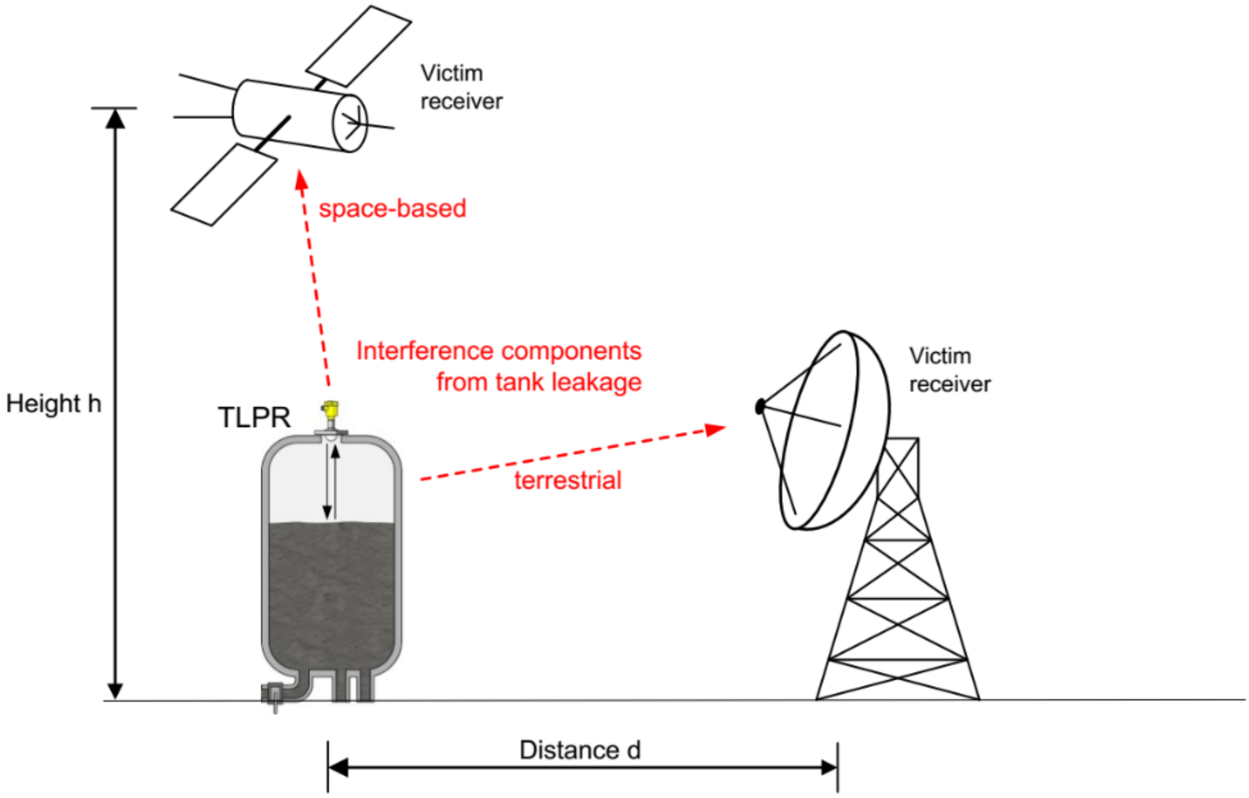


Figure 52: Worst-case interference scenarios for TLPR along horizontal terrestrial and space-based paths

Figure 52 shows the assumed worst-case scenario for tank level probing radars towards space-based and terrestrial victims.

For Fixed Service links however, dedicated interference scenarios have been developed describing a typical geometry where a Fixed Service transmitter attached to a light pole is linked to a receiver located on top of a building and vice versa (see Figure 53 and Figure 54).

In both cases it is assumed that the TLPR main beam points exactly towards the individual FS receiver. In these scenarios the interfering TLPR signal has to virtually penetrate the tank shell once and suffers therefore a particular attenuation (see section 2.3).

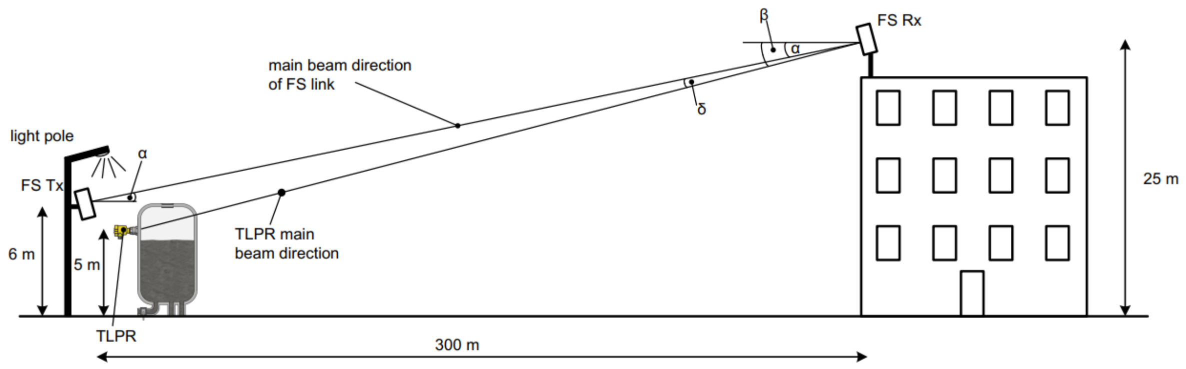


Figure 53: TLPR scenario 1: Light pole connected to a building by means of an FS link – FS Rx on building.

In the first scenario (see Figure 53), the TLPR device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. This constellation yields the smallest angle δ which describes the misalignment between the FS Rx main beam direction and the location of the TLPR device. The height above ground of the TLPR device mounted on a tank wall shall be 5 m. The angle δ becomes in the above example 0.19° which results in approximately 43 dBi antenna gain of the FS Rx antenna towards the TLPR interferer.

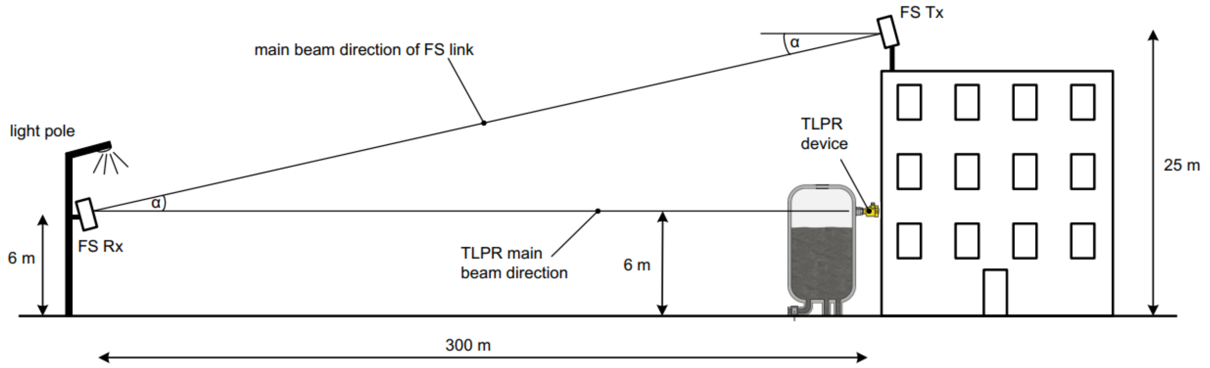


Figure 54: TLPR scenario 2: Light pole connected to a building by means of an FS link – FS Rx at light pole.

In the second scenario (see Figure 54), the FS Tx on the building rooftop is again connected to a receiver at a light pole. In contrast to the first scenario the locations of the FS Rx and the FS Tx are exchanged. The distance between the FS Rx and Tx is again 300 m. For the sake of simplicity, the TLPR device shall be mounted in 6 m height, which is the same height as for the FS Rx.

It should be noted that a TLPR device attached to the tank wall is not a typical use case but is a consequence of the used tank attenuation model. The vast majority of the TLPRs in the field will actually be mounted on top of the tank measuring in a downward direction in order to determine the level or the amount of the substance inside the tank. However, the above-mentioned mechanism to translate the four identified sources of electromagnetic leakage from a tank into an overall frequency dependent tank shell attenuation results in a mounting position of the TLPR as indicated in Figure 53 or Figure 54. In the context of a sharing or compatibility study this is considered to be equivalent to a TLPR mounting position on top of the tank radiating downwards and a source of leakage (e.g. a flange which is not properly sealed against electromagnetic leakage (see Figure 52)) at the vertical tank wall enabling an interference signal coming from the inside of the tank to reach the victim receiver on a line-of-sight path outside the tank.

A further consequence of the tank attenuation model is that in both scenarios only the interference component in main beam direction of the TLPR device is considered to be a potential source of interference. Other interference components e.g. through sidelobes are neglected.

Special conditions in aggregate interference scenarios

TLPR devices can be arbitrarily aligned in their individual measurement scenario (inside the tank). In aggregate interference scenarios, where many of these RDI devices can affect the victim, the usage of an average TLPR antenna gain of 10 dBi towards the victim receiver was therefore assumed.

2.2.8 Radiodetermination systems for industry automation in shielded environments (RDI-S)

2.2.8.1 Application scenario

Radiodetermination devices for industry automation in shielded environments are potentially used in many different applications. All RDI-S sensors have in common that they are mainly used in a professional industrial environment to sense the characteristics of target objects. Compared to other technologies radiodetermination is able to reliably work also in harsh production environments with an outstanding measurement accuracy. Compared to RDI devices, RDI-S devices are operated in a fully controlled environment that assures a high shielding level (similar to LPR and TLPR categories) to prevent interference with other spectrum users. Additionally, RDI-S systems are installed and operated by highly trained personnel only and are no consumer products. This ensures compliance with the device’s mounting and operation requirements given in the system manual.

The following list of categories gives a non-exhaustive insight of example applications where RDI-S sensors are used to detect or characterise objects (fixed and portable sensors):

1 Presence detection (objects/humans):
- Industrial surveillance radar;
- Microwave barrier sensing in automated backwater vessel;
- Object detection in harsh environments.

2 Precise distance measurement:
- Position measurement for equipment condition monitoring;
- Tube/pipe diameter/ovality measurement (metal/dielectric);
- Tube/pipe wall thickness measurement (dielectric);
- Sheet thickness/width measurement (metal/dielectric).

3 Velocity measurement (via Doppler or by consecutive distance measurements):
- Platform speed/velocity sensing;
- Production line speed/velocity sensing;
- Rotation speed sensing;
- Vibration measurement;
- Flow speed/velocity sensing (dielectric/metal).

4 Radiodetermination sensors for millimetre wave imaging:
- Radar imaging for quality assurance;
- Radar imaging of industrial platform surroundings for navigation/positioning.

The following example applications of potential RDI-S sensors are used for generic frequency response measurements (fixed and portable). The desired information of the target object or material is then extracted from the frequency response or measured transfer function:
- Object/field-of-view fingerprinting;
- Material roughness measurement;
- mmW transfer function characterisation (dielectric properties, material classification);
- Generic transfer function determination for different applications.

Most measurements in this list highly benefit from covering an extremely wide frequency bandwidth to achieve a good range resolution and high measurement precision. Spreading the transmit signal power over a very large bandwidth of e.g. 55 GHz with a relatively low transmit power also reduces the risk of interference with primary services significantly and ensures therefore an efficient use of spectrum. Due to the large covered bandwidth the systems are also very robust against interferences caused by other spectrum users.

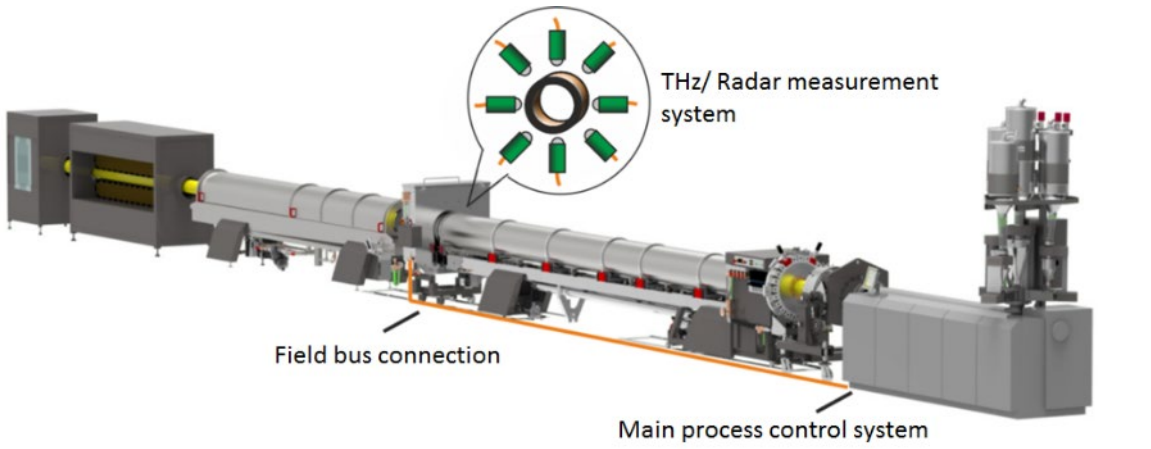


Figure 55: Extruder for plastic pipes with a shielded Radar thickness measurement system

One recently fast-growing category are RDI-S systems for plastic extrusion thickness measurement, like shown in Figure 55. In this application, it is often very beneficial to replace ultrasound-based thickness measurement systems that need water for coupling of the ultrasound signal into the pipe with non-contact high resolution radiodetermination devices. One or more radar sensors are mounted in a fixed position pointing towards the pipe or mechanically rotate around the pipe. A common modulation technology is FMCW or pulse radar with a very wide bandwidth and duty cycles up to 100% combined with short sweep times for fast inline testing. To measure thick pipes with black carbon (high absorption/attenuation) it is important to use radar systems with a sufficient output power. Thin pipes require a bandwidth as high as possible to allow separation of the inner and outer pipe wall reflection in signal processing. RDI-S systems for pipe measurement are designed to have a high level of shielding to prevent unwanted radiation of the wideband signals. There is no line-of-sight to victim receivers possible and the signal only leaves the enclosure after being scattered and attenuated several times. Some systems also use focused antenna beams that ensure radiation of high field strength only in areas where needed and the unwanted signals are scattered/attenuated in the enclosure

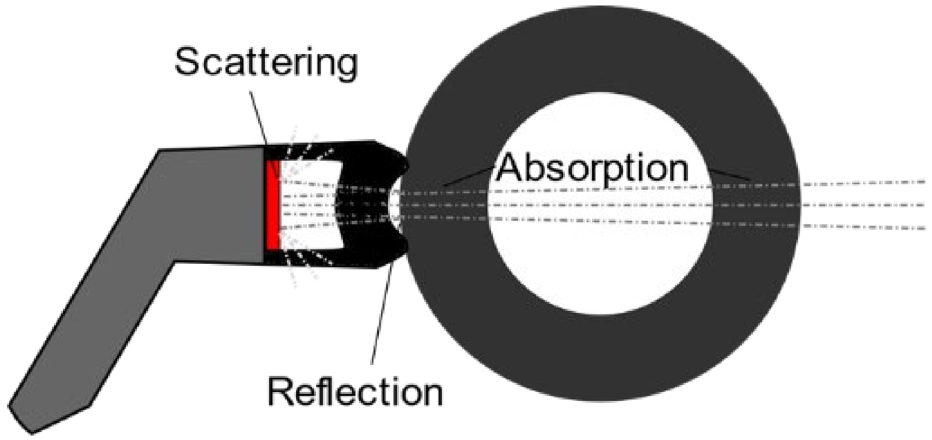


Figure 56: Portable pipe scanner

Figure 56 shows a portable pipe scanner in handheld version. Those systems are designed to allow non-inline testing of pipe diameter and thickness. A measurement is triggered by a push-button and the time between measurements can be limited. To ensure wide bandwidth operation only with a measurement object in front of the sensors the systems operate in dual mode. A material detection measurement in small-bandwidth RDI mode will be conducted first and the wide-bandwidth measurement in RDI-S mode will be triggered only if a measurement object is inside the beam to ensure no line-of-sight operation towards victim receivers

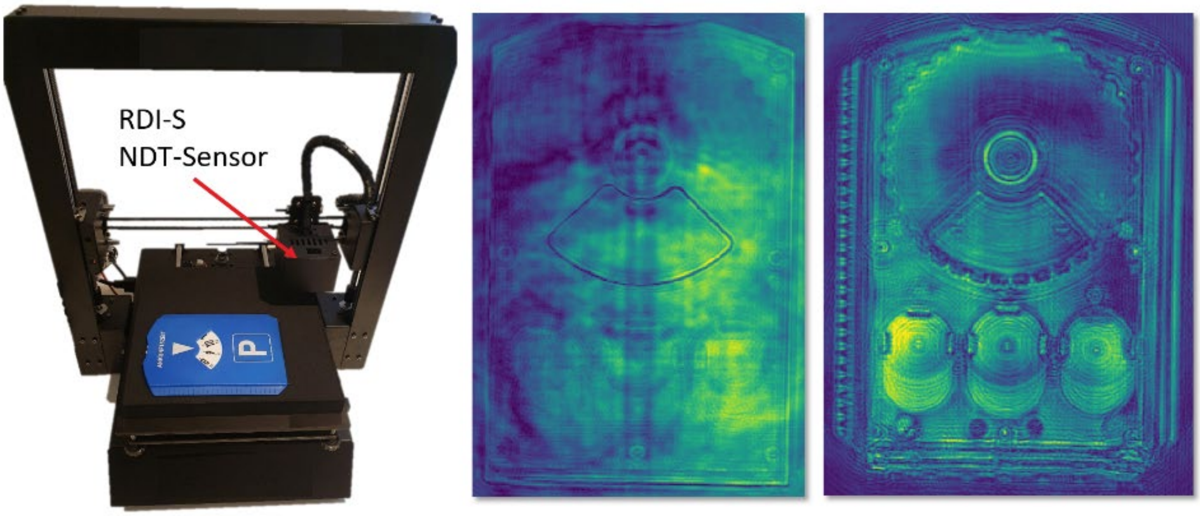


Figure 57: High resolution mmW non destructive testing (NDT) sample evaluated in slices at two different heights

Another important and emerging application is high resolution imaging, like shown in Figure 57. Those systems are used for 3D quality control of material samples. The resolution in X-Y direction is achieved by using focused beams pointing at the object or by synthetic aperture radar (SAR) focusing techniques. The example images shown are D-Band SAR images with 55 GHz bandwidth. The object is typically scanned with an open waveguide directed to the object and focusing is done in signal processing. A large bandwidth ensures a good resolution also in height, allowing slicing of objects in different height layers, as shown in the example SAR images in Figure 57.

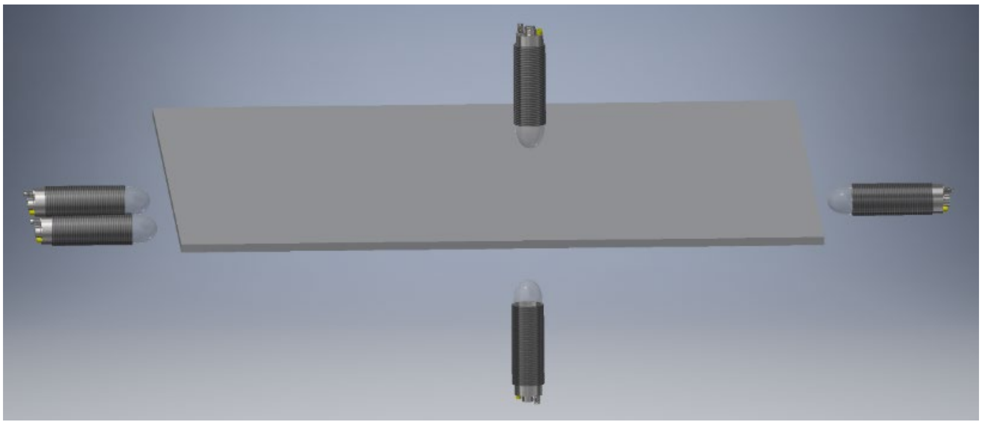


Figure 58: Steel sheet thickness measurement and other in-line sensors

Figure 58 shows RDI-S sensors for sheet thickness measurement and other inline sensing applications. For this purpose, the RDI-S sensors are integrated into or are installed close to production lines. One possible application is steel sheet thickness and width measurement. Here the wide bandwidth is needed for superior measurement precision also in harsh environments. The UWB operation allows to characterize/compensate dust coatings of antennas and targets for measurements with single digit micrometre precision. Compared to laser interferometers the innovative wideband radar technology is very beneficial due to its capability of absolute, one-shot multi-target measurements and robustness against dust and dirt due to the larger wavelength of the signals

2.2.8.2 Frequency ranges and application types

Radiodetermination systems for industry automation in shielded environments have been categorised as type C applications (see section 2.1). The following frequency range is proposed to be considered for this type of application (see Table 33):

- 116 GHz to 260 GHz.

2.2.8.3 Technical parameters

Table 30 gives an overview of the technical parameters of RDI-S devices which may be relevant for conducting the compatibility studies.

Table 30: Technical parameters of RDI-S type C devices for industry automation in shielded environments

Parameter	Value	Notes
Modulation scheme	Frequency Modulated Continuous Wave (FMCW)	
Operating frequency range (OFR)	116−260 GHz	
Available modulation bandwidth	144 GHz	
Used modulation bandwidth	35-144 GHz	-10 dB bandwidth aligned somewhere in the OFR
Sweep-time	10 µs to 15 ms	for a single frequency sweep over entire modulation bandwidth
Duty cycle	Max. 100%	Use of smaller values as an additional mitigation should be permitted
Conducted peak carrier power	up to -5 dBm	Maximum saturated output power at antenna feeding point
Conducted mean power	-5 dBm	with 100% duty cycle and -5 dBm peak carrier power
Conducted mean power spectral density	-50.44 dBm/MHz	with 35 GHz modulation bandwidth and -5 dBm mean power
Maximum mean power spectral density (e.i.r.p.)	-14.44 dBm/MHz	calculated with 36 dBi antenna gain (worst-case)

The modulation scheme of the RDI-S devices is similar to the LRP/TLPR modulation scheme in section 2.2.5.3. A single or multiple frequency ramps are transmitted within one measurement burst with duration T_{meas} between the frequency boundaries f_L and f_H. The used modulation bandwidth is consequently $f_H - f_L$. Between individual measurement bursts, during the time T_{off}, the transmitter may be switched off and no transmission occurs. The overall measurement cycle is denoted with $T_{meas_{cycle}}$. For some emerging applications it might be interesting to allow also more complex FMCW ramping schemes with different ramping directions, reconfigurable sweep-rates, frequency ranges and time durations. For this purpose, a regulation, based on a frequency dependent limit-mask, similar to the one given in ECC Decision (07)01 [26] would be perfectly suitable.

The duty cycle is the ratio of active measurement periods (bursts, sweeps, scans) within the overall repetitive measurement cycle, i.e. $T_{meas}/T_{meas_{cycle}}$, provided that these time durations are constant during the designated observation period T_{obs}. For determining the duty cycle, T_{obs} is usually a continuous one-hour period. Using a duty cycle mitigation is possible in many applications with slowly changing measurement environments. But especially the new and emerging applications often need 100% duty cycle to also monitor fast changing environments and e.g. also measure vibrations.

The following points give a short overview of typical application line speeds to justify the need for fast FMCW sweeps and a high measurement rate:

- For large pipes and pipes with high wall thickness the measurement application exhibits a typical extrusion speed of 60 cm per minute (0.01 m/s, compare section 2.5). Provided that the spot size of the radar on the pipe is 2 cm in diameter, it has to rotate around the pipe (medium pipe size of 50 cm diameter and a resulting circumference of 157 cm) with 0.5 Hz measurement rate to form an overlapping spiral on the pipe surface with the measurement spot of the RDI-S device. This results in a scanning speed on the pipe surface of 0.785 m/s and thus a sample spacing of 0.78 mm for 1 kHz measurement rate;

- For SAR imaging the Nyquist theorem in space has to be met to prevent aliasing, which leads to a minimum needed spacing of approximately 1 mm. The sampling requirement is hardly met for this application and even faster ramps (that are not easy to generate with 50 GHz to 100 GHz bandwidth) would be appreciated;
- Conclusion: 1 kHz is needed as a minimum sampling rate to allow for 100% quality testing of pipes;
- Many other applications like the SAR scanner used to acquire the parking disc image (see Figure 57) need this high measurement rate to finish the excessive mechanical meander scan of the object in an acceptable time;
- Many applications in the steel industry, packaging or logistics industry have typical fast line-speeds of the conveyor belts of 0.1 to 5 m/s, so here also a really short sweep time is needed to comply with the application demands.

The time duration of a single frequency ramp over the entire used modulation bandwidth depends on several technical aspects and considerations. This time span is expected to take values between 10 µs and 15 ms.

In order to achieve a sufficient radar resolution to cover the new applications and to allow robust high accuracy sensing [RDI-S] devices require a contiguous modulation bandwidth of up to 144 GHz. The boundaries of the proposed frequency range are derived from technical considerations and boundaries. A minimum bandwidth of 35 GHz is proposed to ensure an efficient use of the spectrum and keep the power density in the covered bands small.

The used antenna type highly depends on the applications. There are applications where high gain and pencil beam width antennas are needed, like e.g. precision distance measurements. Other application like non-destructive testing devices can also require focusing antennas or open-waveguide antennas for high resolution synthetic aperture focusing.

The available saturated output power depends strongly on the used semiconductor technology. For medium volume devices SiGe is the most interesting technology but GaAs is also an opportunity. With well-designed systems (especially for the receiver part) an output power of -5 dBm should be sufficient for most applications and detection ranges of up to 100 metres, having in mind that only indoor applications and applications in highly shielded environments are concerned.

2.2.8.4 Antenna data

The antenna characteristics of radiodetermination systems for industry automation in shielded environments (RDI-S) are identical to those applied with radiodetermination systems for industry automation (RDI) in the open air (refer to section 2.2.2.4).

2.2.8.5 Market size

ETSI TR 103 498 [1] does not give any figures for the market size for RDI-S devices. The applications are new and there is a significant market potential, but sales figures are at this early time difficult to predict. However, similar sales figures compared to LPR devices are used for the MCL calculations. This estimation should serve as a starting point but might turn out to be too optimistic.

The estimated numbers for the whole RDI-S market are given in Table 31. This rather rough estimation also considers a considerable growth within the first five years after market launch. Given the European land area of 10523000 km², this translates to the average density of 0.0076 RDI-S devices/km² in the band 116-260 GHz.

Table 31: Estimated sales figures and device densities of RDI-S devices in the band 116 GHz to 260 GHz

Parameter	Value
Worldwide accumulated number of RDI-S devices in the field 5 years after launch	200000
Fraction of RDI-S devices sold for the European market	40%
Accumulated number of RDI-S devices in the field in Europe 5 years after launch	80000
European land area	10523000 km²
Average density of RDI-S devices in Europe	0.0076 devices/km²

An additional re-assurance to the credibility of the provided estimates can be implemented by doubling the estimated mean device densities in Europe for the MCL calculations. This conservative overestimation emphasizes the worst-case approach of the compatibility studies.

It may be seen from the numbers given above, that the projected average density of RDI-S devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude certain cases, where multiple RDI-S devices could be used in very near proximity in an industrial plant for instance. But given the additional building shielding and the shielding case of the devices in addition to that the nevertheless unsynchronised nature of RDI-S devices, even in such cases, adverse aggregation effects may be considered unrealistic.

It should be further noted that it is expected that the majority proportion of RDI-S will actually be installed indoors and has special covers reducing the level of emissions outside the installation scenario.

However, in order to implement the philosophy of worst-case simulations of RDI-S interference, no additional natural shielding should be considered in the MCL calculations of this Report, i.e. all MCL calculations shall be performed for the worst-case of RDI-S devices being placed indoors with line-of-sight (LOS) conditions, taking into account a building entry loss (BEL) of 50 dB (refer to section 2.3) and without accounting for any additional natural shielding (As a result, all calculated interference probabilities represent the most conservative estimates, which in many real-life scenarios will be further reduced due to aforementioned natural shielding.

2.2.8.6 Interference scenarios

Due to the wide variety of RDI-S devices that need to be covered by regulation and to allow generic use of the devices in order not to limit industrial innovation for this emerging technology (improved production quality, safety, optimization of resource utilisation and production energy efficiency, …) an interference scenario as generic as possible should be used in this report.

The points that contribute to the interference probability on a victim receiver are:

- RDI-S device output power
- RDI-S duty cycle and sweep bandwidth
- RDI-S device antenna gain, antenna pattern and antenna type (pencil-beam antennas, focal-point antennas, open waveguide antennas)
- RDI-S device antenna orientation and shielding/scattering/reflexion attenuation (ensured by proper use/installation of the sensor)
- Building shielding (extended BEL model)

The first four points can be generally regulated by limiting the e.i.r.p. spectral density of the device on a half sphere around the scenario in a typical mounting situation at 100% duty cycle.

To keep things simple for MCL calculations a single RDI-S sensor without any additional application dependent attenuation is assessed. In a real-world scenario, there will always be an additional attenuation caused by the object that the device is pointed at (scattering/reflexion/transmission attenuation and antenna misalignment attenuation, assured by mounting requirements and intended use in the RDI-S's manual) or caused by RDI-S device housing. Because of the wide variety of different application types, a one-fits-all value is hard to find, and this attenuation should not be considered in the generic worst-case MCL calculation. However, this circumstance has to be kept in mind when the interference scenario is evaluated. The use of unjustified constructed worst-case interference scenarios that do not exist in real-world needs to be avoided and further, the MCL calculation should be conducted in a technology independent way. Otherwise this would inevitably lead to technically unnecessary burden for an innovative radiodetermination technology and would stand against an efficient use of spectrum.

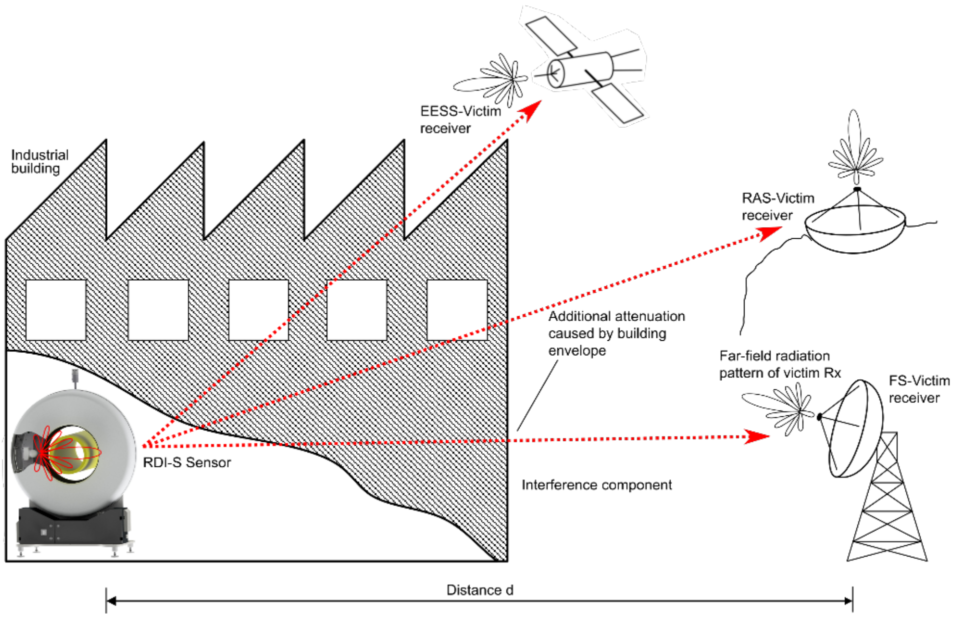


Figure 59: Interference scenario for RDI-S sensors

The selected generic interference scenario for RDI-S devices is similar to the scenario described for TLPR devices (see section 2.2.7.6) because of the similar nature of both systems and operation in highly controlled and shielded industrial environments. In contrast to taking into account the shielding of the metallic tank in the case of TLPR, here the building entry loss (BEL) is included to account for the building shielding effects The used indoor-outdoor attenuation for buildings is based on all the relevant loss mechanisms that arise in a typical RDI-S operation. These include building entry loss, mounting restrictions, and typical operation of these devices. Any additional device specific shielding (see section 2.3.2), e.g. housing shielding, has not been accounted for in the MCL studies and aggregate studies. Figure 59 shows a typical interference scenario of RDI-S devices for terrestrial and space-based victim services.

In Annex 1, an extension of the ITU-R P.2109-1 [23] BEL model for frequencies up to 300 GHz is described and building material measurements are provided to support the suggested BEL values. In the MCL calculations an assumed BEL attenuation of 50 dB is used. The appropriateness of this value is explained and justified in section 2.3.

For Fixed Service links dedicated interference scenarios have been developed in a unique geometry. They are illustrated in Figure 60 and Figure 61. These typical situations can occur in environments where e.g. a Fixed Service transmitter attached to a light pole is linked with a receiver located on top of a building and vice versa (see Table 40). In both cases it is assumed that the RDI-S main beam points exactly towards the individual FS receiver. However, as RDI-S devices are only operated indoors or in similar shielded environments, the interference signal has to penetrate the building envelope once and suffers therefore an additional attenuation (named building entry loss, BEL) (see section 2.3).

Both scenarios are defined according to the application of radiodetermination of industry automation (RDI) illustrated in Figure 12 and Figure 13 in the Report but with considering the additional circumstance of being operated indoors only.

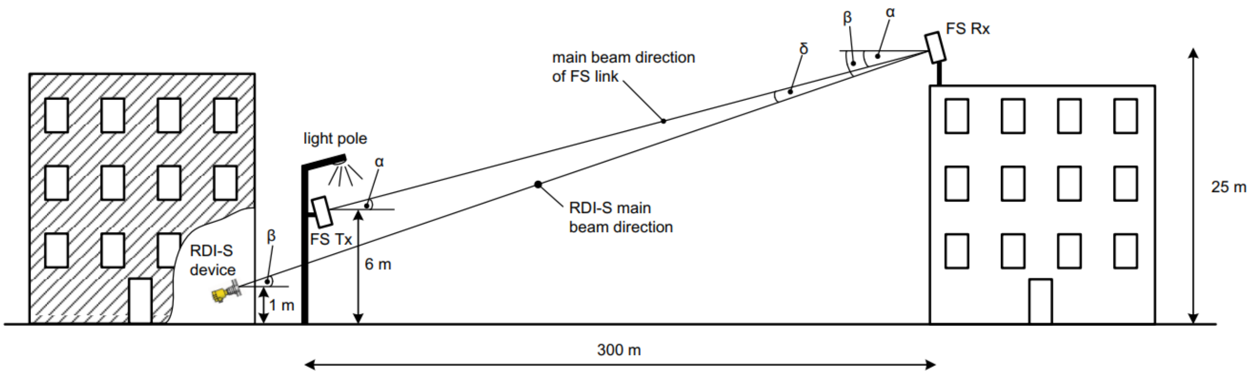


Figure 60: RDI-S scenario 1: Light pole connected to a building by means of an FS link – FS Rx on building.

In the first scenario (see Figure 60), the RDI-S device is placed at the location of the FS Tx, thus in 300 m distance from the FS Rx. This constellation yields the smallest angle δ which describes the misalignment between the FS Rx main beam direction and the RDI-S device. The height of the RDI-S device above ground shall be 1 m which is similar to the RDI application (see section 2.2.2.6). The angle δ becomes in the above example approximately 0.95° which results in approximately 38 dBi antenna gain of the FS Rx towards the RDI-S interferer.

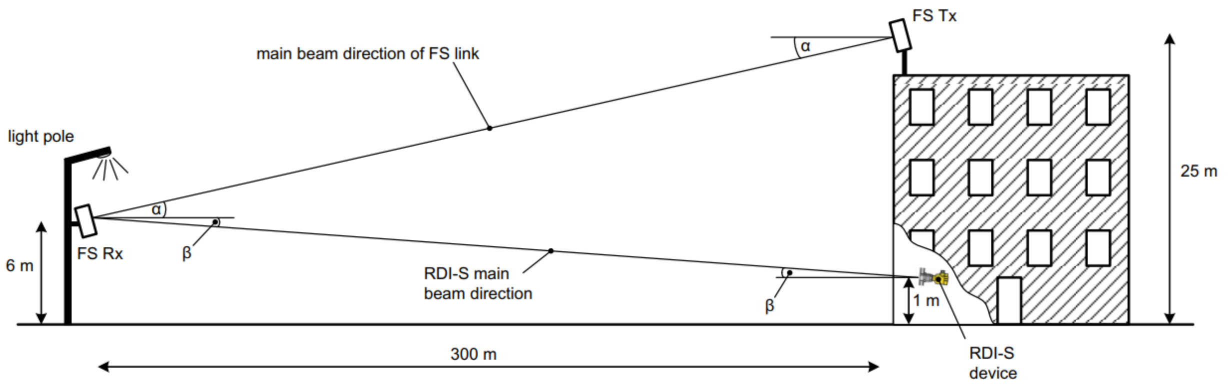


Figure 61: RDI-S scenario 2: Streetlamp post connected to a building by means of an FS link – FS Rx on building.

In the second scenario (see Figure 61), the building rooftop is again connected to a light pole. In contrast to the first scenario, the locations of the FS Rx and the FS Tx are exchanged. The distance between the FS Rx and Tx is again 300 m and also the separation distance between the RDI-S device and the FS Rx is again 300 m resulting in an angle α+β which describes the misalignment between the FS Rx direction of main radiation and the location of the RDI-S device.

In both scenarios only the interference component in main beam direction of the RDI-S device is considered to be a potential source of interference. Other interference components e.g. through sidelobes are neglected.

Special conditions in aggregate interference scenarios

RDI-S devices can be almost arbitrarily aligned in their measurement scenario. In aggregate interference scenarios, where several of these RDI-S devices can affect the victim, the usage of an average RDI antenna gain of 10 dBi towards the victim receiver was therefore assumed.

2.3 INDOOR-OUTDOOR ATTENUATION FOR APPLICATIONS OPERATED IN SHIELDED ENVIRONMENTS

2.3.1 Summary

In section 2.2 there are applications listed which are only operated indoors or in other shielded environments. Depending on the deployment scenario of the specific application and the shielding nature of the enclosure, in which the device is operated, different shielding losses have been defined. The defined indoor-outdoor attenuations for the different natures of applications are summarised in Table 32.

Table 32: Summary of defined indoor-outdoor attenuations/shielding losses for the different applications covered in this Report for both single-entry and aggregate interference scenarios

<table>
<tr><th>Application</th><th>Nature of application concerning shielding</th><th>Indoor-outdoor attenuation/shielding loss definition for single-entry interference scenarios</th><th>Indoor-outdoor attenuation/shielding loss definition for aggregate interference scenarios</th></tr>
<tr><td>RDI-S</td><td>Professional indoor device with installation requirements (main beam pointing to windows is prohibited)</td><td>50 dB</td><td>BEL, BEL correction, clutter loss, polarisation loss according to Figure 62
plus
potential technical condition for additional shielding</td></tr>
<tr><td>LPR, CDR</td><td>Professional device with installation requirements (main beam is downwards oriented)</td><td>0 dB (device considered outdoors for the single-entry study)</td><td>BEL, BEL correction, clutter loss, polarisation loss according to Figure 62
plus
potential technical condition for additional shielding (only applicable for the portion of devices located indoors)</td></tr>
<tr><td>TLPR</td><td>Device operated inside metallic or concrete tanks with installation requirements (e.g. openings and windows are prohibited, sight glasses must be covered (see ETSI EN 302 372 V2.1.1, annex E [7])</td><td colspan="2">Extended BEL model for 100% efficient buildings, p=0.5 (median), 0° incidence angle</td></tr>
<tr><td>Generic indoor surveillance radar</td><td>Indoor devices with no installation requirements</td><td>0 to 16 dB depending on the interference scenario</td><td>BEL, BEL correction, clutter loss, polarisation loss according to Figure 62</td></tr>
<tr><td>RDI, Short-range assist (car radar), GBSAR</td><td>Outdoor devices</td><td colspan="2">0 dB</td></tr>
</table>

2.3.2 Indoor-outdoor attenuation for aggregate interference scenarios

For devices operated inside buildings or inside other similar shielded environments without further installation requirements (e.g. generic indoor surveillance radar) an indoor-outdoor attenuation derived from the following independent components has been derived:

- Averaged elevation angle dependent building entry loss (BEL) model according to Recommendation ITU-R P.2109-1 [23] at a frequency of 100 GHz (see Annex 1);

  Note: The model described in Recommendation ITU-R P.2109-1 is valid for an omnidirectional antenna inside the building and is only defined up to a frequency of 100 GHz. Therefore, in this Report the BEL components have been evaluated at this highest valid frequency. Nevertheless, it has to be kept in mind that the BEL in the range from 116 GHz to 260 GHz is expected to be higher;
- BEL model correction factor for antenna beamwidths <10° according to Recommendation ITU-R P.2109-1.

  Note: In Recommendation ITU-R P.2109-1, which contains a model for the prediction of the building entry loss, it is assumed that directive antennas can act as a spatial filter. By means of antennas with 10° beamwidth, a 5.3 dB higher BEL was measured in a campaign conducted in Korea on a frequency of 32 GHz compared to the standard model defined in ITU-R P.2109-1. Due to the lack of data for the considered frequency range from 116 to 260 GHz no correction has been used for determining the indoor-outdoor attenuation for aggregate interference scenarios in this Report. However, it should be kept in mind that the spatial filtering will also occur in the range 116 to 260 GHz when using high directive antennas. Consequently, the non-consideration of this correction can be interpreted as an additional safety margin for the protection of other spectrum users;
- Averaged elevation dependent clutter loss model according to Recommendation ITU-R P.2108-0 section 3.3 for a frequency of 100 GHz;
- Average polarisation loss of 3 dB, except for FS since the FS links in these bands are expected to be dual-polarised;
- A weighted distribution of 70% traditional and 30% thermally efficient buildings is assumed. This assumption is founded on the evaluation of the thermal efficiency of building window types across Europe (see Annex 6).

Figure 62 shows the calculation scheme of the total indoor-outdoor attenuation of generic indoor devices without specific installation requirements in aggregate scenarios.

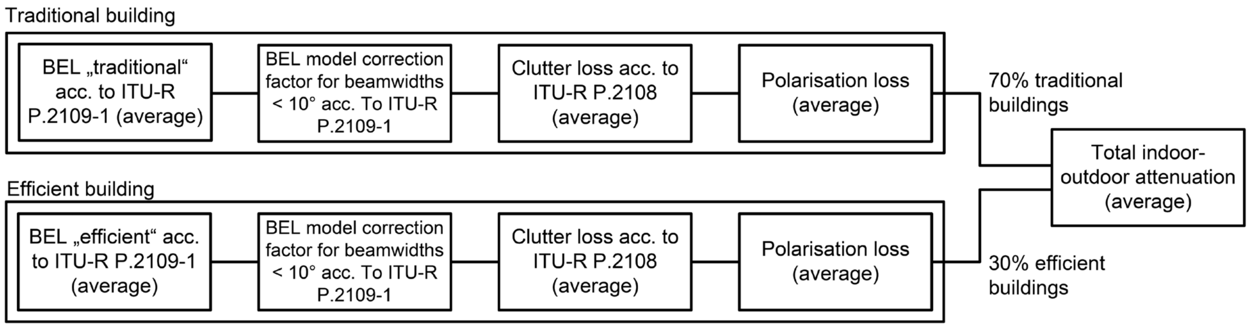


Figure 62: Calculation scheme of the total indoor-outdoor attenuation for generic indoor devices in aggregate scenarios.

For devices operated inside buildings or inside other similar shielded environments which are imposed with additional installation requirements so that it can be ensured that the main beam direction is not pointing towards windows (e.g. RDI-S, LPR, CDR), an optional additional shielding loss can be considered in aggregate scenarios which could be rooted in:

- Reflection and transmission losses when there is the measurement object or other shielding objects in the main beam;
- An inherent device shielding (e.g. an additional enclosure around the sensor installation).

This optional additional shielding loss, if needed in order to maintain sharing/compatibility without harmful interference, is proposed to be treated as a technical condition that the individual application or device shall comply with.

For devices operated inside highly shielded metallic or concrete tanks (e.g. TLPR) and additionally imposed with certain installation requirements (see ETSI EN 302 372 V2.1.1, annex G [7]) a high shielding loss can be expected. However, measurements have not been conducted for this very specific case. The overall indoor-outdoor attenuation is derived from the extended BEL model according to Recommendation ITU-R P.2109-1 with probability p=0.5, an elevation angle of 0° and 100% thermally efficient buildings (Annex 1).

For devices operated outdoors (e.g. RDI, GBSAR or short-range assist and surrounding monitoring for vehicles and autonomous systems) consequently no indoor-outdoor attenuation can be taken into account.

2.3.3 Indoor-outdoor attenuation for single-entry interference scenarios

For devices operated inside buildings or inside other similar environments without further installation requirements (e.g. generic indoor surveillance radar) an overall indoor-outdoor attenuation between 0 dB and 16 dB was assumed depending on the used interference scenario.

For devices operated inside buildings or inside other similar shielded environments which are imposed with additional installation requirements so that it can be ensured that the main beam direction is not pointing towards windows, identified as the weakest parts of a building structure in terms of signal attenuation, a lump sum shielding loss of 50 dB has been defined. This is applicable especially to RDI-S devices. LPR and CDR installations are considered as pure outdoor devices in single-entry studies with consequently no indoor-outdoor attenuation.

The above determined indoor-outdoor attenuations for buildings are supported by the provided brick material measurements (Annex 2) which represent the energy efficient building type. All transmission attenuation measurements of even thin building material samples (concrete, AAC, brick, wooden materials like multiple layers of beech-multiplex boards and even 3-layer insulation glass) show an attenuation of at least 60 dB in the measured frequency range (refer to the measurement results in Annex 2). In real world scenarios an even higher shielding loss is therefore expected.

For devices operated inside highly shielded metallic or concrete tanks (e.g. TLPR) and additionally imposed with certain installation requirements (see ETSI EN 302 372 V2.1.1, annex G [7]) a high shielding loss can be expected. However, measurements have not been conducted for this very specific case. The overall indoor-outdoor attenuation is derived from the extended BEL model according to Recommendation ITU-R P.2109-1 [23] with probability p=0.5, an elevation angle of 0° and 100% thermally efficient buildings (Annex 1). This approach applies to single-entry scenarios as well as also for aggregate interference scenarios (see section 2.3.2).

2.4 SHARING AND COMPATIBILITY STUDIES BETWEEN RDI-S AND SERVICES OPERATING IN PASSIVE BANDS LISTED IN ITU RR FN 5.340

Note: The sections 2.4 and 2.5 contain the technical justifications of the industry as requested by the 52nd ECC meeting (see item 4 in section 2.4.1), for the wide bandwidth need and why notching out the bands identified by RR FN 5.340 is not possible.

2.4.1 Background information

ITU Radio Regulations [71] Footnote (FN) 5.340 is applicable for portions of the band studied in this Report (e.g. for RDI-S devices). During the studies there was a controversial discussion, if the sharing and compatibility studies may be allowed to be carried out in these passive bands protected by RRs. This report focuses on the purely technical studies in terms of sharing and compatibility. The relevant information to follow the discussion on ECC level are given in the minutes of the 52nd ECC meeting in section 11.4.

ECC decided that the studies should continue as foreseen under the following conditions:

1. The studies on this very specific type of application (in particular very low number of devices) shall not be understood as precedence for general allowance for studies in bands covered by ITU RR-5.340.

2 There shall be no widening of the studies beyond the specific limited type of applications, meaning UWB radiodetermination applications Type C (according to SRdoc ETSI TR 103 498 [1]).

3 The usage scenario for those UWB radiodetermination applications Type C, which target bands listed in RR 5.340, shall be maintained to professional indoor applications (in shielded industrial environments) limited in numbers.

4 The studies shall also consider the technical justification for the wide bandwidth as required in the ETSI SRdoc and why notching out the bands identified by RR 5.340 is not possible. This shall not delay the ongoing compatibility and sharing studies.

5 After technical studies will have been undertaken in WG SE, WG FM will reassess these conditions before deciding on next steps.

2.4.2 RDI-S application description and device number limitation

SRdoc ETSI TR 103 498 defines type C applications as: “Applications emitting inside a confined and shielded environment or a housing”. The only application types in this Report that fit into this category are TLPR and RDI-S devices. But for RDI-S devices there is a physical need (see section 2.4.3.3) to use a large contiguous bandwidth to achieve a certain level of performance. RDI-S devices are the only device type that is identified in this Report as a type C application with a potential need to use the RR FN 5.340 protected bands for certain applications inside highly shielded environments. If in future any other application claims the type C device class its risk of interference has to be carefully reviewed and again separately evaluated on a case-by-case basis without referring to the RDI-S device class as a precedent. Minimum radiation is intended to be emitted outside the shielded environment for this type of application.

RDI-S devices are used in professional UWB radiodetermination applications and are only intended for use in highly shielded industrial environments (see section 2.3). Industrial environments are – compared to consumer applications – a highly controllable area, where many special rules apply, and mounting requirements and the intended use of devices are strictly respected. Companies selling RDI-S equipment have their own highly trained professional integration teams, since integration of for example a pipe wall thickness scanner or RDI-S device integration into a steel production factory is a complex task and needs a lot of specialised expertise in terms of EMC knowledge, radar knowledge and so on. Respecting installation requirements and intended use of the devices will not be an issue in this very limited and controlled application field and will be guaranteed by the operator and the commissioning experts of the RDI-S device. Professional industrial users are liable for the equipment they operate and thus have a special interest in compliance with existing laws and rules.

The number of RDI-S devices is estimated to around 80000 in Europe for the purpose of MCL calculations. This is a very conservative estimate, because wideband RDI-S devices will be mainly used in special niche markets, like e.g. thin dielectric layer thickness measurement or micrometre precision positioning, where their high performance is essential and needed to fulfil the measurement task. Achieving the wide bandwidth instantly comes with significantly higher sensor cost, due to the demand for expensive precision-milled mechanical or PCB based wideband waveguide parts. Additionally, the signal processing chain hardware requirements in terms of bandwidth and sample- or data-rate are much higher and cost-intensive for wideband radar sensor hardware.

The resulting significantly higher cost for wideband sensors will automatically prevent the sensor from getting into the mass market. In many applications low-cost sensors with a still acceptable performance based on the lower bandwidth RDI device class will be sufficient. Those sensors will be automatically used due to the significant lower cost of small bandwidth transitions and antennas, resulting in more cost-efficient sensor designs compared to RDI-S devices. Consequently, the majority of devices in the market will be cost-effective RDI sensors and only where needed due to application performance requirements, RDI-S sensors based on more expensive wideband-technology will be used. This results in a natural limitation of the overall number of RDI-S devices in the market.

2.4.3 RDI-S justification of frequency range and contiguous wide bandwidth needs

2.4.3.1 General considerations

It is acknowledged that keeping the RR FN 5.340 passive bands clean from harmful interference is fundamental for the passive band services like radio astronomy or passive remote sensing satellite applications. Some industrial devices and applications consider a strong need for covering large continuous regions of the spectrum to enable new and innovative applications. This need is based on the fact that radiodetermination applications – as the name already implies – uses the information of the propagation properties of radio waves to determine the position, velocity and/or other characteristics of an object, or obtaining information related to these parameters. This can of course be done in different frequency regions. In the following sections a justification is given why the use of the D-Band (110 to 170 GHz) and above frequency ranges, in combination with a large continuous bandwidth, is essential for RDI-S devices.

2.4.3.2 Need for considered frequency range

Especially, the frequency range 116-190 GHz shows a strong potential for industrial application, because it is a technological sweet spot for high precision radiodetermination applications.

From the technological point of view, the frequency range between 116 and 190 GHz is very interesting, because modern SiGe semiconductor technologies allow in these bands a still exceptional good performance, whilst providing still a good robustness against environmental challenges like dirt/dust on antennas. Designs based on half frequency VCOs and Gilbert or push-push frequency doublers allow a sufficient output power generation for short-range devices and the noise figures of SiGe technology circuits are still good, while still having suitable compression points and small signal gain in the Rx stages. Additionally, the frequency range is still suitable for wideband bond-wire connection between chips and PCB structures. Unwanted lower fundamental signals can easily be blocked by the high-pass nature of waveguide structures that are in a size that can still be manufactured at reasonable cost to provide a clean and efficient output spectrum. The wavelength allows manufacturing of high-gain antennas relatively small in size for even small sensors.

The higher frequency range above 200 GHz has the advantage that patch antennas can directly be integrated on-chip [63] but this leads to the disadvantage that the fundamental oscillator emissions are hard to filter and are thus also radiated, causing additional interference risk in the spurious domain. Waveguides are very hard to manufacture in the frequency range above 200 GHz and bond-wires for chip to waveguide transitions have an extensive inductive behaviour and do not work anymore. This is especially a disadvantage for wide bandwidth sensors, because other structures like patch antennas are very bandwidth-limited, but do not properly filter unwanted signals, especially if used in combination with dielectric lenses. On-chip patch antennas in comparison to waveguide-based antenna feeding concepts often show a disadvantage in achieving a precise beam alignment, when used together with dielectric lens antennas, due to alignment difficulties. Additionally, systems operating above 200 GHz are approaching the THz gap and are very limited in performance or can only be realised by using very expensive hand-picked III-V semiconductor chips. This might be suitable for high performance measurement equipment like network analysers but is too expensive for industrial sensors.

Another disadvantage of the higher frequency bands are the much higher losses. Especially for the plastic sheet thickness measurement system, often plastics, with a large portion of carbon black or other highly lossy material layers, have to be measured. The higher frequencies would combine in this case a degraded SNR because of the technology limitations with a higher loss of the material in the application, which leads to the result that many materials cannot be measured anymore.

Considering the BEL model, which is used throughout this Report, the propagation and shielding losses increase with higher frequencies. This could be considered as a big advantage for the higher frequency ranges. The propagation through buildings is almost line-of-sight-only. Compared to the frequencies below 100 GHz where still a significant transmission through building materials occurs the high shielding loss can much easier be guaranteed. In the single-entry calculations of this Report a very conservative shielding loss lump sum value of 50 dB is used for RDI-S (compare section 2.3 and ECC Report 190 [21], where a shielding-loss value of > 60 dB is used for indoor/outdoor attenuation at 122 GHz).

Consideration of lower frequency ranges for this application is also not an option. The frequency range below 116 GHz is already widely used, the large wavelength has disadvantages in terms of antenna size and achievable antenna spot size, and this frequency range does not offer the possibility for new large bandwidth applications anymore because of many radio services and applications and the reduced shielding losses in this frequency range. Also, the achievable absolute bandwidth is smaller at lower operating frequencies assuming the same relative bandwidth.

Additionally, the widest frequency range window without the need to sweep over a ITU RR 5.340 FN band is located at 116 GHz to 148.5 GHz, which is unfortunately still too narrow to meet the requirements of industrial RDI-S applications, but is a good starting point. A bandwidth of 50 GHz as the current and urgent industrial need is in line with ETSI TR 103 498 [1] and the sentence that "In order to measure plastic workpieces down to a thickness of only a few millimetres, a bandwidth of 25 GHz or higher is required." This value of 25 GHz was derived from a radar system operating at 80 GHz. Technology at 116-190 GHz allows a doubled bandwidth, which is needed to also resolve pipes with a small wall thickness. The ability to also measure pipes with a small wall thickness is an important key factor for successful integration of the RDI-S technology into the market.

2.4.3.3 Need for contiguous wide bandwidth

RDI-S applications are high precision radiodetermination applications that can be compared to network analyser measurements for industrial applications with a high measurement rate. The RDI-S category shall be limited to applications with an inherent need to cover a large bandwidth like e.g. high precision measurements, high resolution measurements or material property measurements. Consequently, simple devices like e.g. presence detection switches shall not be allowed to be operated as RDI-S devices. Similar to network analyser systems those devices measure the frequency response over a large portion of bandwidth by means of amplitude and phase. From this transfer function the measurement signal is derived by complex mathematical model comparison or other signal processing techniques. Similar to laboratory network analyser applications for e.g. imaging, material measurements, and many more, covering a large bandwidth and thus determining a large part of the transfer function of the object $H(j\omega)$, is essential to deduce a high quality measurement result in combination with high spatial resolution. In contrast to systems based on operation in distinct frequency channels, like communication devices, that can easily exclude the ITU RR FN 5.340 bands by technical measures (e.g. filtering/notching, channel arrangements), RDI-S devices cannot work around these bands, because they need to acquire a continuous phase information and need to sense the object's physical characteristics over the entire continuous spectrum interval. Applications that directly benefit from covering a large bandwidth are:

High resolution imaging or material property determination of objects with e.g. SAR or real aperture focusing techniques. In this application the X-Y direction resolution depends on the aperture and resolutions of 1mm are easily achieved in this frequency range. However, the resolution Δr in Z direction is proportional to $\Delta r = \frac{c \cdot c_w}{2B \cdot (n)}$, where B is the bandwidth covered by the FMCW sweep signal, c the wave's propagation speed in air, and c_w a factor describing the influence of the window function [67]. Inside a material the propagation speed is reduced by the refractive index n, resulting in a better resolution compared to free space propagation with n=1. To get close to a uniform resolution cell, preferably a -3 dB bandwidth of 100 GHz is needed, and at least, covering 50 GHz of bandwidth is essential to achieve a suitable range resolution to distinguish between different material layers for a large number of materials. A bandwidth of 50 GHz allows, depending on the material permittivity, a resolution of pipe wall thicknesses of down to 2 to 2.5 mm. With a bandwidth of 100 GHz the systems are getting close to 1 mm wall thickness. The 2 to 2.5 mm wall thickness is an essential threshold to enable the RDI-S devices to be used in the very important market of combined and multilayer material pipes, because the used material thickness combined with the material permittivity of a large number of pipe products in this field can only be measured with a minimum bandwidth of 50 GHz. Achieving only 32.5 GHz of bandwidth would lead to a drastically reduced application field and thus a drastically reduced profitability of RDI-S devices. Furthermore, many production lines that cannot be equipped with radar technology control loops to improve product quality and raw material utilisation are wasting important resources like plastics, energy and thus carbon dioxide day by day. For this application also a high measurement rate is essential to meet the Nyquist criterion in space, while recording the measurement data.

Figure 63 shows an example to justify the argumentation above. A synthetic aperture radar image of a parking disk as a representative thin multi-layer is measured with 32.5 and 55 GHz bandwidth. The X and Y axis resolution remains the same, as this depends on the used frequency range and the aperture. But in Z axis the resolution depends on the radar bandwidth. This results in degraded imaging quality, because reflections of other layers are folding into the layer of interest and reduce image quality. The rotating disc inside of the object is for example much better visible with the wider bandwidth. Reduced image quality can especially not be tolerated, if small defects need to be detected or if automated inspection of the images is desired. The 55 GHz bandwidth SAR image even allows to almost resolve the “Arrival time” marking, which is completely hidden in the reduced bandwidth image.

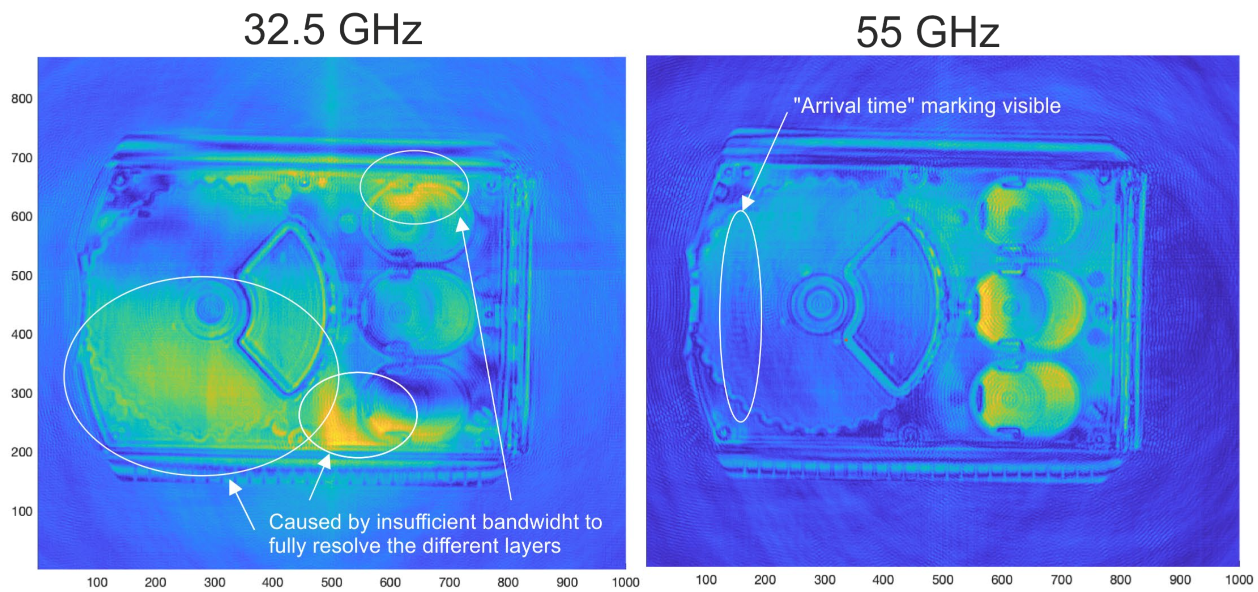


Figure 63: Bandwidth comparison (32.5 GHz and 55 GHz modulation bandwidth) for thin layer SAR-image (n is unknown, Tukey window function).

Thickness and material measurements and object classification are other very important application classes, where covering a large bandwidth is essential. From the measured object’s transfer function $H(j\omega)$ and a signal model according to the Fabry–Pérot interferometer concept (see Wikipedia for a detailed description) the material parameter in terms of complex permittivity or the thickness are derived. For object classification, the measured transfer function is fed into a previously trained machine learning model or is compared to an analytical model. For all these applications covering a bandwidth as large as possible is needed, because it limits the range resolution. If the covered bandwidth is too small, the detection of fine object details or thin layers, as is needed by the pipe measurement industry, become undetectable. Here a bandwidth of at least 50 GHz is required to meet the applications’ requirements for thickness measurements up to 2 mm and to cover a large range of applications. Reducing the bandwidth to only 32.5 GHz and thus the resolution by 35% would lead to a limited application range that will prevent radar technology from being used in this field for many common pipe thicknesses thinner than 3 mm. Especially for thin pipes every additional GHz of bandwidth and improvement in resolution is important to broaden the application field. For this application a high measurement rate is needed (compare section 2.2.8.3), and the measurement range must not have notched out parts.

Reasons for a large bandwidth – example of plastic measurements

Plastic pipes are used in a huge range of products as different kind of infrastructural pipes (e.g. gas pipes, drinking water, wastewater, cable protection, etc.) or blow moulding parts (consumer products, automotive parts). This market seeks for a cost effective, easy, and harmless inline measurement technique for quality control and process optimization and automation. Manual destructive measurement methods are out of time and shall be replaced by non-destructive methods.

The radar technology is a very promising technique to fill that gap of measurement technology. However, to reach the necessary wall thickness resolution a high bandwidth is necessary as the possible resolution is anti-proportional to the bandwidth BW (resolution~1/BW).

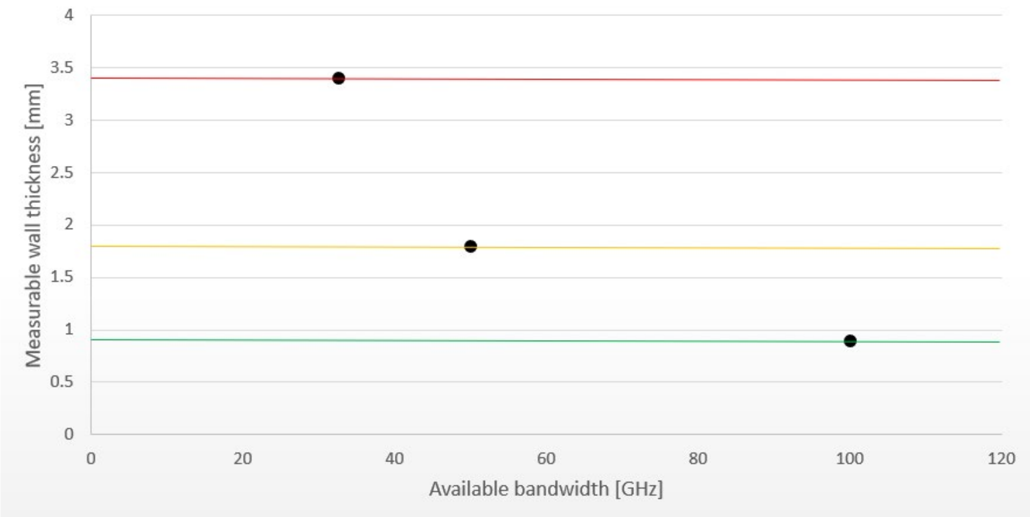


Figure 64: Measurable wall thickness for 32.5 GHz, 50 GHz, and 100 GHz, respectively (n=1.5, rectangular window function, evaluated with Fabry–Pérot principle)

	Water supply pipes out of PE 100 after DIN EN 1555-2/DIN EN 12201-2									Gas pipes	
	SDR										
d	41	33	26	21	17	13.6	11	9	7.4	17	11
16								2	2.3	2.3	3
20							2	2.3	3	2.3	3
25						2	2.3	3	3.5	2.3	3
32					2	2.4	3	3.6	4.4	2.3	3
40				2	2.4	3	3.7	4.5	5.5	2.4	3.7
50			2	2.4	3	3.7	4.6	5.6	6.9	3	4.6
63			2.5	3	3.8	4.7	5.8	7.1	8.6	3.8	5.8
75			2.9	3.6	4.5	5.6	6.8	8.4	10.3	4.5	6.8
90			3.5	4.3	5.4	6.7	8.2	10.1	12.3	5.4	8.2
110			4.2	5.3	6.6	8.1	10	12.3	15.1	6.6	10
125			4.8	6	7.4	9.2	11.4	14	17.1	7.4	11.4
140			5.4	6.7	8.3	10.3	12.7	15.7	19.2	8.3	12.7
160			6.2	7.7	9.5	11.8	14.6	17.9	21.9	9.5	14.6
180			6.9	8.6	10.7	13.3	16.4	20.1	24.6	10.7	16.4
200			7.7	9.6	11.9	14.7	18.2	22.4	27.4	11.9	18.2
225			8.6	10.8	13.4	16.6	20.5	25.2	30.8	13.4	20.5
250			9.6	11.9	14.8	18.4	22.7	27.9	34.2	14.8	22.7
280			10.7	13.4	16.6	20.6	25.4	31.3	38.3	16.6	25.4
315	7.7	9.7	12.1	15	18.7	23.2	28.6	35.2	43.1	18.7	28.6
355	8.7	10.9	13.6	16.9	21.1	26.1	32.2	39.7	48.5	21.1	32.3

Figure 65: Water and gas supply pipe types (diameter d and corresponding wall thicknesses) belong to a certain pressure class (SDR class). Red marked area belongs to 32.5 GHz scenario and yellow marked area belongs to 50 GHz bandwidth scenario (additional measurable product classes, assumed n=1.5, rectangular window function, evaluated with Fabry–Pérot principle). With the 50 GHz scenario the large market of building infrastructure becomes available

Figure 64 shows this behaviour for three different bandwidth scenarios as currently under discussion. The following points demonstrate which kind of pipes and markets become available when bandwidth reaches 32.5, 50 and 100 GHz, respectively.

<u>Scenario 1: 32.5 GHz bandwidth (red line in Figure 64):</u>

- Infrastructural pipes (e.g. water and gas) for wide range distribution become measurable (compare Figure 65);
- This scenario covers pipe wall thickness measurements above 3 mm.

<u>Scenario 2: 50 GHz bandwidth (yellow line Figure 64);</u>

- Infrastructural pipes for wide range distribution become measurable (compare Figure 65);
- Large market of end customer pipelines (e.g. gas and water supply to and in buildings) become measurable (compare Figure 65);
- Corrugated pipes for wastewater pipelines or for agricultural water supply become measurable;
- Many blow moulding parts e.g. in automotive market become measurable (e.g. inlet manifolds).

Scenario 3: 100 GHz (green line Figure 64):

- All products mentioned before are measurable;
- Blow moulded consumer products like packaging parts (shampoo bottles, food storages) become measurable;
- Multilayer pipes or products for special applications become measurable.

Due to the large growing market and product range, it is strongly recommended to allow at least 50 GHz bandwidth although 100 GHz would even be preferable.

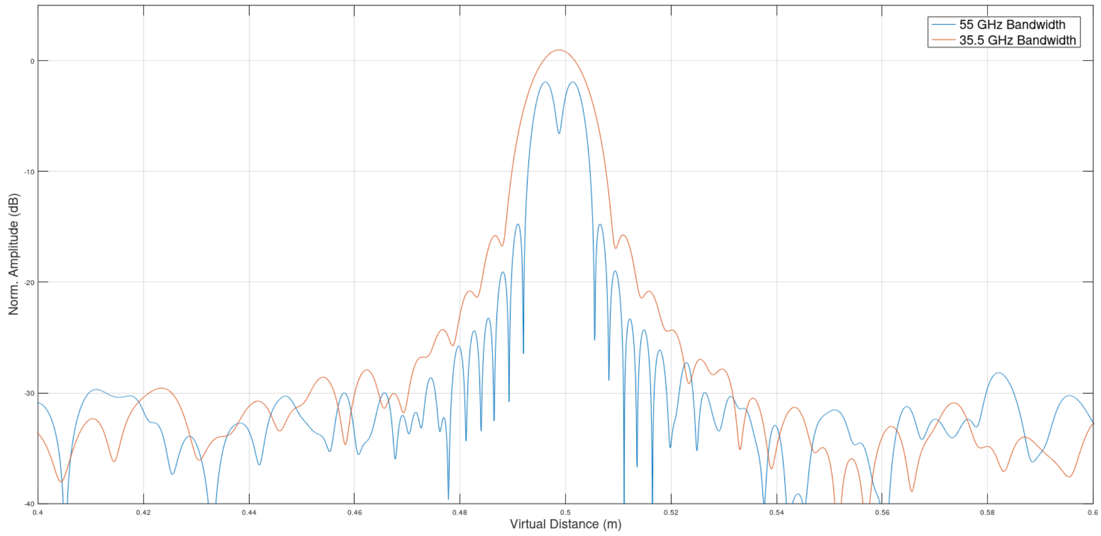


Figure 66: Simulation of two targets with 5 mm distance, which reflects a typical high precision thin layer measurement task. The two targets can be resolved with 55 GHz of bandwidth, but cannot be separated with the smaller bandwidth of 32.5 GHz (n=1, hanning window)

High precision distance measurements are another important application class that demands for a large continuous bandwidth. Millimetre precision distance measurements are nowadays widely used in terms of e.g. LPR/TLPR equipment with a bandwidth up to 10 GHz. For applications requiring sub-micrometre accuracy, the target transfer function has to be corrected in signal processing and a large bandwidth coverage is very important for this process. The latest research results [64] for example presented an absolute measurement accuracy compared to a laser interferometer with +/-5 µm in a distance of up to 5 metre measurement range based on this concept. By covering a large bandwidth, it is also possible to classify objects based on their transfer function or for more complex previously known objects, to estimate the actual view-angle of the object for 3D positioning. These systems also demand for a very high measurement rate to allow tracking of fast-moving objects.

2.4.3.4 Conclusion

Radiodetermination devices for industry automation to be used indoor or in similar shielded environments are potentially used in many different industries. All RDI-S sensors have in common that they are used to sense unique frequency dependent features in the wideband frequency response of target objects. One category are RDI-S systems for plastic extrusion thickness measurement. Covering a wide contiguous frequency bandwidth allows RDI-S applications to improve the range resolution and measurement precision. The operation of RDI-S sensors is envisaged for industrial purposes only.

The operation of RDI-S in the two frequency ranges 116-190 GHz and 190-260 GHz are proposed and the need of large bandwidths is considered in the Report. However, contiguous bands of more than 32.5 GHz could only be realised, if passive bands subject to RR No 5.340 would be used. RR No 5.340 prohibits any emission. However, ECC decided at its 52nd meeting that these bands should also be considered in the studies under the conditions described in section 2.4.1.

This Report includes compatibility studies, which are based on the assumption that a wide contiguous bandwidth was available and also provides the technical justification why the large bandwidths are needed and why no technical solutions, such as notching out some frequencies, exist to avoid emitting in the RR 5.340 bands.

The performance of RDI-S radars in terms of thickness measurements is proportional to the bandwidth used (resolution ~1/BW). In the frequency range 116-190 GHz, the largest bandwidth, which would not need to extend into passive bands, is 32.5 GHz. For the frequency range 190-260 GHz, wideband measurements even with a contiguous bandwidth of only 32.5 GHz are not possible without covering the two RR 5.340 bands 190-191.8 GHz and 200-209 GHz. This bandwidth would allow to measure thicknesses greater than about 3 mm. For measuring smaller thicknesses, a larger bandwidth is required, which is only possible by including passive bands.

2.4.4 RDI-S and notching of ITU RR footnote 5.340 bands

It is noted, that notching out ITU RR 5.340 bands is technically possible for some rare RDI-S applications with low performance requirements and slow measurement rates, for example by using specific higher sweep-slopes of the local oscillator or switched amplifiers. However, this could impact accuracy and therefore it is not applicable for high performance RDI-S measurements needed for the vast majority of applications.

For many of the above-mentioned applications covering a large continuous bandwidth is essential. There are first approaches in research dealing with notching-out of bands in terms of compressed sensing techniques. While such an approach is shown to work in a controlled laboratory environment, it only works with limited success in real-world applications, where the interesting features of the radiodetermination application might also fall within the notched-out bands and the information that is needed for an accurate measurement result might then be missing.

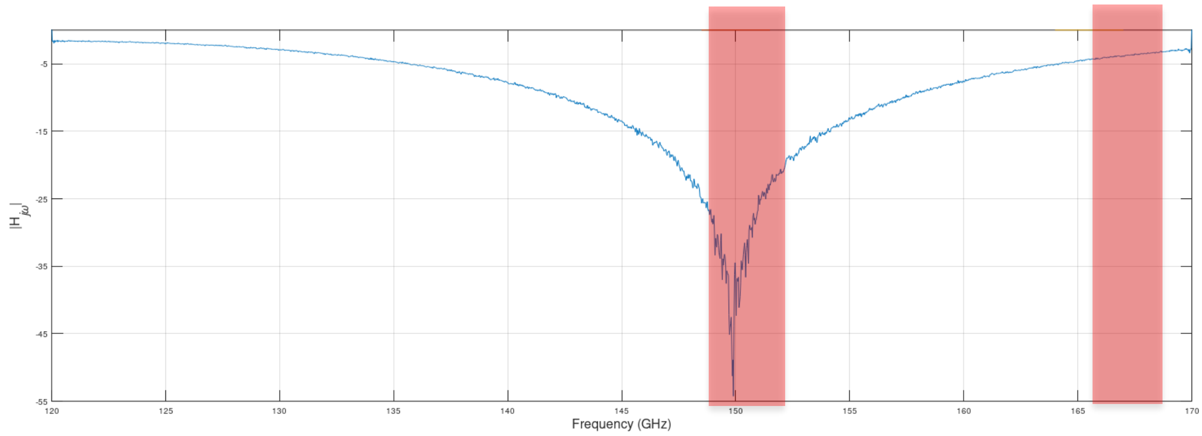


Figure 67: Simulated magnitude of a RDI-S frequency response (FMCW up-ramp from 120 GHz to 170 GHz) with a Fabry–Pérot thin layer target with the minimum inside ITU RR FN 5.340 bands (red) (demonstration example, assumed n=1, rectangular window function, evaluated with Fabry–Pérot principle)

For thin layer detection this is for example the case, if the measured material's thickness is close to the bandwidth resolution limit and the combination of the parallel plate Fabry–Pérot interferometer leads to a single minimum that is located inside the notched-out bands, as shown in the simulated case of Figure 67. In this case the estimation of the exact local minimum with the required accuracy is not possible anymore. The regions outside do not work reliably enough with model-fitting approaches to predict the minimum location due to real-world application degradations like misalignment and so on. The other two applications (compare 2.4.3.3) have similar restrictions regarding missing in-band information. Notching might be acceptable for non-precision measurement tasks (that do not require the wide absolute bandwidth anyway) but notching out ITU RR 5.340 bands is not an option for high performance radiodetermination applications. Consequently, missing sub-bands can unfortunately not be accepted for most RDI-S applications. A network analyser measurement of a filter component with missing frequency ranges is also not an option if the interesting parts of the filter response are located within the missing ranges. Model based approaches with a-priori information can guess that there might be a filter response in the neglected frequency range, but no reliable measurement would be possible anymore with the missing in-band information. This could also happen for precise RDI-S measurements with the notched-out RR FN 5.340 bands.

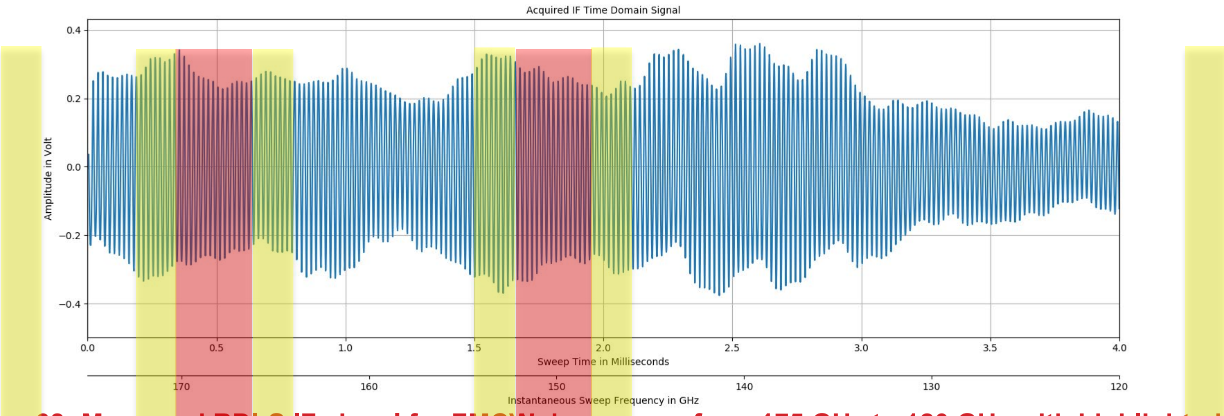


Figure 68: Measured RDI-S IF signal for FMCW down-ramp from 175 GHz to 120 GHz with highlighted degraded ramp linearity regions (yellow) due to PLL settling effects if notching of 5.340 bands (red) is required

Additionally, the high sweep-rate (e.g. 4 ms for a complete 50 GHz sweep) needed for most applications due to high production line speed of the materials that need to be measured prevents notching-out frequency bands without losing FMCW sweep linearity, which can directly be translated into losing measurement performance and accuracy. The sub-micrometre precision measurements require an exceptional linear FMCW sweep without degraded regions. If bands are notched out by stopping the sweep and jumping over the ITU RR FN 5.340 bands this would result in degraded sweep performance close to the notched out regions due to the fact that phase locked loops (PLL) show an analogue settling behaviour, as shown in Figure 68. Due to the use of window functions the non-avoidable regions of degraded ramp linearity at the outer start- and stop-regions of the sweep have only a minor influence compared to such regions in the middle of the covered bandwidth. In addition, spurious or/and out-of-band emissions with much higher power spectral density in the ITU RR FN 5.340 bands, because of PLL locking and settling processes at the FMCW start and stop regions, might be the consequence. Experience shows that the start and stop regions of a FMCW sweep are often the most critical parts in terms of power spectral density emission levels as it can increase spurious emissions in the adjacent bands. Another technique, the notching of bands with switchable components like amplifiers in the transmit path of the radar is unavoidably causing load pulling at the VCO, because of changing the load of the VCO during the highly linear frequency ramp. Phase locked loops will correct the frequency drift of the VCO caused by the changing load, but due to the analogue behaviour of the loop-filters this also highly influences the FMCW sweep linearity and is not suitable for high performance radiodetermination applications.

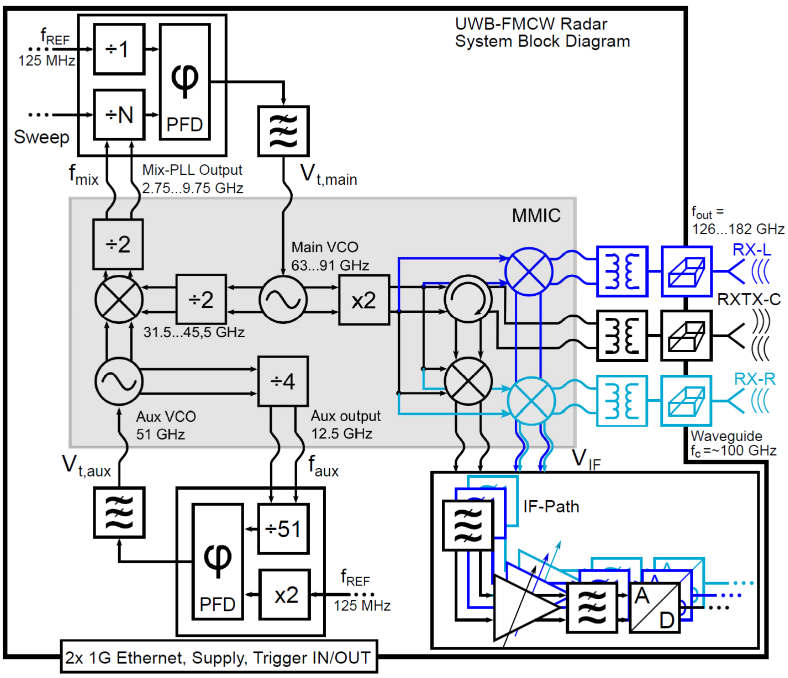


Figure 69: Block diagram of a typical precision FMCW radar. This example system operates in a frequency range from 126 to 182 GHz

A block diagram of a typical high performance FMCW radar operating at 126-182 GHz is shown in Figure 69, other systems for the frequency range between 116 to 260 GHz might look similar with scaled frequencies or with an additional frequency doubler located behind the fundamental VCO.

Summary: Notching out ITU RR FN 5.340 bands is not an option for high performance radiodetermination applications as the measurement degradation would eliminate such an application. The sub-micrometre precision measurements like e.g. precision dielectric sheet thickness measurements require an exceptional linear FMCW sweep without degraded regions in order to function at all and have an inherent need to collect the frequency response from a large continuous bandwidth without missing sub-bands.

For non-precision RDI-S measurement tasks, notching is acceptable. Slow sweeping RDI-S devices with sweep slopes smaller than 2.5 GHz/ms shall notch out the ITU-RR FN 5.340 bands with at least 10 dB reduction in mean and peak power.

2.4.5 RDI-S sharing and compatibility in RR FN 5.340 bands

2.4.5.1 RDI-S sharing and compatibility-general considerations

Protection criteria are already available (for EESS) or can easily be derived (for RAS) for all passive services in the frequency region above 116 GHz. Atmospheric losses, line of sight losses, diffraction, and building entry (shielding) losses are much higher compared to low frequencies, which adds additional protection from interference.

Due to the wide bandwidth, high shielding loss, low output power and fast sweeping behaviour, the expected emission of RDI-S devices would be even below the limits that are already allowed for short-range device unwanted emissions in the spurious domain. The radiated energy outside the shielded enclosure is unwanted radiation, which unfortunately cannot be avoided for this application.

2.5 TECHNICAL JUSTIFICATION FOR THE WIDE BANDWIDTH NEED FOR RDI-S USING THE EXAMPLE OF PLASTIC PIPE AND SHEET THICKNESS MEASUREMENT

Note: The sections 2.4 and 2.5 contain the technical justifications of the industry as requested by the 52nd ECC meeting (see item 4 in section 2.4.1), for the wide bandwidth need and why notching out the bands identified by RR FN 5.340 is not possible.

2.5.1 General information on pipes and sheets

Pipes and sheets are often made of PVC (polyvinyl chloride), PP (polypropylene) or PE (polyethylene), but other materials are of course possible (see Figure 70 and Figure 71). In order to meet the desired requirements for the intended application, especially pipes are made of several layers. Often, this is optically not visible because the layers can have the same colour. The exterior colours of the pipes are specified by standards, depending on the application. The colour component has no influence on the physical properties of the pipes. These properties are influenced not only by the used materials, but also by the parameters of the production process and the layered design of the pipe itself. E.g. there may be layers for pressure protection, to add resistance against chemicals and so on.

Figure 70: Standard pipes for gas, long-distance-heating, sheathing and fluid waste (left to right)

In addition to diameter, ovality and wall thickness, the standards specify (depending on the application) the mechanical properties of the pipes, e.g. pressure, thermal stability and weather resistance. Plastic sheets are mostly used for insulation, cladding and/or sound insulation. This means that they can be used in many areas and are now almost without an alternative (see Figure 71).

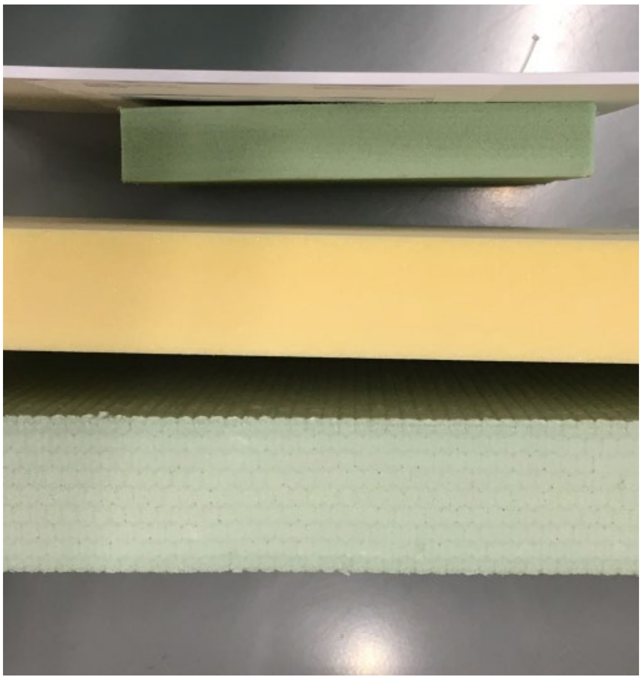


Figure 71: Plastic sheets, foamed and not foamed made from different materials

2.5.2 Extrusion of plastic profiles from engineering plastics

The plastic materials are generally fed as pellets or granules to an extruder, which heats the base material up to 200 °C in several heating zones and through the mechanical energy from the feeding screw. Due to the high temperatures, the base material is plasticised into a homogeneous mass. By means of a rotating screw in the extruder, the mass is pushed through the extruder tool kit which determines the basic shape. Immediately after the tool kit the preformed pipe passes through a calibration sleeve into a first cooling section (see Figure 72).

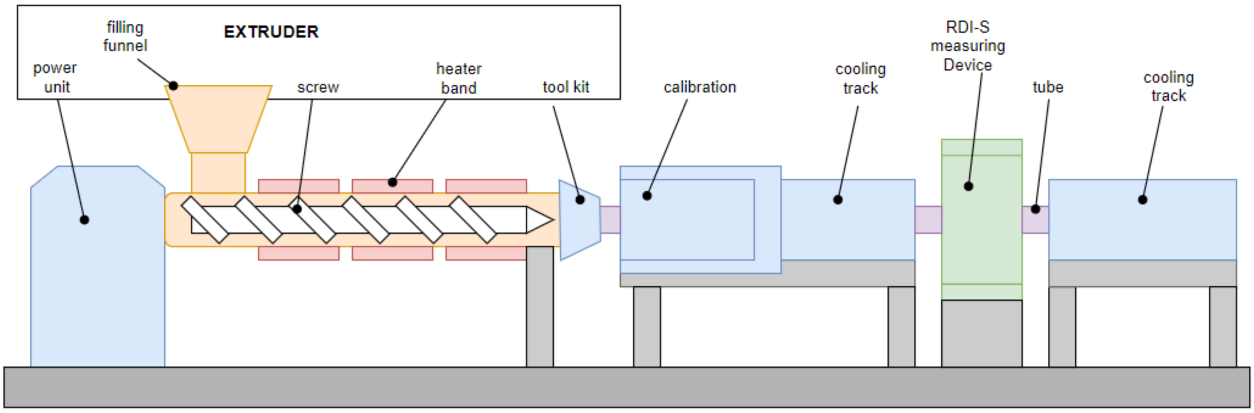


Figure 72: Cross section schematic of the first section of an extrusion line for pipe manufacturing

Exiting the first cooling section, the wall thickness can be measured at several points along the circumference between the first and the next cooling section. This happens e.g. with the help of a rotating radar sensor or with several radar sensors which are distributed over the circumference. This is the first possible measurement position, where the machine operator receives information about the current wall thickness and can compensate for deviations from the nominal value by changing the output of the extruder accordingly.

With a typical pipe production speed of 0.6 metres per minute and a 12-metre cooling section, 20 minutes pass before reaching this point. Already this period may appear long but taking into account that several corrections might be needed before specifications are met, it might take up more than an hour. This extends the time until good production quality is reached to potentially several hours. Typical extrusion lines require additional cooling sections to completely cool down the pipes. It is therefore possible that it takes an hour until the product travels from the extruder die to the cutting saw and can be finally inspected or its final dimensions be checked.

2.5.3 Use of measuring devices in extrusion lines

The precise measurement of the products mentioned in section 2.5.1 is also of great importance because the start-up of such extrusion lines is very complex. Without a non-contact measurement of the wall thicknesses as close as possible to the location of the extrusion, as described in section 2.5.2 it will take many hours. Thus, a lot of start-up scrap is generated before stable and reliable values are produced that are within the specification. In addition to these start-up losses, it is of great economic importance for the manufacturers of such products to use only as much material as is required by the specifications.

By using precise radar systems in extrusion lines, 250000 to 300000 euros can be saved every year in material value while at the same time the start-up process can be shortened significantly, adding to the overall savings.

The use of suitable measurement systems means that the quality of the product can be continuously monitored, and also closed loop control and high cost and time savings become possible, especially during process start-up. Extrusion lines can be operated by less qualified personnel or less personnel per line is needed as a consequence.

2.5.4 Defects in plastic pipes

When the pipe exits the extruder die, the material begins to solidify from the outside while the inner wall is still viscous. Cooling mainly works from the outside, as the inside can only be cooled by injecting cooling gas while from the outside, chilled water is sprayed onto the pipe. With the inside wall still being viscous, a non-optimal process may lead to so called “sagging”, where a part of the material sags down due to gravity, leading to a non-uniform wall thickness distribution and the product not meeting the specified requirements (see Figure 73). Sagging and other defects can be detected by continuously monitoring the production process by means of an RDI-S measurement system with sufficient bandwidth using UWB technology.

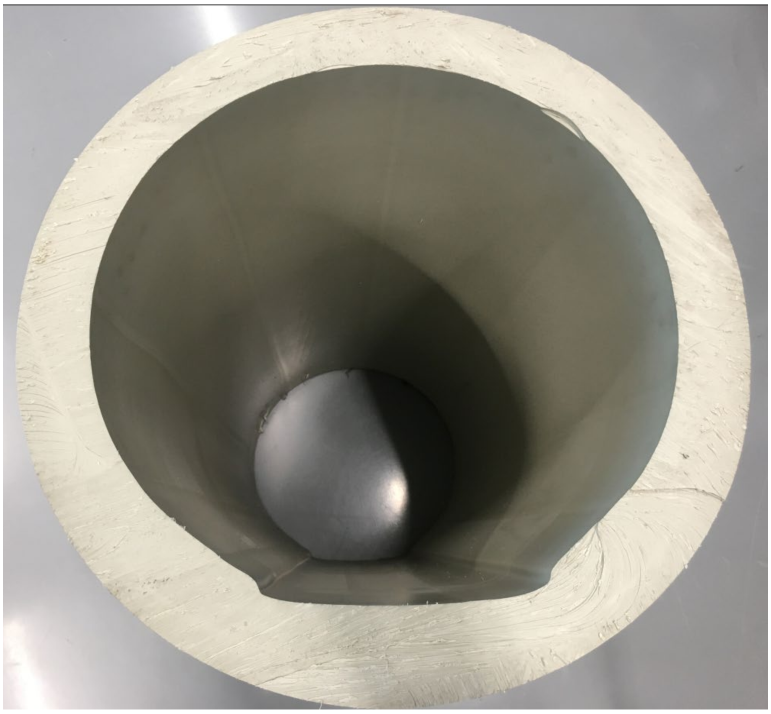


Figure 73: Cross section of a pipe where ”sagging” occured during production

2.5.5 Advantage of a large bandwidth when used in measuring systems

For example, FMCW radar sensors are particularly suitable for measuring wall thicknesses in products that can be irradiated with millimetre waves. Basically, the area of application is limited when it comes to small wall thicknesses, e.g. of sheets, but also especially of tubes. While optical devices may also be suitable for the measurement of sheets, e.g. with the help of distance measurements, such a measurement method when measuring tubes, especially during the manufacturing process is not possible because the tube inside is usually not accessible. A general formula to determine the smallest measurable wall thickness as a function of bandwidth is given by:

$$d_{min} = \frac{c \cdot c_w}{2Bn} \qquad (3)$$

where:

- d_{min} – smallest measurable wall thickness in millimetres;
- c – speed of light;
- c_w – correction factor for use of window function [67];
- B – bandwidth in GHz;
- n – refractive index of the material (approximately 1.5 for polyethylene and polypropylene).

With a bandwidth of B = 100 GHz and a refractive index of n = 1.5 the smallest theoretically measurable wall thickness is consequently 1 mm. This example shows that even with a high bandwidth thin layers used on small sheets and tubes cannot be measured. Nevertheless, many products are above this minimum value and could reliably be measured with today's available technology. On the other hand, especially for multilayer pipes, individual sheet thicknesses can be well below the minimum measurable value.

Figure 74 shows the echoes of two reflectors placed at a distance of 50 mm using different sweep bandwidths. It can be seen that with an insufficient bandwidth (e.g. 1 GHz) it is not possible to distinguish between the two targets. Increasing the bandwidth to 2 GHz improves the resolution, but the two targets can still not clearly be separated (top right). A further increase of the bandwidth to 10 GHz (bottom left) or 20 GHz (bottom right) shows how the resolution increases further. Now the two targets can be distinguished. This is a visual representation of the given equation above. It shows that high bandwidths are essential to enable the measurement of smaller wall or layer thicknesses.

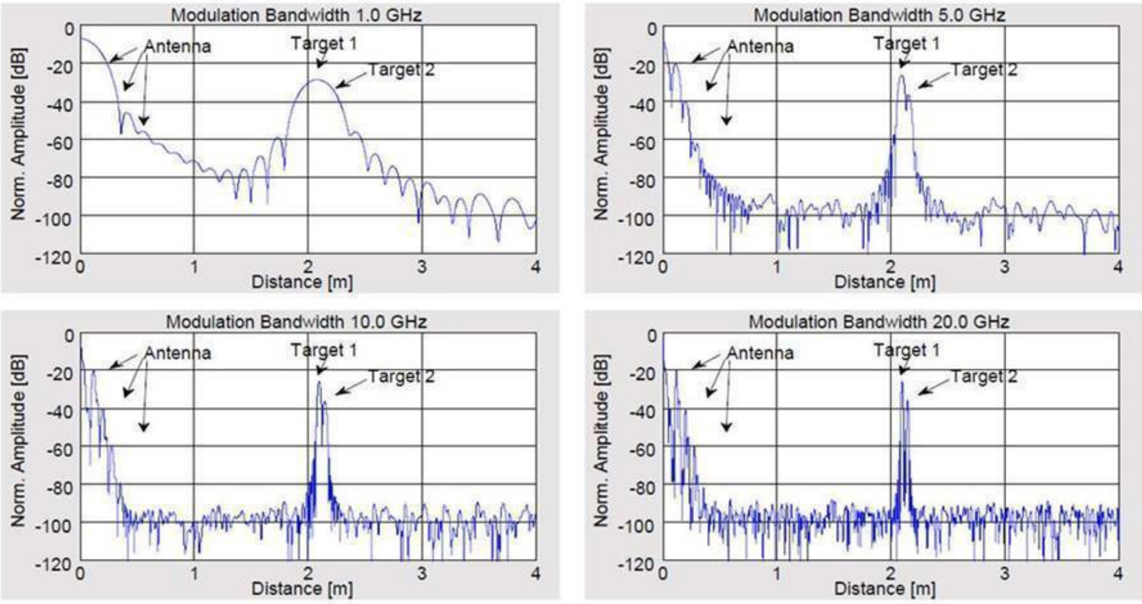


Figure 74: Effect of echo resolution for different bandwidths from 1 GHz (top left) to 20 GHz (bottom right)

2.5.6 Suitability of the frequency range from 116 GHz to 260 GHz

As already mentioned before, RDI-S devices require a large bandwidth for the precise measurement of small layer thicknesses in order to guarantee a broad coverage of products available on the market. The frequency range between 116 and 260 GHz is particularly suitable for this, because the attenuation of millimetre waves by materials made of PE or PP as well as PVC is still moderate with 0.3 dB per millimetre. This means on the other hand that large pipes with wall thicknesses of up to 200 mm can still be measured. The resolution of individual layers in the frequency range of 110-260 GHz is also easier, provided that these do not fall below the theoretically detectable minimum wall thicknesses d_{min} according to the equation above. Also, this frequency range allows for easier and better focussing of the radar wave using relatively small antennas, leading to less unwanted emissions.

2.5.7 Conservation of resources and CO2 reduction

The above-mentioned cost savings of around 250000 to 300000 euros a year by using a precise radar measurement system is based on the avoidance of unnecessary excess and start-up losses. This calculation is based on a material price of 1.1 euros/kg of polyethylene (which is a very conservative number). This corresponds to a reduced material quantity of 225 to 270 tons/year which equals an amount of 500 to 1500 tons of CO_2 released during production of the raw material, depending on the refinery process.

Therefore, not only costs and time can be significantly saved by using RDI-S measurement systems during production, but also natural resources which results in a significant reduction in CO_2 generation and emission.

2.5.8 Upcoming measurement applications

Research is already underway to manufacture radar sensors capable of processing bandwidths of 100 to 200 GHz to measure even smaller hoses or tubes, such as cardiac catheters and dialysis tubes. These medical products are particularly dependent on high precision and accuracy, as the specifications' tolerances are much tighter for this kind of products compared to larger plastic pipes or sheets. The goal for these precise measurement systems is to be ready for market launch in two to three years.

Another possible application could be the thickness measurement of foils, which is not possible in the frequency range below 116 GHz due to their small thickness and the correspondingly high bandwidth requirements.

2.5.9 Today's achievable measurement accuracies

In Figure 75, a real-life example of a current measurement system operating at 80 GHz and using a bandwidth of 25 GHz shows the measurement results of a PVC pipe with an outer diameter of 400 mm and a wall thickness of slightly above 22 mm. The system is rotating a single sensor around the pipe. The diagram on top shows the angular resolution of the wall thickness (blue), compared to repeated manual measurements taken at steps of about 22.5° (amber). Good overall accordance of the measurements can be perceived. The diagram in the middle shows the deviation from the manual measurement to the radar measurement system. The diagram at the bottom shows the repeatability of the two different approaches. While the standard deviation of the manual measurement is in the range of +/-20 µm, the radar measurement system stays in the range of +/- 1 µm.

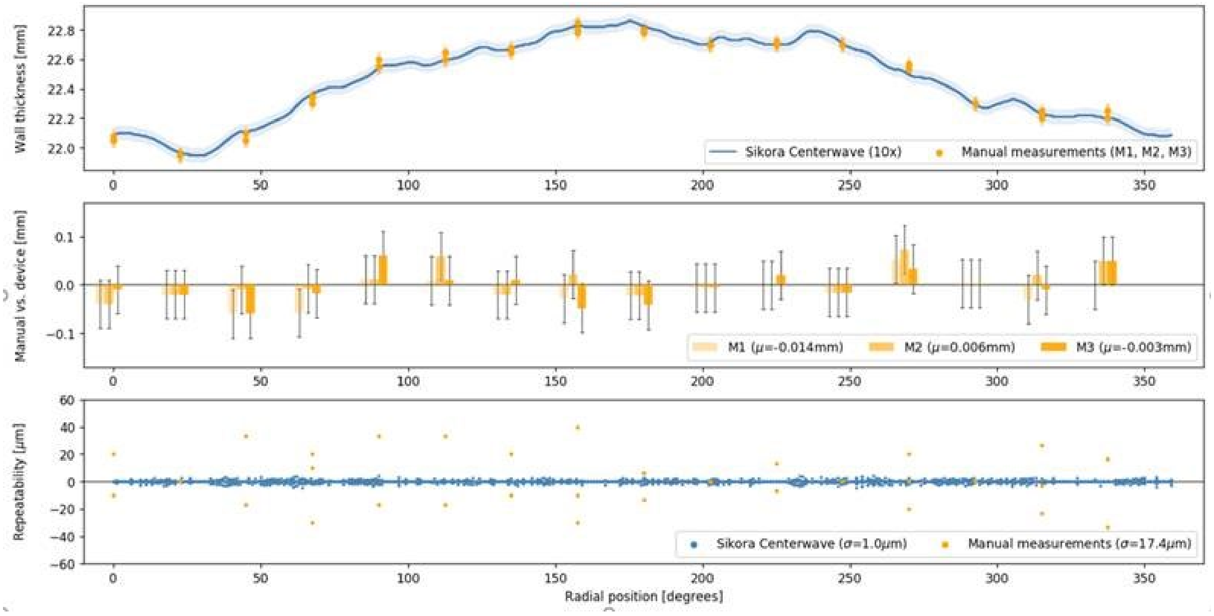


Figure 75: Comparison of measured values (blue) by a radar and a tactile optical measurement (amber) (measurement object: PVC pipe with 400 mm diameter)

3 RADIO SERVICES AND SYSTEMS

3.1 PROPOSED BANDS TO BE CONSIDERED IN THE STUDY WITHIN THE FREQUENCY RANGE 116−260 GHZ

The current European frequency allocation and utilisation information provided in the ECO Frequency Information System (EFIS) [2] and in ERC Report 025 [3] had been used in ETSI TR 103 498 [1] in order to identify possible frequency bands in the frequency range from 116 to 260 GHz for new Radiodetermination applications. In this context the two European Common Allocation (ECA) Footnotes 5.149 and 5.340 turned out to be most relevant for accomplishing this task.

The footnote 5.340 prohibits all emissions in dedicated frequency bands. In the frequency range 116−260 GHz the following bands are affected by this footnote: 114.25−116 GHz, 148.5−151.5 GHz, 164−167 GHz, 182−185 GHz, 190−191.8 GHz, 200−209 GHz, 226−231.5 GHz, 250−252 GHz.

The footnote 5.149 lists various frequency bands from 13360 kHz to 275 GHz advising administrations to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations are said to possibly be serious sources of interference to the radio astronomy service. In the overall frequency range from 116 to 260 GHz the following bands are affected by this footnote:

- 128.33−128.59 GHz;
- 129.23−129.49 GHz;
- 130−134 GHz;
- 136−148.5 GHz;
- 151.5−158.5 GHz;
- 168.59−168.93 GHz;
- 171.11−171.45 GHz;
- 172.31−172.65 GHz;
- 173.52−173.85 GHz;
- 195.75−196.15 GHz;
- 209−226 GHz;
- 241−250 GHz;
- 252−275 GHz.

In addition to these two footnotes the following frequency ranges, allocated to Fixed Service (FS) as a primary service, had also been considered in order to identify suitable frequency ranges for new Radiodetermination applications: 130−134 GHz, 141−148.5 GHz, 151.5−164 GHz, 167−174.8 GHz.

For type A applications, footnote 5.340 and the FS allocations had been taken into account to identify suitable frequency ranges. For type B applications, only footnote 5.340 had been taken into account. For type C applications, no restrictions were proposed as these applications are applied solely in highly shielded environments.

The remaining possible frequency bands for new Radiodetermination applications from those suggested in TR 103 498 [1], according to the categorisation in section 2.1, are depicted in Table 33.

Table 33: Possible frequency bands for the different application types

Application Type	Frequency Bands
A	116−130 GHz (Note 2)
	134−141 GHz
	141−148.5 GHz (Note 1)
	174.8−182 GHz

Application Type	Frequency Bands
	185−190 GHz (Note 1)
	209−226 GHz
	231.5−250 GHz
B	116−148.5 GHz (Note 2)
	151.5−164 GHz
	167−182 GHz
	185−190 GHz (Note 1)
	209−226 GHz
	231.5−250 GHz
C	116−260 GHz (Note 2)
Note 1: The frequency ranges 141 − 148.5 GHz for type A applications and 185 − 190 GHz for type A and B applications have been proposed during SE24 M97 in addition to the bands suggested in the SRdoc TR 103 498 [1]. Note 2: SE24 M97 agreed to request WG SE and WG FM to change the lower edge of the frequency band from 120 GHz, proposed in TR 103 498 [1], to 116 GHz. This request was endorsed both, by WG FM and WG SE at their recent meetings.	

3.2 EUROPEAN FREQUENCY ALLOCATIONS AND APPLICATIONS IN THE FREQUENCY RANGE OF INTEREST

Table 34: European frequency allocations and applications and proposed bands for type A, B and C radiodetermination applications

Frequency band in GHz	Allocation	Applications	UWB type A	UWB type B	UWB type C	Notes
114.25-116 (5.340) (5.341)	SPACE RESEARCH (PASSIVE) RADIO ASTRONOMY EARTH EXPLORATION-SATELLITE (PASSIVE)	Radio astronomy				
116.00-119.98 (5.340) (5.341)	EARTH EXPLORATION-SATELLITE (PASSIVE) INTER-SATELLITE (5.562C)	Passive sensors (satellite)	X	X	X	
119.98-120.02 (5.341)	INTER-SATELLITE (5.562C) EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite)	X	X	X	
120.02-122.25 (5.138)	EARTH EXPLORATION-SATELLITE (PASSIVE) INTER-SATELLITE (5.562C) SPACE RESEARCH (PASSIVE)	Non-specific SRDs Passive sensors (satellite)	X	X	X	
122.25-123.00 (5.138)	INTER-SATELLITE MOBILE (5.558) FIXED Amateur Amateur-Satellite	Non-specific SRDs Amateur Amateur-satellite	X	X	X	
123.00-130.00 (5.149) (5.554)	FIXED-SATELLITE (SPACE-TO-EARTH) RADIONAVIGATION-SATELLITE RADIONAVIGATION MOBILE-SATELLITE (SPACE-TO-EARTH) Radio Astronomy	Radio astronomy	X	X	X	

Frequency band in GHz	Allocation	Applications	UWB type A	UWB type B	UWB type C	Notes
130.00-134.00 (5.149) (5.562A)	RADIO ASTRONOMY FIXED MOBILE (5.558) INTER-SATELLITE EARTH EXPLORATION-SATELLITE (ACTIVE) (5.562E)	Fixed Radio astronomy		X	X	Note 1 Note 2
134.00-136.00	AMATEUR-SATELLITE AMATEUR Radio Astronomy	Amateur Amateur-satellite Radio astronomy	X	X	X	
136.00-141.00 (5.149)	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite	Amateur-satellite Amateur Radio astronomy	X	X	X	
141.00-148.50 (5.149)	MOBILE FIXED RADIOLOCATION RADIO ASTRONOMY	Radio astronomy Fixed	X	X	X	Note 1
148.50-151.50 (5.340)	RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) Radio astronomy			X	
151.50-155.50 (5.149)	FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION	Radio astronomy Fixed		X	X	Note 1
155.50-158.50 (5.149)	MOBILE RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) (5.562B) FIXED EARTH EXPLORATION-SATELLITE (PASSIVE)	Fixed Passive sensors (satellite) Radio astronomy		X	X	Note 1
158.50-164.00	FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE (SPACE-TO-EARTH)	Fixed		X	X	Note 1
164.00-167.00 (5.340)	RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) Radio astronomy			X	
167.00-174.50 (5.149)	INTER-SATELLITE FIXED-SATELLITE (SPACE-TO-EARTH) FIXED MOBILE (5.558)	Radio astronomy Fixed		X	X	Note 1
174.50-174.80	MOBILE (5.558) INTER-SATELLITE FIXED	Fixed		X	X	Note 1
174.80-182.00	EARTH EXPLORATION-SATELLITE (PASSIVE) INTER-SATELLITE (5.562H)	Passive sensors (satellite)	X	X	X	

Frequency band in GHz	Allocation	Applications	UWB type A	UWB type B	UWB type C	Notes
	SPACE RESEARCH (PASSIVE)					
182.00-185.00 (5.340)	SPACE RESEARCH (PASSIVE) RADIO ASTRONOMY EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) Radio astronomy			X	
185.00-190.00	EARTH EXPLORATION-SATELLITE (PASSIVE) INTER-SATELLITE (5.562H) SPACE RESEARCH (PASSIVE)	Passive sensors (satellite)	X	X	X	
190.00-191.80 (5.340)	SPACE RESEARCH (PASSIVE) EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) Radio astronomy			X	
191.80-200.00 (5.149) (5.341) (5.554)	FIXED MOBILE (5.558) INTER-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE MOBILE-SATELLITE	Radio astronomy			X	
200.00-202.00 (5.340) (5.341) (5.563A)	RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) EARTH EXPLORATION-SATELLITE (PASSIVE)	Radio astronomy Earth exploration-satellite			X	
202.00-209.00 (5.340) (5.341) (5.563A)	EARTH EXPLORATION-SATELLITE (PASSIVE) SPACE RESEARCH (PASSIVE) RADIO ASTRONOMY	Earth exploration-satellite Radio astronomy			X	
209.00-217.00 (5.149) (5.341)	RADIO ASTRONOMY FIXED FIXED-SATELLITE (EARTH-TO-SPACE) MOBILE	Radio astronomy	X	X	X	
217.00-226.00 (5.149) (5.341)	MOBILE FIXED-SATELLITE (EARTH-TO-SPACE) FIXED RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) (5.562B)	Radio astronomy	X	X	X	
226.00-231.50 (5.340)	SPACE RESEARCH (PASSIVE) RADIO ASTRONOMY EARTH EXPLORATION-SATELLITE (PASSIVE)	Radio astronomy Passive sensors (satellite)			X	
231.50-232.00	FIXED MOBILE Radiolocation		X	X	X	
232.00-235.00	Radiolocation MOBILE FIXED-SATELLITE (SPACE-TO-EARTH) FIXED		X	X	X	
235.00-238.00 (5.563A) (5.563B)	EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) Radio astronomy	X	X	X	

Frequency band in GHz	Allocation	Applications	UWB type			Notes
			A	B	C	
	FIXED-SATELLITE (SPACE-TO-EARTH) SPACE RESEARCH (PASSIVE)					
238.00-240.00	RADIONAVIGATION RADIONAVIGATION-SATELLITE RADIOLOCATION FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE FIXED		X	X	X	
240.00-241.00	FIXED MOBILE RADIOLOCATION		X	X	X	
241.00-248.00 (5.138) (5.149)	RADIOLOCATION RADIO ASTRONOMY Amateur-Satellite Amateur	Amateur Radio astronomy Amateur-satellite Non-specific SRDs	X	X	X	
248.00-250.00 (5.149)	AMATEUR AMATEUR-SATELLITE Radio Astronomy	Amateur-satellite Radio astronomy Amateur	X	X	X	
250.00-252.00 (5.340) (5.563A)	RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) EARTH EXPLORATION-SATELLITE (PASSIVE)	Radio astronomy Earth exploration-satellite			X	
252.00-265.00 (5.149) (5.554)	FIXED MOBILE RADIONAVIGATION RADIONAVIGATION-SATELLITE MOBILE-SATELLITE (EARTH-TO-SPACE) RADIO ASTRONOMY	Radio astronomy			X	

Note 1: ECC Recommendation (18)01 [22] Bandwidth is a multiple of 0.250 GHz.
Note 2: Some characteristics are available in Appendix 2 to Report ITU-R F.2107 [19].

Relevant RR Footnotes included in Table 34:

5.138: The following bands: 6765-6795 kHz (centre frequency 6780 kHz), 433.05-434.79 MHz (centre frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. 5.280, 61-61.5 GHz (centre frequency 61.25 GHz), 122-123 GHz (centre frequency 122.5 GHz), and 244-246 GHz (centre frequency 245 GHz) are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorisation by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations.

5.149: In making assignments to stations of other services to which the bands:13360-13410 kHz, 25550-25670 kHz, 37.5-38.25 MHz, 73-74.6 MHz in Regions 1 and 3, 150.05-153 MHz in Region 1, 322-328.6 MHz, 406.1-410 MHz, 608-614 MHz in Regions 1 and 3, 1330-1400 MHz, 1610.6-1613.8 MHz, 1660-1670 MHz, 1718.8-1722.2 MHz, 2655-2690 MHz, 3260-3267 MHz, 3332-3339 MHz, 3345.8-3352.5 MHz, 4825-4835 MHz, 4950-4990 MHz, 4990-5000 MHz, 6650-6675.2 MHz, 10.6-10.68 GHz, 14.47-14.5 GHz, 22.01-22.21 GHz, 22.21-22.5 GHz, 22.81-22.86 GHz, 23.07-23.12 GHz, 31.2-31.3 GHz, 31.5-31.8 GHz in Regions 1 and 3, 36.43-36.5 GHz, 42.5-43.5 GHz, 48.94-49.04 GHz, 76-86 GHz, 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 128.33-128.59 GHz, 129.23-129.49 GHz, 130-134 GHz, 136-148.5 GHz, 151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz, 172.31-172.65 GHz, 173.52-173.85 GHz, 195.75-196.15 GHz, 209-226 GHz, 241-250 GHz, 252-275 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

5.340: All emissions are prohibited in the following bands: 1400-1427 MHz 2690-2700 MHz, except those provided for by No. 5.422 10.68-10.7 GHz, except those provided for by No. 5.483 15.35-15.4 GHz, except those provided for by No. 5.511 23.6-24 GHz 31.3-31.5 GHz 31.5-31.8 GHz, in Region 2 48.94-49.04 GHz, from airborne stations 50.2-50.4 GHz (1) 52.6-54.25 GHz 86-92 GHz 100-102 GHz 109.5-111.8 GHz 114.25-116 GHz 148.5-151.5 GHz 164-167 GHz 182-185 GHz 190-191.8 GHz 200-209 GHz, 226-231.5 GHz 250-252 GHz. (WRC-03) (1) 5.340 The allocation to the Earth exploration-satellite service (passive) and the space research service (passive) in the band 50.2-50.4 GHz should not impose undue constraints on the use of the adjacent bands by the primary allocated services in those bands. (WRC-97)

Frequency band in GHz	Allocation	Applications	UWB type A B C	Notes
5.341: In the bands 1400-1727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. 5.554: In the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 123-130 GHz, 191.8-200 GHz and 252-265 GHz, satellite links connecting land stations at specified fixed points are also authorized when used in conjunction with the mobile-satellite service or the radionavigation-satellite service. (WRC-2000) 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the intersatellite service (see No. 5.43). (WRC-2000) 5.562A: In the bands 94-94.1 GHz and 130-134 GHz, transmissions from space stations of the Earth exploration-satellite service (active) that are directed into the main beam of a radio astronomy antenna have the potential to damage some radio astronomy receivers. Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible. (WRC-2000) 5.562B: In the frequency bands 105-109.5 GHz, 111.8-114.25 GHz and 217-226 GHz, the use of this allocation is limited to space-based radio astronomy only. (WRC-19) 5.562C: Use of the band 116-122.25 GHz by the inter-satellite service is limited to satellites in the geostationary-satellite orbit. The single-entry power flux-density produced by a station in the inter-satellite service, for all conditions and for all methods of modulation, at all altitudes from 0 km to 1 000 km above the Earth's surface and in the vicinity of all geostationary orbital positions occupied by passive sensors, shall not exceed -148 dB(W/(m² · MHz)) for all angles of arrival. (WRC-2000) 5.562E: The allocation to the Earth exploration-satellite service (active) is limited to the band 133.5-134 GHz. (WRC-2000) 5.562F: In the band 155.5-158.5 GHz, the allocation to the Earth exploration-satellite (passive) and space research (passive) services shall terminate on 1 January 2018. (WRC-2000) 5.562H: Use of the bands 174.8-182 GHz and 185-190 GHz by the inter-satellite service is limited to satellites in the geostationary-satellite orbit. The single-entry power flux density produced by a station in the inter-satellite service, for all conditions and for all methods of modulation, at all altitudes from 0 km to 1000 km above the Earth's surface and in the vicinity of all geostationary orbital positions occupied by passive sensors, shall not exceed -144 dB(W/(m² · MHz)) for all angles of arrival. (WRC-2000) 5.563A: In the bands 200-209 GHz, 235-238 GHz, 250-252 GHz and 265-275 GHz, ground-based passive atmospheric sensing is carried out to monitor atmospheric constituents. (WRC-2000) 5.563B: The band 237.9-238 GHz is also allocated to the Earth exploration-satellite service (active) and the space research service (active) for spaceborne cloud radars only. (WRC-2000)				

3.3 COMPATIBILITY SCHEMES OVERVIEW INSIDE AND NEARBY THE CANDIDATE FREQUENCY BANDS

Section 3.1 gives an overview of the considered frequency bands within the frequency range 116 to 260 GHz for the new Radiodetermination applications described in-depth in section 2.2. In Figure 76 to Figure 79, a graphical overview of the compatibility schemes inside and nearby each requested candidate band is given.

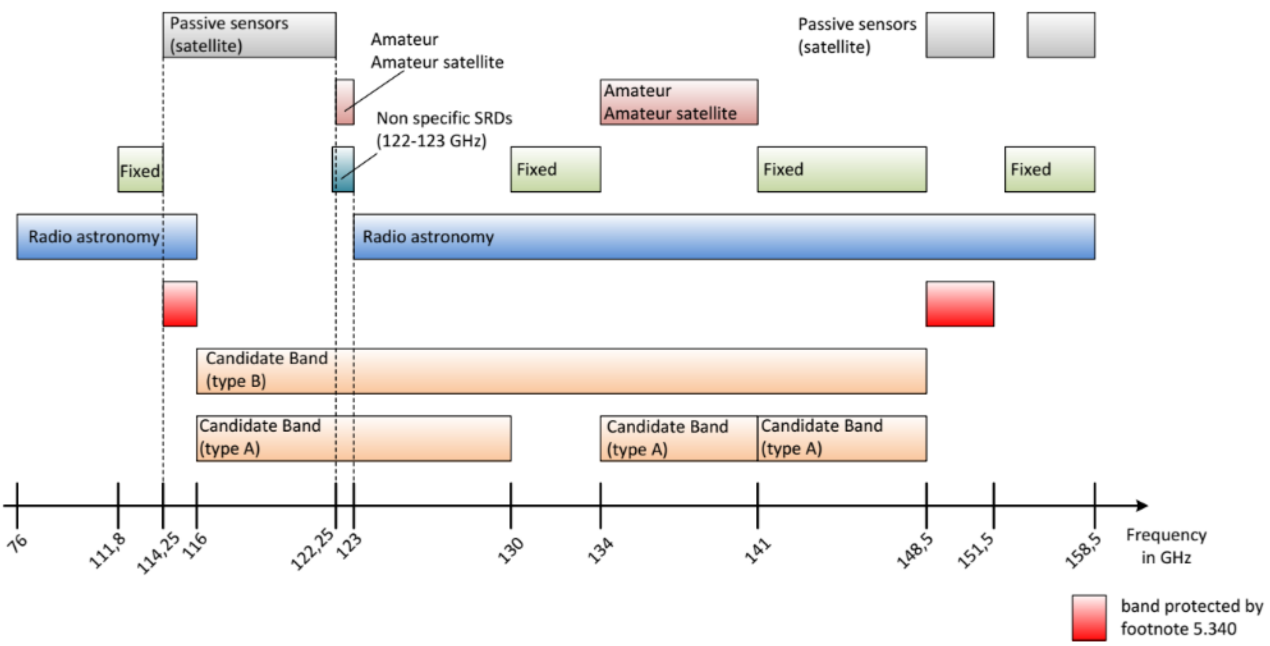


Figure 76: Compatibility scheme for the frequency range 116 to 148.5 GHz

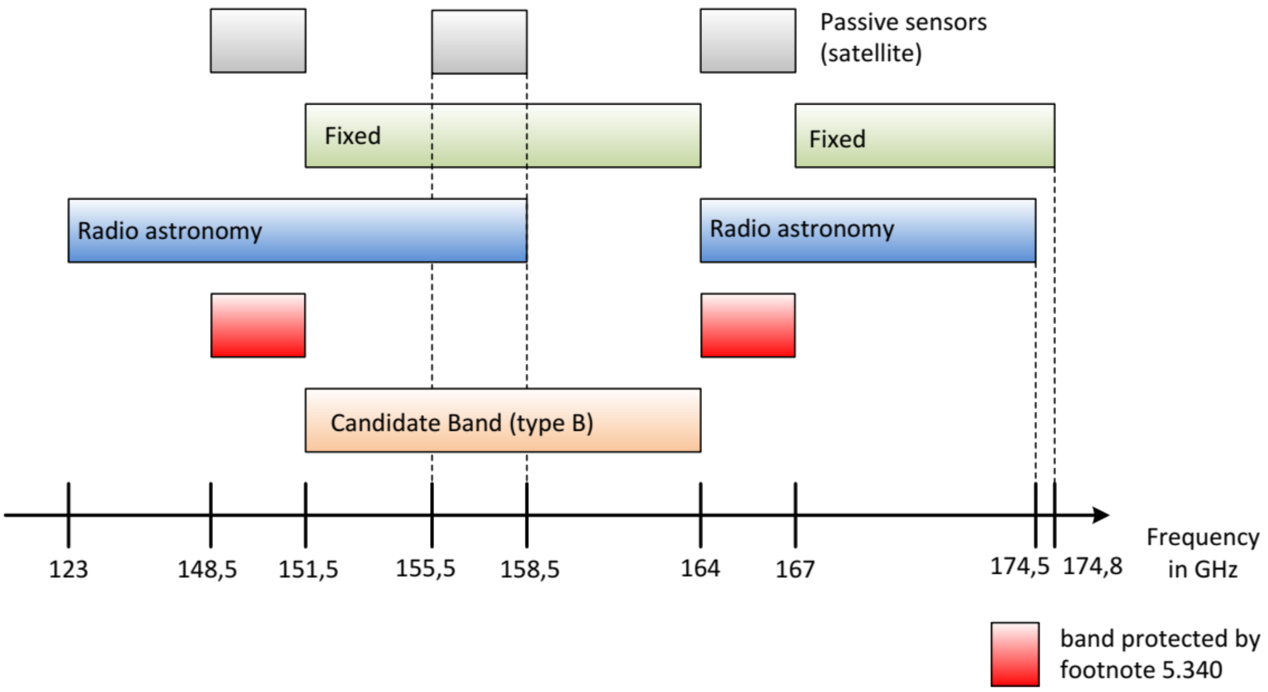


Figure 77: Compatibility scheme for the frequency range 151.5 to 164 GHz

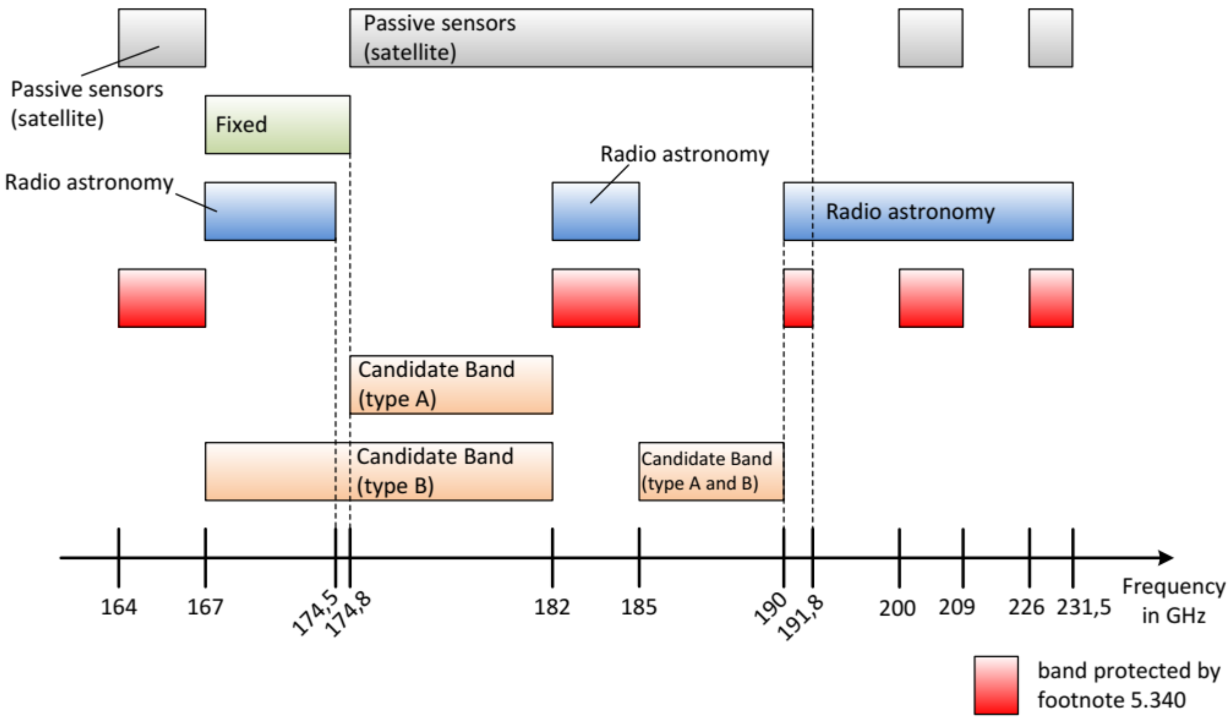


Figure 78: Compatibility scheme for the frequency range 167 to 190 GHz

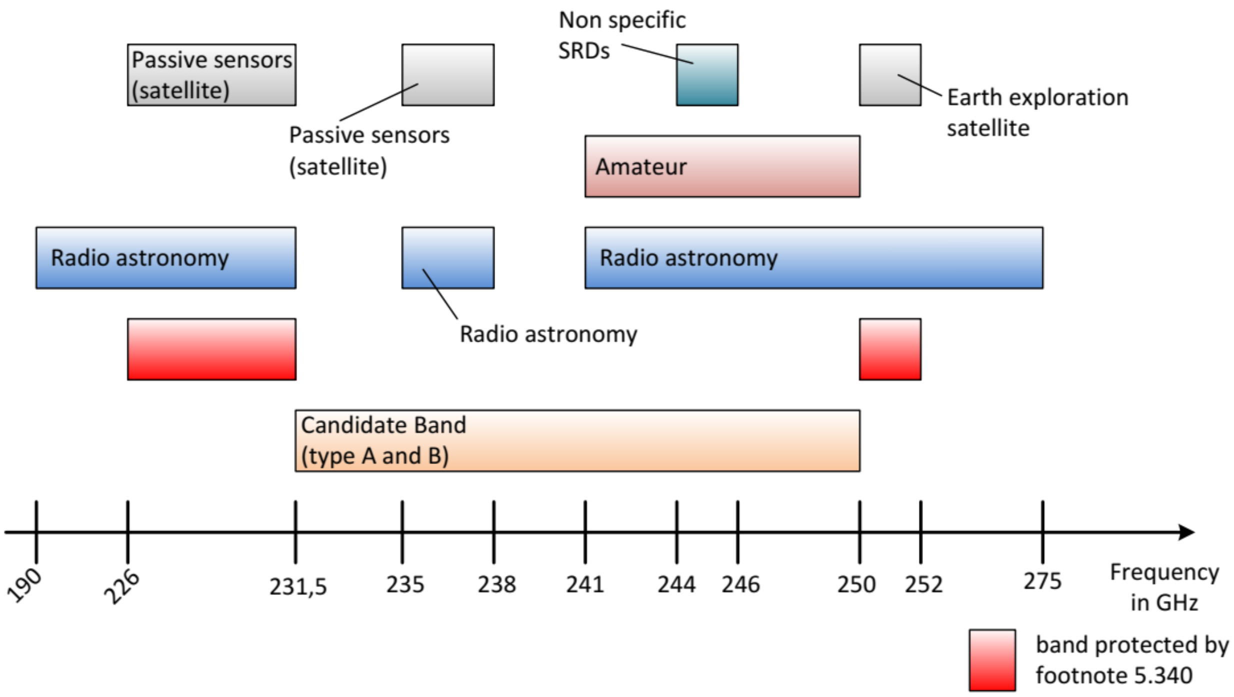


Figure 79: Compatibility scheme for the frequency range 231.5 to 250 GHz

3.4 INTERFERENCE SCENARIOS

3.4.1 Introduction

When considering the range of the identified victim services in section 3.5, it may be suggested to divide the possible interference scenarios into two categories:

- Interference over terrestrial line-of-sight (LOS) paths;
- Interference to spaceborne passive satellite receivers over LOS paths.

The terrestrial interference scenario where victim station receivers are affected through emissions in horizontal direction along the Earth's surface and the space-based scenario where spaceborne receivers are affected by emissions in vertical or slantwise upward direction can be in turn divided into four different cases, taking into account the three different types of applications defined in sections 2.1 and 2.2:

- Direct LOS link between interferer and victim antenna (typical for type A applications);
- Interference caused by reflections from the measured surface (typical for type B applications);
- Interference caused by emissions over antenna side lobes or back lobe (typical for type B; can also occur for type A applications);
- Interference caused by leakage from shielded environments in all directions (only applicable for type C applications).

3.4.2 Terrestrial interference scenario

The scenario where the interference signal propagates along horizontal terrestrial paths near the Earth's surface is probably the most typical case. It is relevant when evaluating the compatibility of devices with the following victim systems:

- Radio astronomy service (conducted from the Earth's surface);
- Fixed service (e.g. point-to-point (PP) and broadband wireless access (BWA));
- Amateur service;
- Non-specific Short Range Devices.

MCL-based calculation method for terrestrial interference paths

Step 1: Evaluation of the noise floor and maximum permissible interference power level at the victim receiver

The evaluation of a receiver's noise floor is obtained by applying the fundamental equation of thermal noise:

$$N = kBT \tag{4}$$

where:

- N – noise power in W;
- k – Boltzmann constant, $1.381 \cdot 10^{-23}\ ^{J}/_{K}$;
- B – bandwidth in Hz;
- T – noise temperature in K.

If the victim receiver's noise is given by the noise figure (NF) the equation above can be rearranged to:

$$N_{Rx}[dBm] = -113.83\ dBm + 10 \cdot log_{10}(B_{Rx}[MHz]) + NF\ [dB] \tag{5}$$

It should be noted that the equation above requires a receiver input termination on standard noise temperature of 290 K.

If the victim receiver's noise is given by the system noise temperature T_s the following equation applies:

$$N_{Rx}[dBm] = -138.60\ dBm + 10 \cdot log_{10}(B_{Rx}[MHz]) + 10 \cdot log_{10}(T_S)[K] \tag{6}$$

The maximum permissible interference power level I_{max} at the victim system in front of the receiving antenna is obtained by taking into account the given I/N threshold (protection criterion), the gain of the receiving antenna G_a^{Rx} and possible feeder losses L_{feeder} and additional losses in the atmosphere $L_{atmosphere}$ for the terrestrial case along horizontal or slightly inclined paths close to the Earth's surface caused by atmospheric gases:

$$I_{max}[dBm] = N_{Rx} + {}^{I}/_{N} - G_a^{Rx} + L_{feeder} + L_{atmosphere} \tag{7}$$

Step 2: Calculation of the minimum coupling loss (MCL)

The minimum coupling loss is the path loss attenuation that is at least necessary to keep the interfering signal power at the victim receiver to below the interference threshold I_{max}, identified in step 1.

$$\mathrm{MCL} = \mathrm{e.i.r.p.}_{mean}^{interferer \rightarrow victim} - I_{max} + BWCF_{mean} \tag{8}$$

Where:

- $\mathrm{e.i.r.p.}_{mean}^{interferer \rightarrow victim}$ – equivalent isotropically radiated mean power of the interferer in the direction of the victim service;
- $BWCF_{mean}$ – bandwidth correction factor for correcting the mean power of the interferer's UWB transmit signal as a conditional function of its pulse repetition frequency (PRF):

$$BWCF_{mean} = \begin{cases} 10 \cdot log_{10}\left({}^{PRF}/_{B_{Tx}}\right), if\ B_{Rx} \leq PRF\ and\ B_{Tx} \geq PRF \\ 10 \cdot log_{10}\left({}^{B_{Rx}}/_{B_{Tx}}\right), if\ B_{Rx} > PRF\ and\ B_{Tx} \geq PRF \end{cases} \tag{9}$$

ECC Report 064 , section 6.3.3.2 [17] gives two more conditions for calculating $BWCF_{mean}$, which are not mentioned here as they address cases where $PRF > B_{Tx}$ which is considered as not relevant to radiodetermination devices in the higher frequency range 116 to 260 GHz.

In order to correctly evaluate the peak interference criterion for FS, the bandwidth correction factor was not applied when evaluating the peak interference criterion.

In this case the radiated power of the interferer in the direction of the victim service can consist of several components due to a potential multipath propagation environment in the used interference scenario. The interference scenario should be derived individually taking into account the peculiarities of every different radiodetermination application.

Step 3: Evaluation of the interference range

The final evaluation of the minimum interference range r_{min} is achieved by solving the inverted free space path loss model for the previously determined MCL value:

$$r_{min}[km] = 10^{\frac{MCL[dB]-32.44\,dB-20\cdot log_{10}(f[MHz])}{20}} \quad (10)$$

3.4.3 The radio horizon

The MCL calculation procedure outlined in section 3.4.2 assumes a flat terrain and line-of-sight (LOS) conditions from the interferer to the victim receiver. The radio horizon of a certain radio link depends on the antenna heights of the transmitter and receiver above the flat ground. Figure 80 shows the simplified geometrical model for determining the radio horizon. This model does not take into account any obstacles in the line of sight nor any effect of the atmosphere on the propagation of the radio frequency signal.

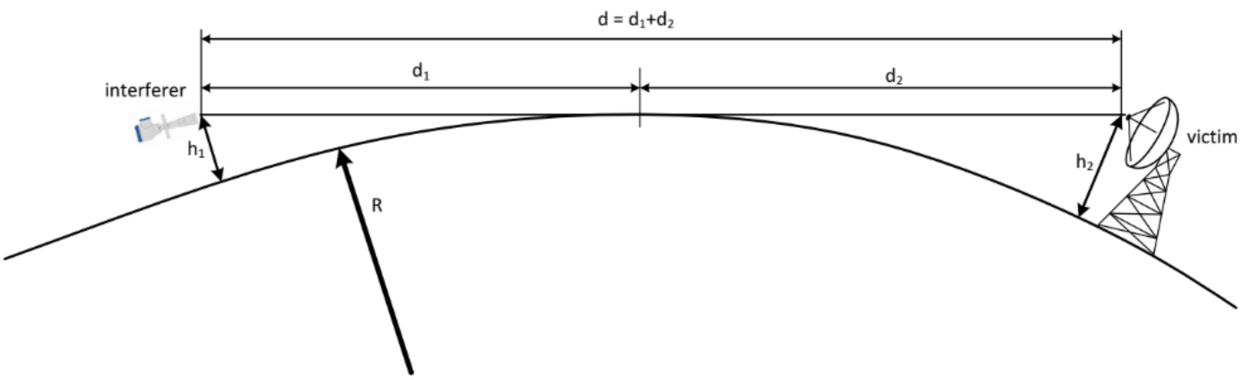


Figure 80: Geometrical illustration of the radio horizon

The radio horizon d is calculated as follows:

$$d_1 = \sqrt{\frac{8}{3}Rh_1 + h_1^2} \qquad d_2 = \sqrt{\frac{8}{3}Rh_2 + h_2^2} \quad (11)$$

$$d = d_1 + d_2$$

where:

- h_1 – antenna height above ground of interferer;
- h_2 – antenna height above ground of victim;
- R – radius of the Earth, 6371 km.

The equations above take into account the refractive effects of atmospheric layers with different temperatures under normal conditions. Under these conditions, RF signals do not propagate in straight lines but rather follow the Earth's curvature and can propagate beyond the geometrical horizon. Therefore, the radio horizon can be increased by approximately a factor of 4/3 compared to the geometrical horizon. Table 35 shows the calculated radio horizon for a representative set of interferer and victim antenna heights.

Table 35: Calculation of the radio horizon for different antenna heights of interferer and victim

Antenna height h_1 of interferer above ground (m)	Antenna height h_2 of victim including terrain height (m)	Radio horizon d (km)	Path loss FSL+0.8 dB/km (dB) (Note 1) (f = 136 GHz)	Path loss FSL+1 dB/km (dB) (Note 1) (f = 171 GHz)	Path loss FSL+3 dB/km (dB) (Note 1) (f = 237 GHz)
15	500	108	219	221	224
15	100	57	193	195	198
10	100	54	192	194	196
10	50	42	185	187	189
5	20	28	175	177	180
5	10	22	171	173	176
3	10	20	169	171	174
2	10	19	168	170	173
1.5	10	18	168	170	172
5	2187	202	262	264	267
Note 1: The attenuation in excess of free space attenuation corresponds to gas absorption in the atmosphere.					

From Table 35, it can be concluded that even for small antenna heights of 1.5 m for the interferer and 10 m for the victim still a radio horizon of 18 km exists. This is in the same range as the maximum impact ranges calculated for example for the industry automation sensors in open air applications. Therefore, the assumed free-space-loss (FSL) propagation model, which represents the most critical case, seems to be valid for this study.

The last row of Table 35 characterises the example of an interfering device in the city of Granada and the 30 m-telescope on Pico del Veleta in the Spanish Sierra Nevada (at an elevation of 2850 m above sea level) as the potential victim. The theoretical radio horizon of 202 km shows that in this scenario the application of the free-space-loss (FSL) propagation model is valid, provided that of course no obstacles within the relevant Fresnel zones interrupt the transmission.

3.4.4 Interference scenario to spaceborne passive satellite receivers

The scenario where the interference signal propagates along a slant path or a path in zenith direction towards the spaceborne satellite receiver is relevant when evaluating the compatibility of interferers with the earth exploration satellite service (EESS).

Step 1: Evaluation of the maximum permissible interference power level at the victim receiver

The protection criteria for satellite passive receivers are given as maximum interference power levels at the victim receiver over a certain reference bandwidth. These levels should not be exceeded for a given percentage of measurement time or sensor viewing area.

Step 2: Calculation of the interference level at the victim receiver

For passive satellite receivers an MCL-based approach and the calculation of an impact range is less applicable as the distance between the interferer and the victim receiver is determined by the orbital parameters of the satellite. Therefore, the power level at the victim receiver generated by the interferer may be calculated utilizing the free-space-loss and the atmospheric attenuation models; then it is compared to the relevant maximum interference level.

Since passive satellite sensors usually monitor larger areas of the Earth's surface or atmosphere, aggregation effects of several interferers within the satellite's instantaneous field of view (IFOV) may be considered from the beginning.

The interference power I at the satellite receiver usually given in dBW can be calculated using the following equation, taking into account additional losses $L_{atmosphere}$ for the spaceborne case along slant paths through the Earth's atmosphere caused by atmospheric gases:

$$\mathrm{I}[dBW] = \mathrm{e.i.r.p.}_{mean}^{interferer \rightarrow victim} - FSL + G_a^{Rx} - L_{atmosphere} + BWCF_{mean} \tag{12}$$

Where:

- FSL – free space loss on the LOS path from the interferer to the victim receiver in a distance R:

$$FSL = 20\ log_{10}\left(\frac{4\pi R}{\lambda}\right). \tag{13}$$

The radiated mean power of the interferer in the direction of the victim service $\mathrm{e.i.r.p.}_{mean}^{interferer \rightarrow victim}$ can also in this case consist of several components due to a potential multipath propagation environment in the used interference scenario or in addition due to aggregation of several interferers inside the satellite's FOV. The interference scenario should be derived individually taking into account the peculiarities of every different radiodetermination application.

Step 3: Evaluating the residual margin

In a last step the actual obtained interference power level I is compared with the maximum permissible interference power level at the victim receiver I_{max} evaluating the residual margin.

3.4.5 Interference scenario to limb sounding systems

Recommendation ITU-R RS.1861 provides e.g. the characteristics for sensor M1 which is a limb sounder operating between 114.25 and 122.25 GHz. These systems measure naturally-occurring microwave thermal emission from the limb (edge) of Earth's atmosphere to remotely sense vertical profiles of atmospheric gases, temperature, pressure, and cloud ice https://mls.jpl.nasa.gov/ [34].

Figure 81 (left) illustrates the operation of a Limb sounder. To calculate the power level at the sounder receiver, its antenna gain in the direction from where interference would be originated on the surface of the earth should be estimated. Unfortunately, Recommendation ITU-R RS.1681 does not provide information on the sensor antenna pattern. According to Recommendation ITU-R RS. 515, "Limb scan modes view the atmosphere “on edge” and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height." Since this behaviour seems be difficult to achieve from a physical point of view, the following reasoning was made to calculate the receiver antenna gain in the direction of interest.

The limb sounder gain is maximum at the tangent point height. According to [62], the satellite instrument acquires an instantaneous set of measurements at different tangent heights (TH). This height can be as low as 5 km and can go up to several tenths of km with the same instrument using sampling steps as low as 0.2 km. For the rest of the geometry, information on "Instantaneous field of view", "−3 dB beam width" and "−3 dB beam dimensions" provided in ITU-R RS.1861 can be used as illustrated in Figure 81 (right).

In Figure 81, angle β is the one defined between the direction of maximum gain and the direction of the ground. With the previous information, it is calculated as 0.52°. Assuming the typical antenna pattern for EESS (passive) sensors described in Recommendation ITU-R RS.1813, and the maximum antenna gain of 60 dBi from the Recommendation, the limb sensor antenna gain in the relevant direction is calculated as 33 dBi.

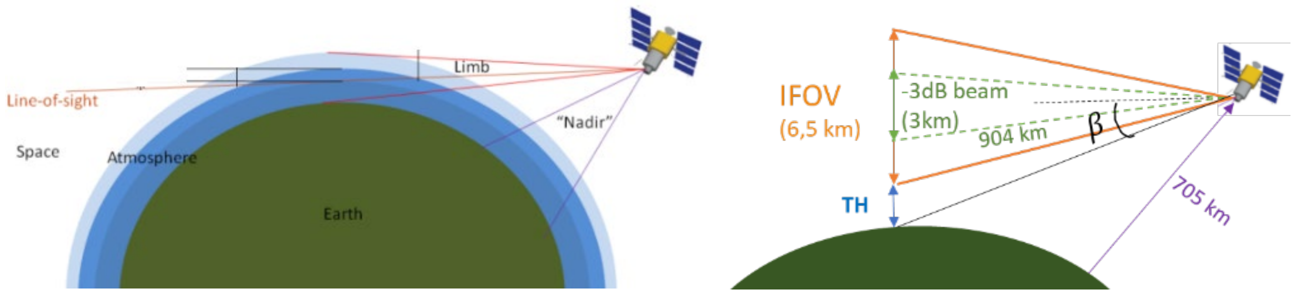


Figure 81: Operation of a Limb sounder sensor

3.5 TECHNICAL PARAMETERS AND PROTECTION CRITERIA FOR RADIO SERVICES

3.5.1 Introduction

Table 34 in section 3.2 shows an extract from the European Common Allocations (ECA) table in ERC Report 025 [3]. In the relevant frequency range from 116 to 260 GHz a very broad range of primary and secondary allocations to various radio services is defined. However, in order to limit the amount of addressed coexistence considerations to a practical degree, it is proposed to limit the studies for the candidate bands to the defined applications in the ECA table which are:

- Radio Astronomy Service (RAS);
- Fixed Service (FS);
- Earth exploration satellite service (EESS);
- Amateur Service;
- Non-specific shortrange devices.

An overview of the frequency ranges of these applications together with the proposed candidate bands (see Table 33) is given in Figure 76 to Figure 79.

When considering the range of the above identified victim services, it may be suggested to divide the possible interference scenarios into two categories:

- Interference over terrestrial paths;
- Interference to spaceborne passive satellite receivers;
- For type A applications line-of-sight (LOS) conditions can be assumed for both interference scenarios. In contrast to that for type B and C applications obviously non-line-of-sight conditions (NLOS) prevail. That means the victim can only be reached over antenna sidelobes, reflections, scattering or by penetrating a shielding enclosure.

3.5.2 Radio Astronomy Service

Radio astronomy systems make observations across the whole of the accessible electromagnetic spectrum, which extends well beyond the visual or "optical" region. Every frequency range provides its own insights and usually requires its own variety of telescopes and detectors. Radio astronomers study objects that radiate or absorb energy at frequencies within the radio spectrum: when ground-based, studies are conducted wherever the atmosphere is at all transparent in the range 13 MHz to 2 THz (compare Handbook on Radio Astronomy [8]).

Millimetre radio astronomy spans the range 72-275 GHz (sub-mm above these frequencies). This range gives unique insights into many aspects of the Universe. Unlike at lower frequencies, the main continuum emission mechanism in the mm range is through thermal emission (emission from a black body), allowing sampling of the distribution and physical properties of dust in various environments. Many molecules, free radicals or ions have their rotation lines within this range (as partly reflected in Recommendation ITU-R RA.314-10 [31]). As of February 2019, around 200 molecules (with up to 12 atoms) have been detected in the interstellar medium and circumstellar shells [30]. The majority of these detections have been made by millimetre radio telescopes; half of these detections were made by the IRAM 30 m antenna alone.

The high frequency of observation permits a better angular resolution for a given instrument size. This is one of the main reasons behind the Event Horizon Telescope, a world-wide astronomical collaboration aiming at imaging the event horizon of the supermassive blackhole at the centre of our galaxy with Very-Long Baseline Interferometry (VLBI).

Last in this non-exhaustive list, the mm domain is a way to sample the Universe in its infancy since the redshift of the infrared peak of galaxies compensates (or more) for the dimming due to distance. Hence the most distant (and youngest) objects in the Universe are detected in the mm-range.

The threshold levels of interference detrimental to Radio astronomy continuum observations (CO), spectral-line observations (SLO) and very long baseline interferometry (VLBI) can be found in Recommendation ITU-R RA.769-2 [9] for centre frequencies from 13.385 MHz up to 270 GHz. Table 36 to Table 38 show the protection criteria for CO, SLO and VLBI in or near the relevant frequency ranges for this study.

Table 36: Radio astronomy protection criteria for continuum observations

Centre frequency (GHz)	Assumed bandwidth Δf (MHz)	Threshold Interference input power ΔPH (dBW)	Reference
89	8000	-189	ITU-R RA.769-2, table 1
150	8000	-189	
224	8000	-188	
270	8000	-187	

Table 37: Radio astronomy protection criteria for spectral-line observations

Frequency (GHz)	Assumed bandwidth Δf (MHz)	Threshold Interference input power ΔPH (dBW)	Reference
88.6	1	-209	ITU-R RA.769-2 , table 2
150	1	-209	
220	1	-207	
265	1	-206	

Table 38: Threshold interference level for VLBI observations

Centre frequency (GHz)	Threshold level dB(W/(m²·Hz))	Reference
86	-172	ITU-R RA.769-2, table 3

For the RAS compatibility studies in this Report continuum observations are assumed, as this is the most sensitive observing mode. The frequency range of interest (116 to 260 GHz) is not well sampled by the Recommendation ITU-R RA.769-2, table 1 [9] entries, but the recommendation also gives guidance on how to calculate the threshold values, which primarily depend on the atmospheric and receiver contributions to the antenna system temperature.

Following Recommendation ITU-R RA.769-2 and according to the latest information from experts in low-noise receiver developments, the receiver noise temperature can be modelled according to the following formula:

$$T_R = \max\left(30K, \frac{4hf}{k_B}\right) \tag{14}$$

where:

- h and k_B are the Planck and Boltzman constants;
- f the frequency under consideration.

Figure 82 shows the evolution of T_R with frequency.

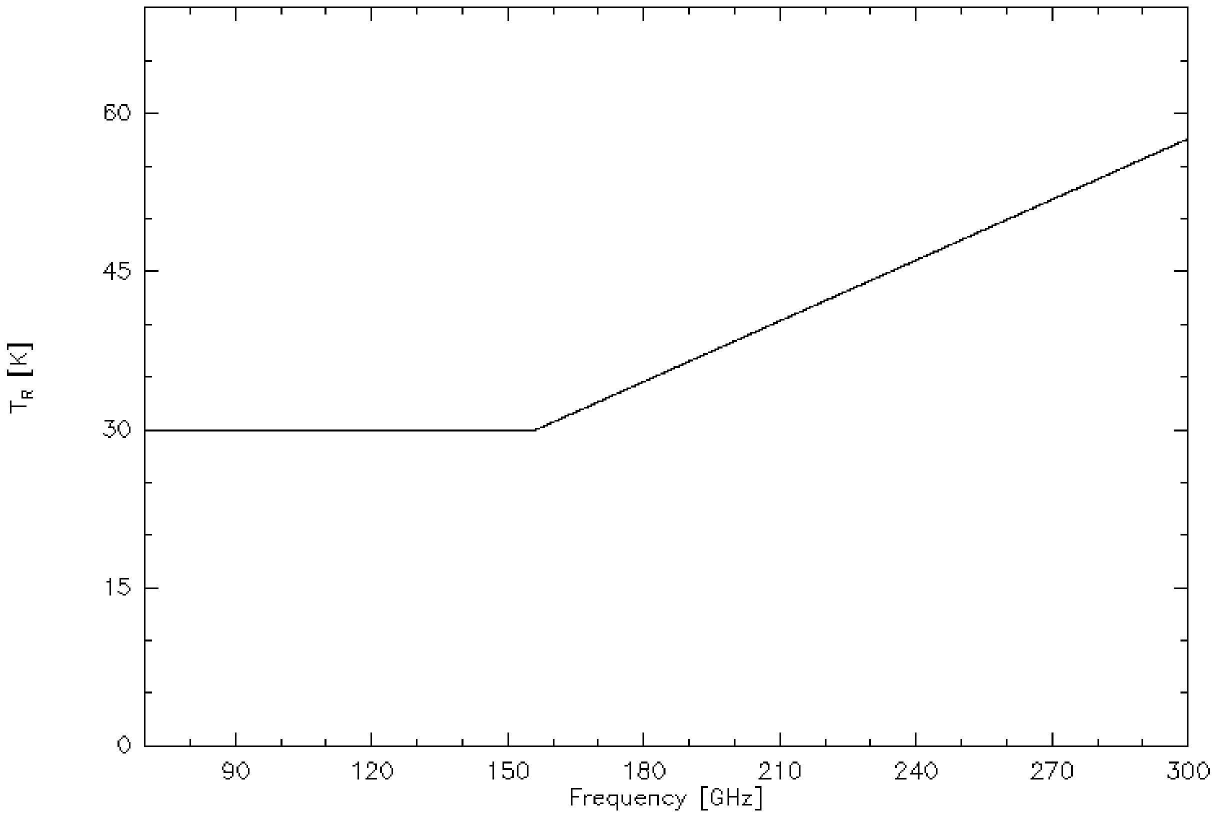


Figure 82: Receiver noise temperature T_R as a function of frequency

Following Recommendation ITU-R RA.769-2, the minimum atmospheric noise temperatures were computed for the Atacama Large Millimeter/submillimeter Array (ALMA) [45] site. Our computations reproduce those indicated in the Tables 1 and 2 in Recommendation ITU-R RA.769-2 at the specified frequencies. The spectral line channel bandwidth applicable in the 70 GHz to 300 GHz range is 1 MHz. However, the frequency spacing used in Figure 83 and Figure 84 is 40 MHz for practical reasons. The calculation can be done on a finer grid if needed

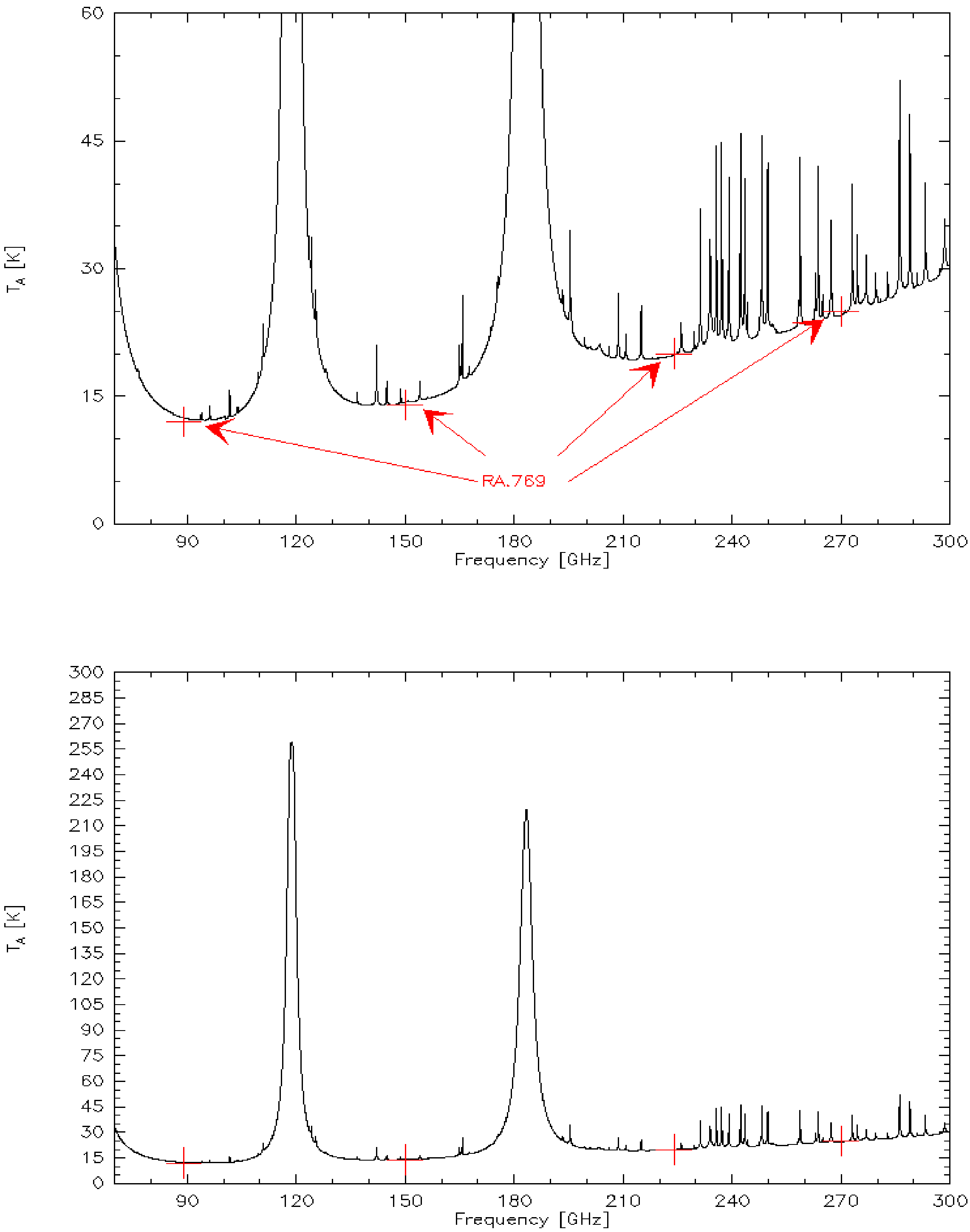


Figure 83: Minimum atmospheric noise temperature T_A as a function of frequency. Values contained in Recommendation ITU-R RA.769-2 are indicated by the red crosses (at 89, 150, 224 and 270 GHz)

Figure 83 shows the evolution of T_A with frequency. The prominent atmospheric lines of O2 (below 70 GHz and at 116 GHz), H2O (at 183 GHz) and the many fainter and narrower O3 lines are clearly visible. The numbers in Recommendation ITU-R RA.769-2 were computed assuming certain RAS receiver bandwidths. Above 100 GHz, a bandwidth of 8 GHz is typically applied to calculate the entries for continuum observations. Therefore, the effective atmospheric temperature as displayed in Figure 83 needs to be smoothed with a box-car filter of width 8 GHz before using the numbers for the power threshold calculation. The result of the box-car filtering is presented in Figure 84.

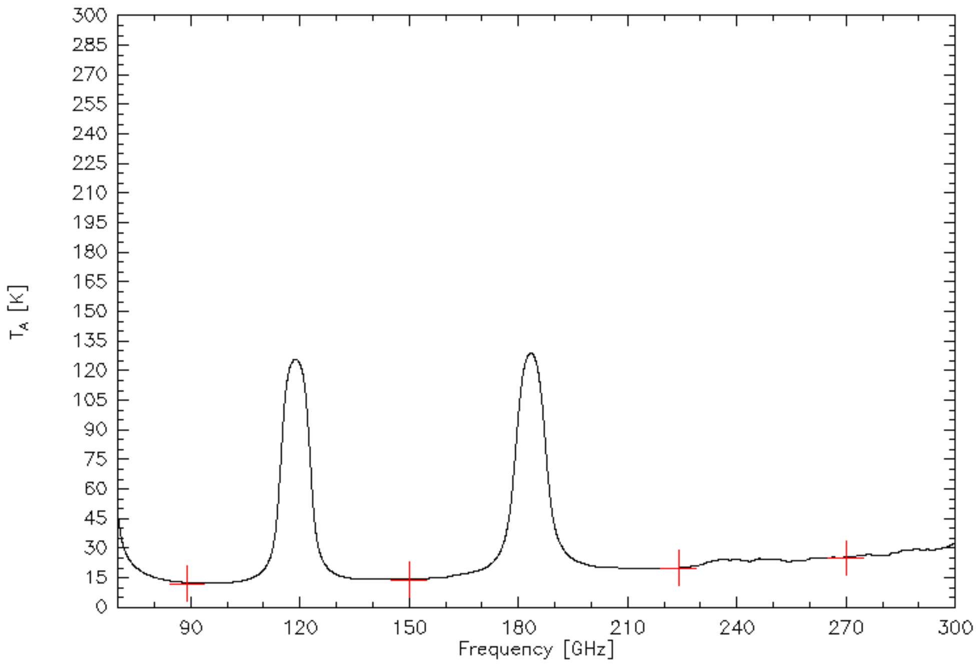


Figure 84: Minimum atmospheric noise temperature T_A after smoothing with a box-car filter (kernel width: 8 GHz)

With the atmospheric and receiver contributions to the antenna temperature, RAS power threshold limits can be calculated for any frequency, assuming a RAS bandwidth of 8 GHz. For the subsequent studies in this report, the bands and resulting power threshold levels presented in Table 39 are used. It has to be noted that for the RAS compatibility study in section 4 a different atmospheric propagation algorithm was used (namely the one proposed in Recommendation ITU-R P.676-12 [28]), which produces slightly different results compared to the (more site-specific) atmospheric model used at the Atacama Large Millimeter/submillimeter Array (ALMA) [45], which formed the basis for the table entries in Recommendation ITU-R RA.769-2. The least deviation is obtained when the "high latitude summer" profile (see Recommendation ITU-R P.835-6 [29]) is used.

Table 39: RAS frequency bands and power threshold levels used in this Report

Centre frequency (GHz)	T_R (K)	T_A (K)	Threshold level dBW
116	30.0	98.4	-184.5
120	30.0	111.8	-184.1
130	30.0	12.5	-189.3
140	30.0	10.7	-189.5
160	30.7	13.9	-189.1
185	35.5	173.3	-182.4
210	40.3	20.3	-187.8
260	49.9	25.9	-186.8

3.5.3 Fixed Service (FS)

Fixed service (FS) systems are used in telecommunication networks in various situations e.g. for:

- Transport networks (trunking, multi-hop, long-haul connections);
- Mobile backhaul networks;
- Fixed wireless access (FWA) systems;
- Temporary networks (e.g. for disaster relief or electronic news gathering).

Significant recent and ongoing increases in data traffic have led to the requirement for network services of being capable of supporting very high data rates. A consequence of these evolution has been an increased use of new higher frequency bands by FS for shorter distances since higher frequencies are associated with wider bandwidths, higher capacity and smaller antenna dimensions. Consequently, there is increasing interest in the 60 GHz (57-64 GHz) and the 70 to 80 GHz (71-76 GHz and 81-86 GHz) bands (see Report ITU-R F.2323-0 [15]). Even some applications operating in the frequency band above 275 GHz such as the point-to-point backhaul and fronthaul for mobile services are introduced and the ultra-high-speed data transmission between fixed stations become feasible.

The technical parameters and protection criteria for Fixed Services (FS) in the frequency ranges from below 1 GHz up to the bands 71-76 GHz and 81-86 GHz can be found in Recommendation ITU-R F.758-7 [10]. For the higher frequency range from 275-450 GHz Report ITU-R F.2416-0 [11] may be consulted. Information on the frequency range from 116 to 260 GHz, is in sections 3.5.3.1 and 3.5.3.2 .

3.5.3.1 Protection criteria

In order to assess the impact of radiodetermination on the FS, it is proposed to adopt the following protection criteria:

- A long-term protection criterion of I/N = -20 dB (see Recommendation ITU-R F 758-7, table 4) for not co primary services not to be exceeded for more than 20% of time.
- Beside the long-term criterion for all UWB applications an Ipeak/N < +5 dB/50 MHz should be considered[3].

It is understood that radiodetermination devices are continuously emitting, therefore, the short-term criteria are not relevant.

3.5.3.2 Fixed service parameters

SE19 considered the parameters that were provided by SE24 valid for the bands 71-76 GHz/81-86 GHz, reviewed the provided table and agreed that the following parameters should be taken into account for the studies.

Table 40: FS parameters in the frequency range 71−260 GHz

System parameter	71-86 GHz (E-band)	92-114.25 GHz (W-band)	130-175 GHz (D-band)	175-260 GHz	References
Receiver noise figure (dB)	10	12	14	16	Extrapolated from Recommendation ITU-R F. 758-7 (for 80 GHz)
Receiver noise power density typical (dBW/MHz)	-134	-132	-130	-128	
Channel bandwidth	Nx250 MHz up to 5 GHz				Extrapolated from ECC Recommendation (18)01 [22] and ECC

[3] However, in those higher bands, the typical FS bandwidth can be considered of 1000 MHz; therefore, in principle, the same limitation (+5 dB) should be evaluated within 1000 MHz rather than 50. Provided that the "N" increases as 10logB, while I_{peak} would increase with higher rate (ideally as 20logB), the peak limitation would become even tighter (or in any case closer to the real UWB peak, being the FS BW comparable to UWB BW).

System parameter	71-86 GHz (E-band)	92-114.25 GHz (W-band)	130-175 GHz (D-band)	175-260 GHz	References
	(noting that current regulation does not set any upper limit for BW)				Recommendation (18)02 [46]
Antenna losses (dB)	0−3				Extrapolated from Report ITU-R F.2416
Antenna gain (dBi)	24−50				
Antenna class	2/3				Extrapolated from the 80 GHz band in ETSI EN 302 217-4 [49]
Antenna height (m)	6 (light pole/Kiosk) to 25 (rooftop)				Extrapolated from Report ITU-R F.2416
Antenna elevation (degrees)	Typically, less than ±20[4],[5]				

SE19 also would like to provide the reference to ECC Report 282 [18] for additional information about FS systems in these ranges.

In particular, ECC Recommendation (18)01 [22] contains specific channel arrangements for the FS allocated bands within the range 130-174.8 GHz and ECC Recommendation (18)02 [46] for the range 92-114.25 GHz.

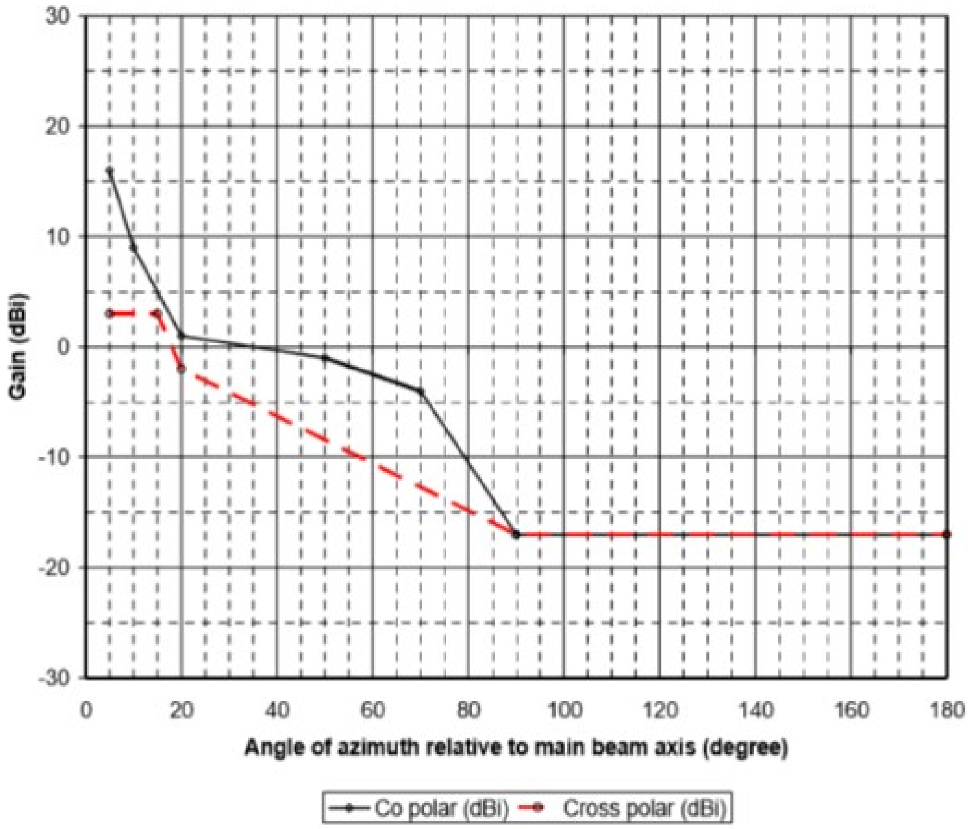
Further SE19 was informed by ITU-R WP 5C about its studies for extending the applicability of antenna reference radiation patterns above 86 GHz, in order to possibly update Recommendations ITU-R F.699-8 [47] and ITU-R F.1245-3 [48], which provide reference radiation patterns to be used for coexistence studies.

For the time being indoor applications are considered potentially possible, but in very specific and limited cases (ECC Report 282, section 6.3 [18].

The radiation pattern envelope (RPE) for a class 3 antenna, which is the one representative for FS in the field, is shown in Figure 85.

[4] The antenna heights in the urban area are estimated in the range 6-25 m.

5 In order to taking in account the different urban areas around the world, it is assumed that a typical elevation would be less than ±20 degrees. The elevation angles of the antenna are calculated from the antenna height of FS stations and the distance between FS links. Although the distance between the base stations in the dense urban area is also indicated to be 200 m, the distance range of 100-300 m is assumed to be used for calculation of elevation angle of antenna.



Angle (°)	Co-polar (dBi)	Angle (°)	Cross-polar (dBi)
5	16	5	3
10	9	15	3
20	1	20	-2
50	-1	60	-10
70	-4	90	-17
90	-17	180	-17
180	-17		

Figure 85: Class 3 antenna RPE (71 GHz – 86 GHz) according to ETSI EN 302 217-4 V2.1.1 (2017-05)

3.5.4 Earth Exploration Satellite Service (passive)

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 data derived from these passive sensor operations are used extensively in meteorology, climatology, and other disciplines for operational and scientific purposes. These sensors are sensitive to in-band emissions. Therefore, RF emissions above a certain level may constitute interference to the passive sensors using the same frequency bands. This is mainly due to the fact 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 output data (see Recommendation ITU-R RS.1861 [13]).

3.5.4.1 Technical and operational characteristics of EESS

Typical technical and operational characteristics of Earth Exploration-Satellite Service (passive) systems using allocations between 1.4 and 275 GHz for utilization in sharing studies can be found in Recommendation ITU-R RS.1861 [13]. The frequency bands and bandwidths used for satellite passive remote sensing with information on specific measurements conducted in these frequency bands (meteorology-climatology, chemistry) can be furthermore extracted from Recommendation ITU-R RS.515-5 [14].

Sections 6.13 to 6.17 of Recommendation ITU-R RS.1861 [13] are relevant to this Report, noting that section 6.15 addresses frequency band 155.5-158.5 GHz in which the EESS (passive) allocation has been suppressed at the last WRC-19.

Table 41, Table 42, Table 43,Table 44 and Table 45 provide the technical and operational characteristics for the various EESS (passive) bands between 114 and 260 GHz. The corresponding EESS (passive) sensors are either taken from Recommendation ITU-R RS.1861 or from ESA/EUMETSAT existing or planned sensors.

Table 41: Passive sensor parameters in the 114.25 to 122.25 GHz band

EESS sensor	MWI	Planned EUMETSAT radiometer (ECC Report 190 [21])
Type of sensor	Conical Scan	Conical Scan
Orbit altitude (km)	830	800
Nadir angle (°)	45.2	45.2
Slant path distance (km)	1269	1219
Free space loss (dB)	195.7	195.3
Elevation angle at ground (°)	36.7	37.0
Attenuation due to atmospheric gases (dB)	3.2	3.2
Reference bandwidth (MHz)	200	200
EESS protection criterion (dBW/reference bandwidth)	-166	-166
Apportionment factor (dB)	12	12
EESS protection criterion (with relevant apportionment) (dBW/reference bandwidth)	-178	-178
EESS sensor antenna gain (dBi)	55.5	55
EESS footprint size (km²)	82	82

Table 42: Passive sensor parameters in the 148.5 to 151.5 GHz band

EESS sensor	System N1 (Nadir)	System N1 (Outer)
Type of sensor	Nadir Scan	Nadir Scan
Orbit altitude (km)	705	705
Nadir angle (°)	0	48.95
Slant path distance (km)	705	1166
Free space loss (dB)	192.8	197.2
Elevation angle at ground (°)	90.0	33.1

EESS sensor	System N1 (Nadir)	System N1 (Outer)
Attenuation due to atmospheric gases (dB)	2	3.8
Reference bandwidth (MHz)	500	500
EESS protection criterion (dBW/reference bandwidth)	-159	-159
Apportionment factor (dB)	12	12
EESS protection criterion (with relevant apportionment) (dBW/reference bandwidth)	-171	-171
EESS sensor antenna gain (dBi)	45	45
EESS footprint size (km²)	154	759

Table 43: Passive sensor parameters in the 164 to 167 GHz band

EESS sensor	System P1	System P2 (Nadir)	System P2 (Outer)
Type of sensor	Conical Scan	Nadir Scan	Nadir Scan
Orbit altitude (km)	828	824	824
Nadir angle (°)	46.8	0	52.725
Slant path distance (km)	1316	824	1563
Free space loss (dB)	199.1	195.1	200.6
Elevation angle at ground (°)	34.5	90.0	26.0
Attenuation due to atmospheric gases (dB)	5.7	3.2	7.4
Reference bandwidth (MHz)	200	200	200
EESS protection criterion (dBW/reference bandwidth)	-163	-163	-163
Apportionment factor (dB)	12	12	12
EESS protection criterion (with relevant apportionment) (dBW/reference bandwidth)	-175	-175	-175
EESS sensor antenna gain (dBi)	54	43.9	43.9
EESS footprint size (km²)	113	254	2083

Table 44: Passive sensor parameters in the 174.8 to 191.8 GHz band

EESS sensor	MHS (Nadir)	MHS (outer)	MWI	MWS (nadir)	MWS (outer)	ICI	AWS (Nadir)	AWS (outer)
Type of sensor	Nadir Scan	Nadir Scan	Conical Scan	Nadir Scan	Nadir Scan	Conical Scan	Nadir Scan	Nadir Scan
Orbit altitude (km)	822	822	830	830	830	830	600	600

EESS sensor	MHS (Nadir)	MHS (outer)	MWI	MWS (nadir)	MWS (outer)	ICI	AWS (Nadir)	AWS (outer)
Nadir angle (°)	0	49.4	45.2	0	49	45.2	0	49
Slant path distance (km)	822	1400	1269	830	1400	1269	600	980
Free space loss (dB)	195.6	200.2	199.4	195.7	200.2	199.4	192.9	197.1
Elevation angle at ground (°)	90.0	31.0	36.7	90.0	31.5	36.7	90.0	34.3
Attenuation due to atmospheric gases (dB)	8.3	16	13.8	8.3	15.8	13.8	8.3	14.7
Reference bandwidth (MHz)	200	200	200	200	200	200	200	200
EESS protection criterion (dBW/reference bandwidth)	-163	-163	-163	-163	-163	-163	-163	-163
Apportionment factor (dB)	12	12	12	12	12	12	12	12
EESS protection criterion (with relevant apportionment) (dBW/reference bandwidth)	-175	-175	-175	-175	-175	-175	-175	-175
EESS sensor antenna gain (dBi)	44.8	44.8	56.9	43	43	52	50	50
EESS footprint size (km²)	201	1103	61	315	1762	164	28	141

Table 45: Passive sensor parameters in the 226 to 252 GHz band

EESS sensor	AWS (Nadir)	AWS (outer)	AWS (Nadir)	AWS (outer)	ICI
Type of sensor	Nadir Scan	Nadir Scan	Nadir Scan	Nadir Scan	Conical Scan
Orbit altitude (km)	600	600	600	600	830
Nadir angle (°)	0	49	0	49	45.2
Slant path distance (km)	600	980	600	980	1269
Free space loss (dB)	195.1	199.4	195.6	199.8	202.1
Elevation angle at ground (°)	90.0	34.3	90.0	34.3	36.7

EESS sensor	AWS (Nadir)	AWS (outer)	AWS (Nadir)	AWS (outer)	ICI
Attenuation due to atmospheric gases (dB)	4.8	8.5	5.3	9.3	8.8
Reference bandwidth (MHz)	200	200	200	200	200
EESS protection criterion (dBW/reference bandwidth)	-160	-160	-160	-160	-160
Apportionment factor (dB)	12	12	12	12	12
EESS protection criterion (with relevant apportionment) (dBW/reference bandwidth)	-172	-172	-172	-172	-172
EESS sensor antenna gain (dBi)	50	50	50	50	52
EESS footprint size (km²)	28	141	28	141	164

For Nadir and Conical scan EESS (passive) sensors, the calculation of the maximum emissions levels on the ground from a population of UWB radars operated within the EESS (passive) footprint area is calculated as follows:

$$E_{max} = I_{max} - G_{max} + L_{Atmos} + L_{FS} \tag{15}$$

where:

- E_{max} – max. emission level on Earth's ground in the direction towards the satellite (in dBW in the reference bandwidth);
- I_{max} – EESS (passive) protection criteria (with appropriate apportionment, in dBW in the reference bandwidth);
- G_{max} – EESS (passive) maximum antenna gain (in dBi);
- L_{Atmos} – Atmospheric losses (at relevant elevation, in dB);
- L_{FS} – Free space loss (along the slant path D, in dB).

The Earth-satellite geometry to be considered for the case of Nadir and Conical scanning instruments is described in Figure 86.

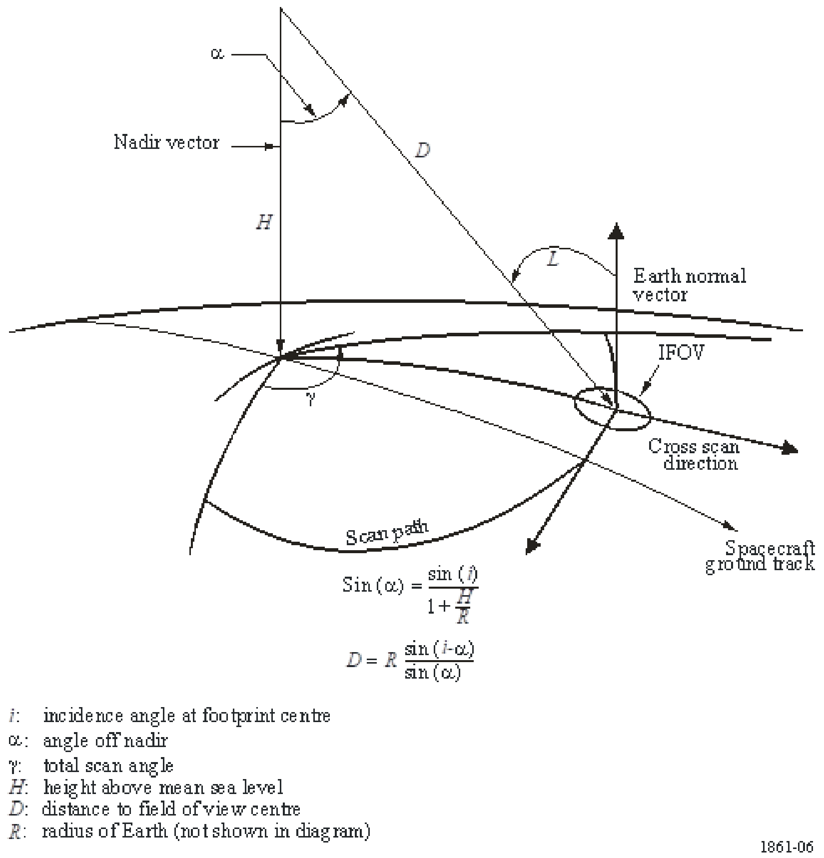


Figure 86: Earth-satellite geometry for the nadir and conical scanning EESS (passive) sensors

Table 46 summarises the various scenarios to be addressed for the different EESS (passive) bands and type of radars.

Table 46: Envisaged in-band and adjacent usage scenarios for the different EESS (passive) bands

Frequency band (GHz)	EESS usage	Generic indoor radar	RDI	SR-assist	GBSAR	LPR, CDR and TLPR	RDI-S
114.25 to 116	Passive FN 5.340	Adjacent	Adjacent	Adjacent		Adjacent	Adjacent
116 to 122.25	Passive	In-band	In-band	In-band		In-band	In-band
148.5 to 151.5	Passive FN 5.340	Adjacent		Adjacent	Adjacent	Adjacent	In-band
164 to 167	Passive FN 5.340					Adjacent	In-band
174.8 to 182	Passive		In-band			In-band	In-band
182 to 185	Passive FN 5.340		Adjacent			Adjacent	In-band
185 to 190	Passive		In-band				In-band

Frequency band (GHz)	EESS usage	Generic indoor radar	RDI	SR-assist	GBSAR	LPR, CDR and TLPR	RDI-S
190 to 191.8	Passive FN 5.340		Adjacent				In-band
200 to 209	Passive FN 5.340						In-band
226 to 231.5	Passive FN 5.340		Adjacent			Adjacent	In-band
235 to 238	Passive		In-band			In-band	In-band
239.2 to 242.2	AI 1.14 (ICI-4) (Note 1)		In-band			In-band	In-band
244.2 to 247.2	AI 1.14 (ICI-4) (Note 1)		In-band			In-band	In-band
250 to 252	Passive		Adjacent			Adjacent	In-band
Note 1: WRC-23 agenda item 1.14 "to review and consider possible adjustments of the existing or possible new primary frequency allocations to EESS (passive) in the frequency range 231.5-252 GHz, to ensure alignment with more up-to-date remote-sensing observation requirements, in accordance with Resolution 662 (WRC-19)".							

3.5.4.2 Protection criteria

Information on the performance and interference criteria for satellite passive remote sensing of the Earth and its atmosphere for microwave passive sensors can be found in Recommendation ITU-R RS.2017-0 [12]. An extract from this Recommendation dealing with interference criteria for the frequency range from 86 to 285.4 GHz is shown in Table 47.

Table 47: Interference criteria for satellite passive remote sensing in the frequency range 86 to 285.4 GHz (extract from ITU-R RS.2017-0 Table 2)

Frequency band(s) (GHz)	Reference bandwidth (MHz) (Note 3)	Maximum interference level (dBW) (Note 3)	Percentage of area or time permissible interference level may be exceeded (%) (Note 1)	Scan mode (Note 2)
86-92	100	-169	0.01	N, C
100-102	10	-189	1	L
109.5-111.8	10	-189	1	L
114.25-116	10	-189	1	L
115.25-122.25	200/10	-166/-189	0.01/1	N, L
148.5-151.5	500/10	-159/-189	0.01/1	N, L
155.5-158.5 (Note 4)	200	-163	0.01	N, C
164-167	200/10	-163/-189	0.01/1	N, C, L

Frequency band(s) (GHz)	Reference bandwidth (MHz) (Note 3)	Maximum interference level (dBW) (Note 3)	Percentage of area or time permissible interference level may be exceeded (%) (Note 1)	Scan mode (Note 2)
174.8-191.8	200/10	-163/-189	0.01/1	N, C, L
200-209	3	-194	1	L
226-231.5	200/3	-160/-194	0.01/1	N, L
235-238	3	-194	1	L
250-252	3	-194	1	L
275-285.4	3	-194	1	L

Note 1: For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km², unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km² unless otherwise justified; for a 1% level, the measurement time is 24 h, unless otherwise justified.
Note 2: N: Nadir, Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions. L: Limb, Limb scan modes view the atmosphere "on edge" and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height. C: Conical, Conical scan modes view the Earth's surface by rotating the antenna at an offset angle from the nadir direction.
Note 3: First number for nadir or conical scanning modes and second number for microwave limb sounding applications.
Note 4: The EESS (passive) allocation in the band 155.5-158.5 GHz has been suppressed at the last WRC-19.

Finally, it should also be considered that under WRC-23 agenda item 1.14, a review of EESS (passive) allocations will have to be addressed in the range 231.5-252 GHz. This would in particular concern the EUMETSAT systems ICI and its specific channels at 239.2-242.2 GHz and 244.2-247.2 GHz.

The EESS (passive) protection criteria for the band 226-231.5 GHz is given in Recommendation ITU-R RS.2017 as -160 dBW/200 MHz for Nadir and Conical scan systems associated with a percentage of area or time it may be exceeded of 0.01%.

For the range 239-248 GHz that is considered under WRC-23 agenda item 1.14 and is hence not addressed yet in Recommendation ITU-R RS.2017, it is proposed to consider the same protection criteria.

3.5.4.3 Apportionment

Recommendation ITU-R RS.2017 [12] specifies the "Maximum interference level (dBW)", within an associated "Reference bandwidth (MHz)", that may be received at the EESS sensor from all sources. There is currently no agreed method within ITU-R and CEPT describing how this maximum interference level should be applied where compatibility with multiple services is required.

When considering UWB applications (i.e. as an underlay technology), one can refer to previous work performed in ECC and ITU-R and in particular Report ITU-R SM.2057 [69] proposing to retain a "1 to 5% apportionment of the interference criteria" for EESS (passive). Such apportionment values represent a factor of 20 dB and 13 dB, respectively, that was used in interference calculations in this Report ITU-R SM.2057.

The EESS (passive) bands between 116 and 260 GHz are already and will continue to be subject to emissions from different Radio Services that occupy spectrum both in and adjacent to the bands under study (e.g. Fixed Service, with relevant unwanted emission levels already given in ECC Recommendation (18)01 [22] and ECC Recommendation (18)02 [46], or wanted in-band emissions for very specific cases such as ISS or FSS in bands not covered by RR footnote 5.340.

Based on the number of allocated incumbent services an apportionment factor of 12 dB was used for all frequency bands and for each UWB radiodetermination application individually (see section 2.2). This value and an additional safety margin was also applied to bands which are protected by RR No. 5.340.

Other approaches could be applied to consider a band-by-band assessment to establish a realistic interference environment and determine an appropriate apportionment factor to ensure protection of the EESS (passive). The following factors should be considered:

- the physical geometries of the different services;
- the timing aspects of the different services;
- appropriate deployment scenarios, i.e. where fixed and mobile services have allocations;
- the number of services with concurrent operation and their relative emission levels.

The band-by-band considerations of the allocations to Radiocommunication Services and other UWB-applications and the resulting derivation of the worst-case apportionment factor can be found in Annex 8.

3.5.4.4 Aggregation

At a given time, interference to EESS (passive) is produced by all radio transmitters present in the sensor footprint (IFOV). The size of the footprint mainly depends on the orbit height, nadir angle and antenna 3 dB beamwidth, and can be in the range of several tens to several hundreds of km² (see section 3.5.4.1). As far UWB radiodetermination applications are concerned, the aggregation from all transmitters in the EESS (passive) footprint will have to be assessed. Considering the number of different radar applications covered, this could probably represent very large numbers of interfering sources for which the aggregate impact cannot be neglected.

To this respect, the notion of “percentage of area or time permissible interference level may be exceeded” associated to the EESS (passive) protection criteria also need to be considered.

For the case where the percentage is 0.01% (i.e. for a 99.99% data availability in all bands where Nadir and Conical sensors are operated), the reference “measurement area is a square on the Earth of 2000000 km²”. Over this area that represents roughly western Europe, the interference protection criteria can only be exceed over a total area of 200 km² (0.01% x 2000000 km²).

This means that for Nadir and Conical EESS (passive) sensors, the protection criteria can be exceeded for a single footprint position or for very few positions over the whole western Europe. Considering the large and ubiquitous deployment of UWB radars, this roughly means that interference analysis can be addressed on a static basis for a worst-case position of the EESS (passive) footprint and the worst-case deployment of UWB radiodetermination systems.

3.5.5 Amateur Service

The Amateur Service is the oldest radio service and pre-dates regulation of radiocommunication. The original reason for regulation of the radio spectrum was to improve maritime safety and to ensure that coast stations would communicate with all ships, not just those using their company’s equipment. In 1912, amateurs could use any frequency above 1.5 MHz, as they were regarded as “of no commercial value for maritime, governmental and commercial communications”. However, the value of the higher frequency bands was recognised in the 1920s. Today, the Amateur Service retains relatively narrow bands throughout the entire radio spectrum. These bands provide the whole range of radio wave propagation mechanisms and, through experimentation, amateurs have contributed to the understanding of propagation. Amateur radio continues to play an important role in disaster communications. It has a unique ability to provide radiocommunication independent of the telephone network or other radio services, particularly in the first few days before relief agencies are at the scene and have set up emergency telecommunication services (see Handbook on Amateur and amateur-satellite services [16]).

The amateur and amateur-satellite services have allocations within the range of study at 122, 134 and 241 GHz as documented in Section 3.2 (see Table 34). Whilst past use has been inhibited by equipment availability, ongoing experimentation, high performance frequency sources and innovative adaptation of commercial chipsets has led to growth in activity which can be currently categorised as:

- Weak-signal reception of Narrowband (e.g. CW-Morse or Voice) terrestrial operation in harmonised sub-bands;
- Growing use of wider bandwidth modes, such as Digital Amateur TV (DATV) and data links;

- Usage of fixed beacon transmitting stations for propagation research and equipment alignment.

In general, most amateur stations are currently portable low-power directional systems with high gain antennas. In order to maximise long-range communications, operation is often from hilltops where they can achieve line of sight contacts up to 50 km.

Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies can be extracted from Recommendation ITU-R M.1732-2 [56] and are illustrated in Table 48 for the applicable frequency range in this study.

Table 48: Technical characteristics of various amateur systems in the frequency range 76 to 250 GHz (extract from Recommendation ITU-R M.1732-2, tables 1 to 8)

Parameter	Amateur system						
	Morse on-off keying	Analogue voice	Data, digital voice and multimedia	Earth-Moon-Earth (EME) systems	Amateur satellite		
					Earth-to-space	Space-to-Earth for LEO	Space-to-Earth for GEO/HEO
Feeder loss (dB) (Note 2)	0 to 6	0 to 6	0 to 6	1 to 4	1 to 10	0.2 to 2	0.2 to 2
Transmitting antenna gain (dBi) (Note 2)	10 to 52	10 to 52	10 to 52	35 to 65	10 to 52	0 to 23	0 to 30
Receiver IF bandwidth (kHz)	0.5	2.7 9 12 16	2.7 6 16 150 10500	2.4	0.4 2.7 16 50 100 400 10000	0.4 2.7 16 50 100 400 10000	0.4 2.7 16 50 100 400 10000
Receiver noise figure (dB)	3 to 7	3 to 7	3 to 7	3 to 7	3 to 7	3 to 7	3 to 7
I/N criteria (dB) (Note 1)	-6/-10	-6/-10	-6/-10	-6/-10	-6/-10	-6/-10	-6/-10

Note 1: For applications with greater protection requirements, such as public protection and disaster relief (PPDR), an I/N of −10 dB may be used to determine the impact of interference (see ITU-R M.1808 [57]).
Note 2: Feeder losses and antenna gains are only given in ITU-R M.1732-2 [56] for the transmitter case.

Further information concerning frequency sharing in the Amateur Services can be found in Recommendation ITU-R M.1044-2 [20].

4 SHARING AND COMPATIBILITY STUDIES WITH RADIO ASTRONOMY SERVICE

4.1 GENERIC INDOOR SURVEILLANCE RADAR

4.1.1 Technical parameters and interference scenario considerations of generic indoor surveillance radar sensors

4.1.1.1 Technical parameters

For hand-held/mobile and fixed generic indoor surveillance radar equipment three potential frequency bands have been defined (see section 2.2.1.2). Due to the fact that in all defined frequency bands allocations for RAS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.1.3), the interference scenarios (section 2.2.1.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report .

The following technical parameters of the hand-held/mobile and fixed generic indoor studies (section 2.2.1.6) have been used in the studies in the different frequency ranges.

Table 49: Technical parameters of generic indoor surveillance radar used for the conducted studies in the different frequency bands

Investigated frequency range	Device type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Mean e.i.r.p. (Note 2)	OOB attenuation (Note 1)
116 to 130 GHz	Hand-held/mobile	1 GHz	20%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%	-10 dBm/MHz	20 dBm	20 dB
134 to 141 GHz	Hand-held/mobile	1 GHz	20%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%	-10 dBm/MHz	20 dBm	20 dB
141 to 148.5 GHz	Hand-held/mobile	1 GHz	20%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%	-10 dBm/MHz	20 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the generic indoor surveillance radar in adjacent bands allocated to RAS.
Note 2: The duty cycles are not considered in the mean e.i.r.p. spectral density and mean e.i.r.p. values. Consequently, the given mean e.i.r.p. spectral density and mean e.i.r.p. is valid for averaging over T_{meas} (time when transmission is on, see Figure 36).

4.1.1.2 Interference scenarios-specific considerations

Due to the generic commercial nature of the devices determined for the private household, the worst-case single-entry interference scenarios were considered.

This includes the consideration of

- usage inside buildings with open windows,
- usage inside less energy efficient (traditional) buildings with low indoor-outdoor attenuation and
- abusive outdoor use.

The generic assumptions for the interference scenario are described in section 2.2.1.6. These considerations on potential scenarios led to four different single-entry interference cases:

1 Single-entry case 1:
   - No indoor-outdoor attenuation;

- Line of sight/main beam coupling;
- No clutter (quasi outdoor).

2 Single-entry case 2
- Indoor-outdoor average attenuation of 16 dB (Model according to Recommendation ITU-R P.2109-1 [23] with 70% traditional and 30% energy efficient buildings at 100 GHz and 10° elevation was used. The radio astronomy stations are assumed to be located on higher level than the considered building.);
- Line of sight/main beam coupling;
- No clutter.

3 Single-entry case 3:
- Indoor-outdoor attenuation of 13 dB (Model according to ITU-R P.2109-1 for P=15% with 100% traditional buildings at 100 GHz and 10° elevation was used);
- Line of sight/main beam coupling;
- No clutter.

4 Single-entry case 4:
- Only for fixed generic indoor surveillance radar devices. Such devices are typically radiating in a downwards direction (see description in section 2.2.1.6) and therefore a lower maximum emission (12 dBm instead of 20 dBm in main beam) over 0 degree elevation was considered;
- No indoor-outdoor attenuation;
- Line of sight/main beam coupling;
- No clutter.

4.1.2 Results

Table 50 shows the single-entry worst-case results for the in-band interference case for hand-held/mobile and fixed indoor equipment, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 50: Required separation distances determined in a single-entry study for generic indoor surveillance radar for in-band interference

Device type	Single-entry case	Required separation distances			
		Allocated RAS band: 123 to 158.5 GHz		Allocated RAS band: 123 to 158.5 GHz	
		Evaluated frequency: 126.5 GHz (lower)		Evaluated frequency: 137.5 GHz (upper)	
		RAS CO	RAS SLO	RAS CO	RAS SLO
Fixed	1	35.2 km	14 km	34.7 km	13.3 km
Fixed	4	17.5 km	6.2 km	17.0 km	5.8 km
Fixed	2	7.8 km	2.5 km	7.5 km	2.4 km
Fixed	3	10.7 km	3.5 km	10 km	3.3 km
Hand-held/mobile	1	19 km	6.8 km	18.7 km	6.4 km
Hand-held/mobile	2	3.7 km	1.1 km	3.5 km	1 km
Hand-held/mobile	3	5.1 km	1.6 km	4.9 km	1.5 km

Table 51 shows the single-entry worst-case results for the adjacent band interference case for hand-held/mobile and fixed indoor equipment, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 51: Required separation distances determined in a single-entry study for generic indoor surveillance radar for adjacent band interference

Device type	Single-entry case	Required separation distances		
		Allocated RAS band: 76 to 116 GHz	Allocated RAS band: 114.25-116 GHz (5.340)	Allocated RAS band: 148.5-151.5 GHz (5.340)
		Evaluated frequency: 113.9 GHz	Evaluated frequency: 115.125 GHz	Evaluated frequency: 150 GHz
		RAS CO (Note 1)	RAS CO (Note 1)	RAS CO (Note 1)
Fixed	1	4.9 km	4.9 km	4.3 km
Hand-held	1	2.4 km	2.4 km	1.9 km
Fixed	2	0.9 km	0.9 km	0.7 km
Hand-held	2	0.4 km	0.4 km	0.3 km
Note 1: The results for RAS spectral line observation (SLO) have not been included in this table since it turned out that the separation distances for the RAS continuum observation (CO) are always larger and therefore more critical (see also Table 50).				

The conclusions drawn from these results can be found in section 8.1.2.

4.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

4.2.1 Technical parameters of RDI

For RDI altogether five potential frequency bands have been defined (see section 2.2.2.2). Due to the fact that in all defined frequency bands allocations for RAS are affected-either within these bands or adjacent to them – all five bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.2.3), the antenna data (section 2.2.2.4), the interference scenarios (section 2.2.2.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI application (section 2.2.2.3) have been used in the studies in the different frequency ranges.

Table 52: Technical parameters of RDI used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 130 GHz	14 GHz	5%	-23.5 dBm/MHz	31 dBm	20 dB
134 to 141 GHz	7 GHz	5%	-20.5 dBm/MHz	31 dBm	20 dB

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
174.8 to 182 GHz	1.5 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
185 to 190 GHz	1.5 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
231.5 to 250 GHz	15 GHz	5%	-25.6 dBm/MHz	31 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the RDI-signal in adjacent bands allocated to RAS. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

4.2.2 Results

Table 53 shows the single-entry worst-case results for RDI, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 53: Required separation distances determined in a single-entry study for RDI

Investigated frequency range	Allocated band for RAS	Required separation distance for RAS CO	Required separation distance for RAS SLO
116 to 130 GHz	123 to 158.8 GHz (In-band)	53.3 km	10.0 km
134 to 141 GHz	123 to 158.5 GHz (In-band)	63.0 km	12.7 km
174.8 to 182 GHz	164 to 174.5 GHz (OOB)	15.3 km	2.4 km
	182 to 185 GHz (OOB)	2.9 km	1.4 km
185 to 190 GHz	182 to 185 GHz (OOB)	2.7 km	1.4 km
	190 to 231.5 GHz (OOB)	9.6 km	1.6 km
231.5 to 250 GHz	190 to 231.5 GHz (OOB)	3.7 km	0.4 km
	235 to 238 GHz (In-band)	19.9 km	3.4 km
	241 to 275 GHz (In-band)	17.6 km	3.3 km

The conclusions drawn from these results can be found in section 8.2.2.

4.3 SHORT-RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

4.3.1 Calculation of the effectual power of "Short-Range assist and Surrounding monitoring for vehicles and autonomous systems"

The following frequency bands are relevant for considering the potential for sharing (co-channel) between radio astronomy service and radiodetermination devices intended to be mounted on vehicles as described in section 2.2.3:

- 123-130 GHz;
- 130-141 GHz;
- 141-148.5 GHz.

The radiodetermination device assumed is type A, and the application analysed is the one described in section 2.2.3.

The power levels used in the simulations are derived from Figure 16, Figure 17 and Figure 18 in section 2.2.3 as follows. The lowest and the highest peak power levels correspond to the cases in which the radio location device uses bandwidths of 1 GHz and 7 GHz, respectively. Given that the application under consideration is mainly intended for close detection of small objects, which implies low RCS and few centimetres of resolution, a distance of 20 m seems reasonable as detection range. From Figure 87, this corresponds to around 48 dBm of peak power for the case of 7 GHz bandwidth (RCS of -30 dBm²).

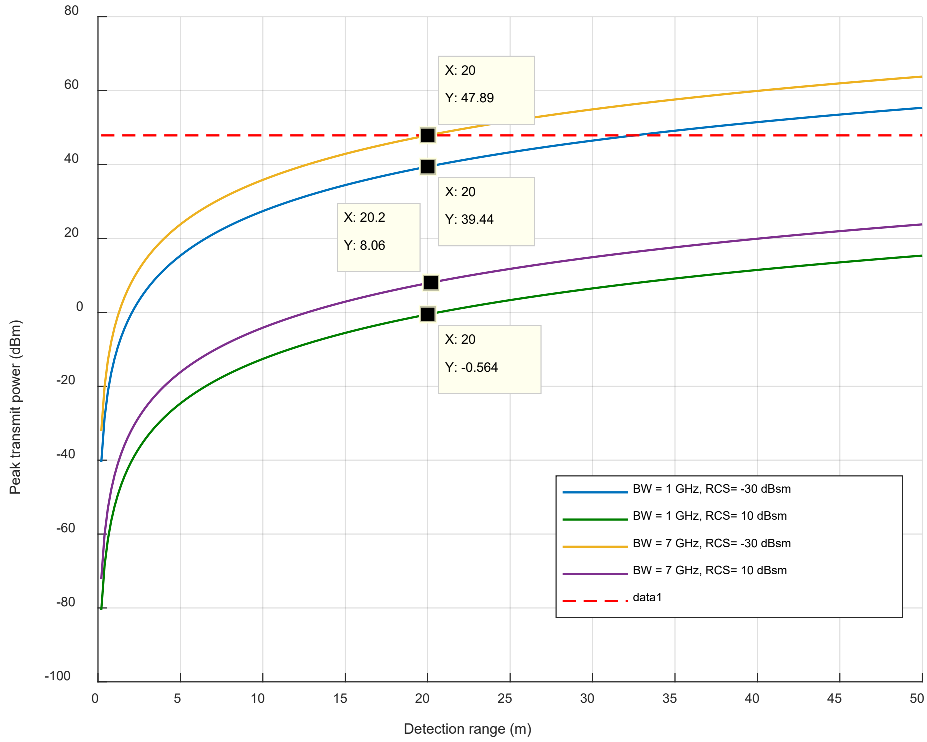


Figure 87: Highest and lowest requirements of peak power level for short-range assist and surrounding monitoring radars for vehicles

The case of a radar using smaller bandwidth typically corresponds to the detection of targets at larger distance from the vehicle performing autonomous functions. In this case, the radar does not require a precise resolution; therefore, a smaller bandwidth would be enough. Given that e.i.r.p. level considered in this study corresponds to the most demanding application in terms of range resolution and target RCS, the same value can be preserved for devices using smaller bandwidths. This leads to different e.i.r.p. density levels for different bandwidths (1 GHz and 7 GHz) but to a single e.i.r.p. value that is not bandwidth dependent.

4.3.2 Bandwidth correction factor

Given that the bandwidth values considered for this application range between 1 GHz and 7GHz, and that the RAS power threshold is provided for a reference bandwidth of 8 GHz, there is no need to apply a bandwidth correction for the calculation of the effective power falling into the RAS frequency band.

4.3.3 Duty cycle

The typical duty cycle values from Table 18 range from 30% to 50% for the considered type of radars. The highest duty cycle 50% leads to a mean power level of 45 dBm. Using the 10 dBi antenna gain from Table 18, the mean e.i.r.p. is calculated 55 dBm for a bandwidth ranging from 1 to 7 GHz.

4.3.4 Antenna pointing

The offset between the main lobe of the transmitting antenna (radiodetermination device) and the direction of the RAS station should be considered to calculate the “effective power” level that can actually reach the RAS station. This is due to the fact that the results in section 4.12 consider that the radar antenna is pointing towards the RAS station with its main beam (maximum antenna gain). This offset is application-dependant. The effective power is considered to reach the RAS antenna through its sidelobe. For the case of automotive radars, the following analysis was performed for the French NOEMA site.

The terrain profile around the RAS station was used to analyse the possible locations from which automotive radars could be in line of sight with the station. This was done, by using the data base of the French roads ROUTE 500 by IGN[6]. In Figure 88, the RAS station is represented by the red point and the roads are presented in blue. The points represented in orange are both located on the roads and in line of sight (LOS) of the RAS station.

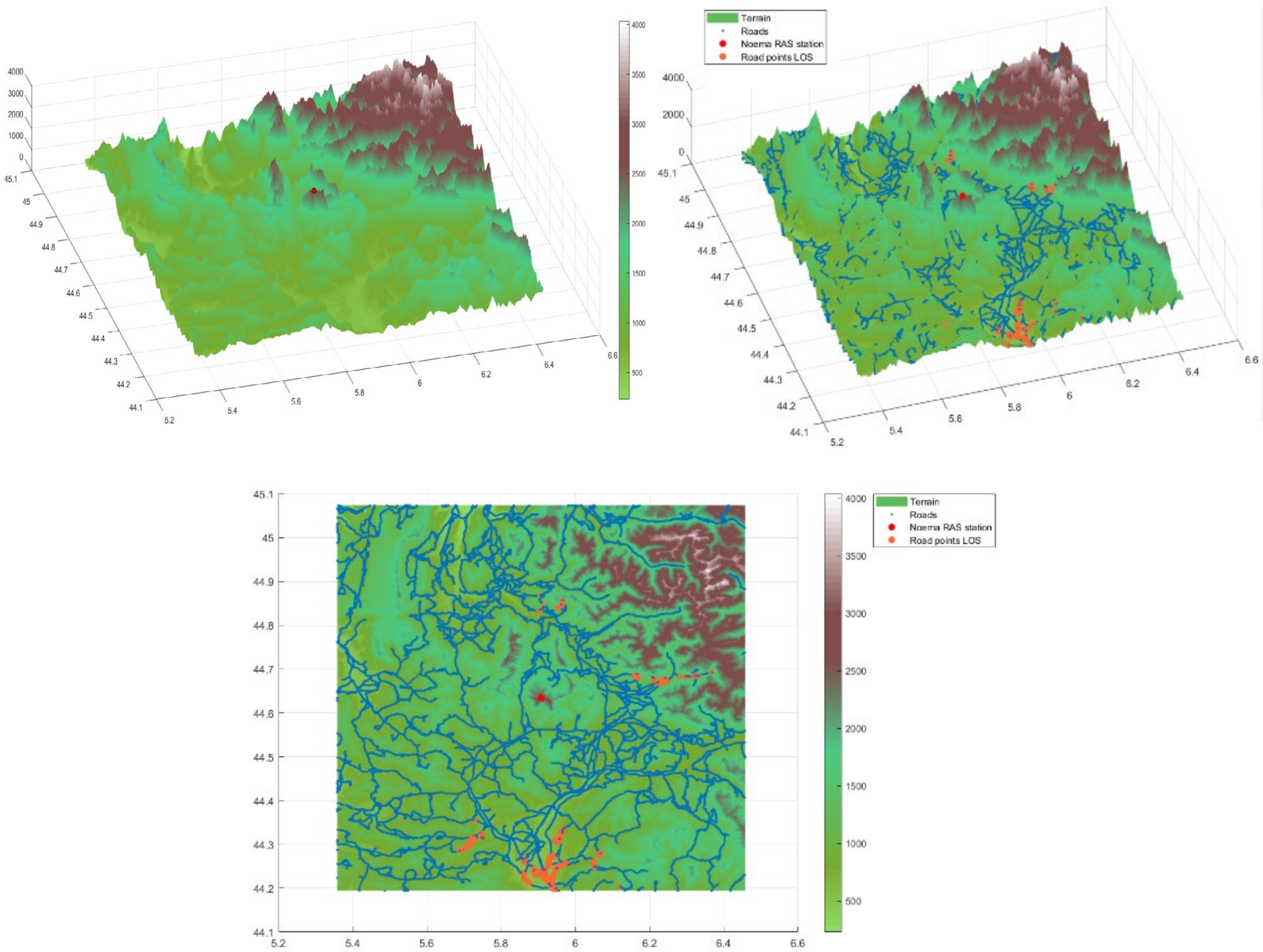


Figure 88: Terrain and road data around Noema station (France)

In addition to the identification of road points in LOS with the RAS station, the elevation angle at which the station is seen from every road point was calculated using the same procedure described in section 4.11.1. Then, by using the road data, the slope of the road was calculated for each of the points in LOS to estimate the orientation in the elevation plane of a vehicle on the road. The results of these calculations are presented in Figure 89.

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[6] Institut National de l’Information Géographique et Forestière

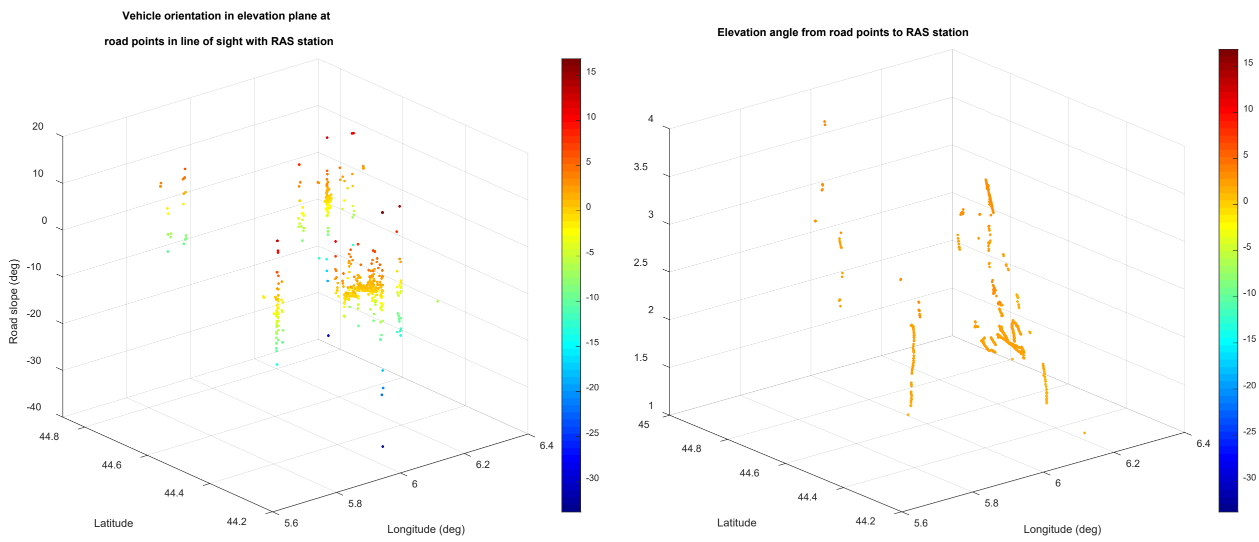


Figure 89: Analysis on pointing direction of automotive radar antenna in the elevation plane

The difference between the elevation angle from the road point towards the RAS station and the orientation of the vehicle at that point, determined by the road slope, is the radar antenna offset in the elevation plane. This offset is the angular difference between the radar pointing direction (in elevation) and its main beam. Figure 90 presents the results of this calculation in the form of histogram and CDF.

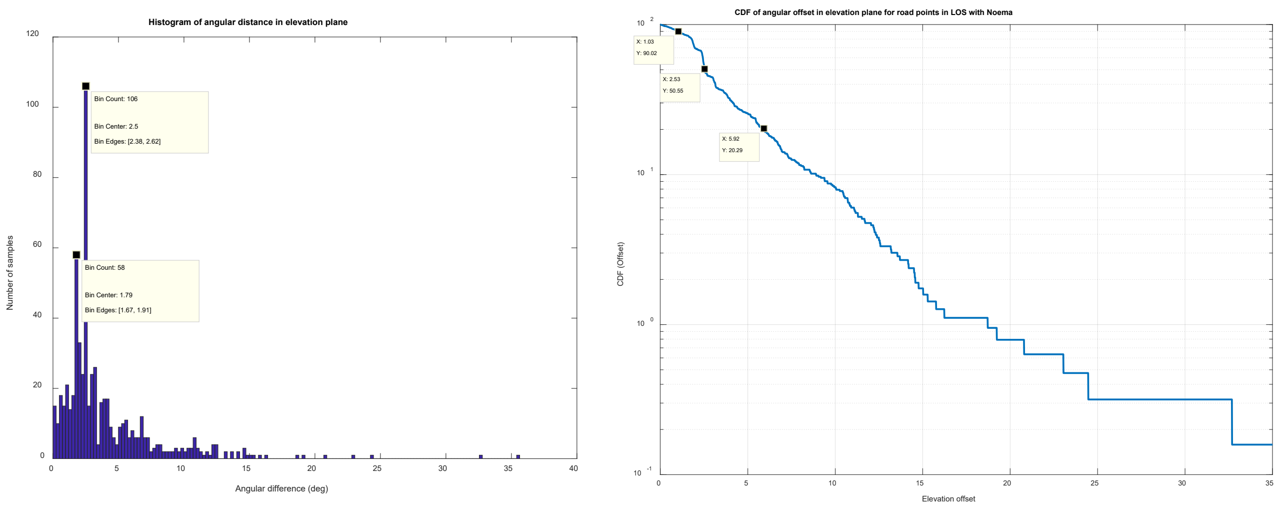


Figure 90: Characteristics of the automotive radar antenna de-pointing in the elevation plane

Most of the road points in LOS are located at around 45 km south to the RAS station with elevation angles of around 2.5°. This low elevation angles are comparable to the slope of the roads in that area. Therefore, the offset angle in the elevation plane is relatively low, in the order of 1° for 90% of the points in line of sight with Noema station. The antenna pattern of the automotive radar described in Table 18 for this application is particularly large in the elevation plane (60° beamwidth) as shown in Figure 91.

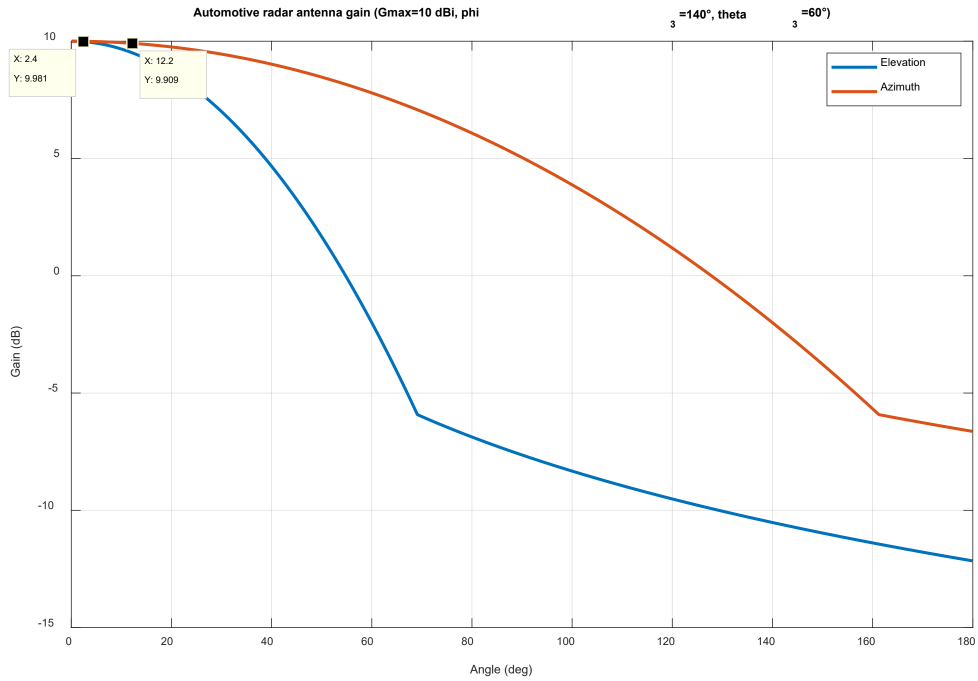


Figure 91: Assumed antenna pattern for radiodetermination devices for short-range assist and surrounding monitoring applications

Given the limited offset in the elevation plane and the large antenna beamwidth of the radar for this application, the antenna discrimination in the elevation plane is negligible.

No dedicated analysis was conducted for the Spanish IRAM 30 m site but by looking at Figure 92 (IRAM 30 m site) and Figure 93 (NOEMA site) one could see that the zones in line of sight are much larger and dense in the case of the IRAM 30 site (from south-west to north-east) compared to the case of the NOEMA site. Moreover, among the many roads that start from the urban zone of Granada at the West of the RAS site, there is one that leads by successive laces to the ski station located at the foot of the IRAM 30 m site. It could be concluded that, for the consideration of the antenna discrimination in the elevation plane, the results would be equivalent for the IRAM 30 m site to those obtained for the NOEMA site.

In the azimuth plane, by considering that at least seven short-range radars could be installed all around the car as shown in Figure 15 in the application scenario and that the antenna azimuth beamwidth could reach 60°, one could conclude that no antenna discrimination can be considered.

This analysis leads to the conclusion that for the radar antenna required for the application described in section 2.2.3 and for the two radio astronomy sites, no antenna gain reduction is applicable and no antenna discrimination in the azimuth and elevation planes can be considered.

4.3.5 Clutter loss

The available Recommendation ITU-R related to the clutter loss do not cover frequencies in the range 116 to 150 GHz. For example, the Recommendation ITU-R.P.2108-0 [25] for the prediction of clutter loss is limited to 100 GHz. Guidance was sought from The ITU Working Party 3M in charge of the propagation issues concerning the quantification and application of the clutter loss, including the effect of obstacles in the signal path, such as guardrails. WP3 noted the difficulty to extend the Recommendation ITU-R P.2108-0 for frequencies above 67 GHz for terrestrial paths and above 100 GHz for slant paths because of the lack of measured data on which these models were based. WP3 advised that in the single-entry interferer scenario and for unobstructed signal paths (unobstructed by clutter between roads or highways and the radio telescope), free space loss plus atmospheric attenuation using slant paths as defined in Rec ITU-R P.676-12 [28] apply. WP3 also considered that the clutter due to guard rails cannot be considered as a constant factor. For the aggregated scenario, only interferers in line of sight (LOS) have to be considered and non-line of sight (NLOS) interferers could be neglected.

It could be concluded that in the sharing and compatibility study for the single-entry interferer scenario developed in section 4.11 and 4.12, no clutter has to be considered.

4.3.6 Calculation of “effectual e.i.r.p.” level for radiodetermination devices for short-range assist and surrounding monitoring for vehicles and autonomous systems

Table 54 summarises the considerations and correction factors developed in this section for the calculation of the effectual e.i.r.p.

Table 54: Calculation of the ”effectual e.i.r.p. level” for radiodetermination devices for short-range assist and surrounding monitoring for vehicles and autonomous systems

Parameter	Value	Comment
Bandwidth	1 GHz to 7 GHz	Depending on the required range resolution
Peak power of the radar for BW = 1 GHz	39.5 dBm	RCS = -30 dBm, detection range = 20 m
Peak power of the radar for BW = 7 GHz	48 dBm	RCS = -30 dBm, detection range = 20 m
Duty cycle correction factor	-3 dB	Maximum radar duty cycle of 50%
Bandwidth correction factor	0 dB	All the radar power falls in the 8 GHz RAS band
Maximum antenna gain	10 dBi	
Mean e.i.r.p. for BW = 1 GHz	46.5 dBm	
Mean e.i.r.p. for BW = 7 GHz	55 dBm	
Radar antenna offset	0 dB	For the points in LOS with the RAS station
Clutter loss for single-entry cases	0 dB	No clutter loss considered
Effectual e.i.r.p. for BW = 7 GHz	55 dBm	Level to be considered to read the results in section 4.12.

The conclusions drawn from these results can be found in section 8.3.2.

4.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

No study has been conducted to evaluate the compatibility between GBSAR and Radio Astronomy Service (see section 8.4.2).

4.5 LEVEL PROBING RADAR (LPR)

4.5.1 Technical parameters of LPR

For LPR three potential frequency bands have been defined (see section 2.2.5.2). Due to the fact that in all defined frequency bands allocations for RAS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.5.3), the antenna data (section 2.2.5.4), the interference scenarios (section 2.2.5.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the LPR application (section 2.2.5.3) have been used in the studies in the different frequency ranges.

Table 55: Technical parameters of LPR used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1.6 GHz	5%	-8 dBm/MHz	37 dBm	20 dB
167 to 182 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB
231.5 to 250 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the LPR-signal in adjacent bands allocated to RAS. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

4.5.2 Results

Table 56 shows the single-entry worst-case results for LPR, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 56: Required separation distances determined in a single-entry study for LPR

Investigated frequency range	Allocated band for RAS	Required separation distance for RAS CO	Required separation distance for RAS SLO
116 to 148.5 GHz	76 to 116 GHz (OOB)	1.2 km	0.3 km
	123 to 158.5 GHz (In-band)	13.0 km	1.6 km
167 to 182 GHz	164 to 174.5 GHz (In-band)	10.0 km	1.4 km
	182 to 185 GHz (OOB)	0.5 km	0.2 km
231.5 to 250 GHz	190 to 231.5 GHz (OOB)	0.9 km	0.1 km
	235 to 238 GHz (In-band)	6.4 km	0.8 km
	241 to 275 GHz (In-band)	5.6 km	0.8 km

The conclusions drawn from these results can be found in section 8.5.2.

4.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

4.6.1 Technical parameters of CDR

For contour determination radar (CDR) three potential frequency bands have been defined (see section 2.2.6.2). Due to the fact that in all defined frequency bands allocations for RAS are affected – either within these bands or adjacent to them – all three bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.6.3), the antenna data (section 2.2.6.4), the interference scenarios (section 2.2.6.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report. In light of compatibility and sharing considerations, the contour determination application is divided into two different systems, digital beamforming CDR (DBF-CDR) and mechanical or phased-array CDR (M- or PA-CDR) as described in section 2.2.6.1.

The following technical parameters of the CDR application (section 2.2.6.3) have been used in the studies in the different frequency ranges.

Table 57: Technical parameters of CDR used for the conducted studies in the different frequency bands

Investigated frequency range	CDR type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	DBF-CDR	5.7 GHz	10%	-32.6 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-12 dBm/MHz	28.6 dBm	20 dB
167 to 182 GHz	DBF-CDR	2.5 GHz	10%	-29 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-9 dBm/MHz	34.6 dBm	20 dB
231.5 to 250 GHz	DBF-CDR	0.63 GHz	10%	-23 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-6 dBm/MHz	37 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the CDR-signal in adjacent bands allocated to RAS. Note 2: The duty cycle of 10% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).						

4.6.2 Results

Table 58 shows the single-entry worst-case results for the two different CDR systems, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 58: Required separation distances determined in a single-entry study for CDR

Investigated frequency range	Allocated band for RAS	Required separation distance for RAS CO		Required separation distance for RAS SLO	
		DBF-CDR	M- and PA-CDR	DBF-CDR	M- and PA-CDR
116 to 148.5 GHz	76 to 116 GHz (OOB)	2 km	1.3 km	0.4 km	0.3 km
	123 to 158.5 GHz (In-band)	19.9 km	14.2 km	2.6 km	1.7 km
167 to 182 GHz	164 to 174.5 GHz (In-band)	18.3 km	13.1 km	2.9 km	1.9 km
	182 to 185 GHz (OOB)	0.9 km	0.6 km	0.3 km	0.2 km
231.5 to 250 GHz	190 to 231.5 GHz (OOB)	3.6 km	1.7 km	0.4 km	0.2 km
	235 to 238 GHz (In-band)	19.3 km	11.1 km	3.3 km	1.5 km
	241 to 275 GHz (In-band)	17.1 km	9.8 km	3.1 km	1.5 km

The conclusions drawn from these results can be found in section 8.6.2.

4.7 TANK LEVEL PROBING RADAR (TLPR)

4.7.1 Technical parameters of TLPR

For TLPR three potential frequency bands have been defined (see section 2.2.7.2). Due to the fact that in all defined frequency bands allocations for RAS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.7.3), the antenna data (section 2.2.7.4), the interference scenarios (section 2.2.7.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the TLPR application (section 2.2.7.3) have been used in the studies in the different frequency ranges.

Table 59: Technical parameters of TLPR used for the conducted studies in the different frequency bands

Investigated frequency range	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
167 to 182 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
231.5 to 250 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the TLPR-signal in adjacent bands allocated to RAS.					

4.7.2 Results

Table 60 shows the single-entry worst-case results for TLPR, e.g. the largest separation distances for the individual frequency ranges, and RAS victim sensor types.

Table 60: Required separation distances determined in a single-entry study for TLPR

Investigated frequency range	Allocated band for RAS	Required separation distance for RAS CO	Required separation distance for RAS SLO
116 to 148.5 GHz	76 to 116 GHz (OOB)	0.8 km	0.2 km
	123 to 158.5 GHz (In-band)	5.3 km	0.6 km
167 to 182 GHz	164 to 174.5 GHz (In-band)	2.7 km	0.3 km
	182 to 185 GHz (OOB)	0.1 km	26 m
231.5 to 250 GHz	190 to 231.5 GHz (OOB)	0.2 m	14 m
	235 to 238 GHz (In-band)	1 km	0.1 km
	241 to 275 GHz (In-band)	0.8 km	0.1 km

The conclusions drawn from these results can be found in section 8.7.2.

4.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

4.8.1 Technical parameters of RDI-S

For the RDI-S application the whole frequency range from 116 to 260 GHz has been defined (see section 2.2.8.2). In this band several allocations for RAS are affected (see section 3.3). In addition to that altogether eight bands are affected which are protected by article 5.340 in the ITU Radio Regulations [71] (compare section 3.4). In all protected bands there are also allocations of the Radio Astronomy Service. All these identified bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.8.3), the antenna data (section 2.2.8.4), the interference scenarios (section 2.2.8.6) and the protection requirements for RAS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI-S application (section 2.2.8.3) have been used in the studies in the different frequency ranges.

Table 61: Technical parameters of RDI-S used for the conducted studies in RAS frequency allocations outside RR article 5.340 protected bands

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
76 to 116 GHz	113.9 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	10 dB
123.5 to 158.5 GHz	126.5 GHz	100 GHz	100%	10 dBm/MHz	60 dBm	
	137.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
164 to 174.5 GHz	169.25 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
190 to 231.5 GHz	210.75 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
235 to 238 GHz	236.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
241 to 275 GHz	245.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to RAS.						

Table 62: Technical parameters of RDI-S used for the conducted studies in RAS frequency allocations inside RR article 5.340 protected bands

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
114.25 to 116 GHz	115.125 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	10 dB
148.5 to 151.5 GHz	150 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
164 to 167 GHz	165.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
182 to 185 GHz	183.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
190 to 191.8 GHz	190.9 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
200 to 209 GHz	204.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
226 to 231.5 GHz	228.25 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
250 to 252 GHz	251 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to RAS.						

4.8.2 Results

Table 63 shows the single-entry worst-case results for RDI-S, e.g. the largest separation distances for the individual frequency ranges outside RR article 5.340 protected bands, and RAS victim sensor types.

Table 63: Required separation distances determined in a single-entry study for RDI-S in frequency ranges outside RR article 5.340 protected bands

Investigated Frequency range	Allocated RAS band	Investigated centre frequency	Required separation distance for RAS CO	Required separation distance for RAS SLO
116 to 260 GHz	76 to 116 GHz (OOB)	113.9 GHz	910 m	105 m
	123.5 to 158.5 GHz (In-band)	126.5 GHz	13.2 km	1.6 km
		137.5 GHz	2.5 km	274 m
	164 to 174.5 GHz (In-band)	169.25 GHz	631 m	71 m
	190 to 231.5 GHz (In-band)	210.75 GHz	432 m	45 m
	235 to 238 GHz (In-band)	236.5 GHz	1.2 km	127 m
	241 to 275 GHz (In-band)	245.5 GHz	1.0 km	122 m

Table 64 shows the single-entry worst-case results for RDI-S, e.g. the largest separation distances for the individual frequency ranges inside RR article 5.340 protected bands, RAS and victim sensor types.

Table 64: Required separation distances determined in a single-entry study for RDI-S inside RR article 5.340 protected bands

Investigated Frequency range	Article 5.340 protected passive band	Investigated centre frequency	Required separation distance for RAS CO	Required separation distance for RAS SLO
116 to 260 GHz	114.25 to 116 GHz (OOB)	115.125 GHz	900 m	104 m
	148.5 to 151.5 GHz (In-band)	150 GHz	707 m	80 m
	164 to 167 GHz (In-band)	165.5 GHz	638 m	72 m
	182 to 185 GHz (In-band)	183.5 GHz	479 m	64 m
	190 to 191.8 GHz (In-band)	190.9 GHz	541 m	62 m

Investigated Frequency range	Article 5.340 protected passive band	Investigated centre frequency	Required separation distance for RAS CO	Required separation distance for RAS SLO
	200 to 209 GHz (In-band)	204.5 GHz	506 m	52 m
	226 to 231.5 GHz (In-band)	228.25 GHz	407 m	42 m
	250 to 252 GHz (In-band)	251 GHz	371 m	38 m

The conclusions drawn from these results can be found in section 8.8.2.

4.9 TECHNICAL PARAMETERS OF RADIO ASTRONOMY STATIONS AND PROTECTION LEVELS IN THE FREQUENCY RANGE 116 TO 260 GHZ

Currently, Europe hosts the world most sensitive millimetre single antenna and the most sensitive millimetre interferometer in the Northern Hemisphere, the IRAM 30 m in Spain and NOEMA in France respectively. The site characteristics are provided in Table 65.

Both, the 30 m IRAM and NOEMA observe more than 50% of the time in the bands 120-175 GHz and 200-275 GHz. As the quest for new molecules (including the search for aminoacids) goes on, one needs ever more sensitive instruments and observations. Recognizing also that the astrophysical lines appear at certain frequencies imposed by physics (often not known prior to the observations), and that a confirmed detection of a new species requires the detection of at least a few lines of that species (spread over the whole band), the RAS has allocations (primary or secondary) and protecting footnotes (RR 5.149 or RR 5.340) in most of the range.

Several representative frequencies are used in this study, 116, 120, 130, 140, 160, 185, 210, and 260 GHz and the relevant protection criteria are contained in section 3.5.2 in Table 39. The most sensitive measurement mode is continuum observations, which are also used extensively at both considered European observatories. Therefore, in this report only calculations for the continuum mode are presented.

Table 65: European radio astronomy observatories operating in the frequency range 116 GHz to 260 GHz

Observatory Name	Administration	Longitude (E), Latitude (N)	Elevation (m AMSL)	Observing mode	Geographical characteristics
NOEMA	France	05°54'28" 44°38'02"	2253	single dish, interferometry, VLBI	Isolated high mountain top in the Alps (Plateau de Bure)
IRAM 30 m	Spain	-03°23'34" 57°23'45"	2850	Single dish, VLBI	Sierra Nevada Mountain (Pico Veleta)

4.10 TECHNICAL PARAMETERS OF SHORT-RANGE RADIODETERMINATIONDEVICES

The radio determination applications considered in this Report are categorised into three types A, B and C relating to their interference potential as explained in section 2. In addition, the technical parameters of the devices are provided in the same section for the different use cases. Since applications of type A may radiate in any direction outside a shielded environment, building or housing, they are considered as the most critical for sharing and compatibility studies.

There is a large variety of potential applications to be covered by this report, each with different technical properties, such as antenna patterns, output power levels, or duty cycles. In order to make the RAS compatibility calculations as generic as possible, they are performed in an application-agnostic fashion, i.e., the results are presented for a range of power levels of interference, which would fall on average into a RAS band (having 8 GHz bandwidth). Therefore, all kinds of mitigation effects, e.g., Radar duty cycles, should already be included in the e.i.r.p. levels before comparing with the results from the subsequent sections.

4.11 PATH ATTENUATION MAPS FOR LINE OF SIGHT REGIONS AROUND TELESCOPES NOEMA AND IRAM

4.11.1 Discussion on path propagation

To calculate the path propagation loss, compatibility studies involving radio astronomy often use the model provided in Recommendation ITU-R P.452-16 [27]. For this study however, the frequencies are outside of the range of this propagation recommendation. Using P.452-16 with the highest possible frequency of 100 GHz reveals that there is a very sharp gap in the derived attenuation between line-of-sight (LOS) and trans-horizon paths. Therefore, this study proposes to restrict the analysis to line-of-sight (LOS) cases and assume that the propagation loss is determined by pure LOS attenuation plus atmospheric dampening. LOS loss depends on distance and frequency as follows:

$$L[dB] = 92.4\ dB + 20 \cdot log(d[km]) + 20 \cdot log(f[GHz]) \qquad (16)$$

while the atmospheric loss is a function of the physical parameters of the atmosphere leading to a height-dependent refractive index which bends the ray of light. Recommendation ITU-R P.676-12 [28] contains algorithms that perform the raytracing through atmospheric layers. For each layer, one first needs to determine the refractive index based on a model of the atmosphere. Here the "high-latitude winter" model as defined in section 4.2 of Recommendation ITU-R P.835-6 [29], is chosen for the NOEMA station and the mid-latitude winter model for the IRAM 30 m station, given the geographical latitude of both RAS stations. Additionally, the specific attenuation (also from Recommendation ITU-R P.676-12) of each atmospheric layer is needed to calculate the total attenuation of a “slant path" through the atmosphere. This slant path is usually implemented for cases involving one station (transmitter or receiver) above the earth surface (e.g. in space or at high atmospheric layers), but the same technique can be used for terrestrial paths. If the RAS station and the interfering transmitter are located at very different altitudes it is more appropriate to use the "slant path" approach. Considering for example radiodetermination devices, which are located in regions at sea level with LOS to the RAS station at high altitude (e.g., 3000 m) the propagation path crosses atmospheric layers of significantly differing physical properties and thus specific attenuation values, which must be taken into account for an accurate determination of the overall atmospheric loss along the path. Recommendations ITU-R P.676-12 and P.835-6 contain further details.

To obtain the actual propagation path elevation angles and the regions of LOS cases around each RAS station, one can still use the methods provided in Recommendation ITU-R P.452-16 [27], as these are independent on the observing frequency. For this, topographic (i.e., terrain height) data is needed. For the RAS sites considered in this contribution, there are very precise topographic GIS data sets available, which are based on LIDAR campaigns.

In Figure 92 and Figure 93, topographic maps of the IRAM 30 m and NOEMA observatories are displayed. The regions in direct LOS with respect to the telescopes are shaded in red. For these areas, the free-space basic transmission loss and atmospheric gases absorption loss were calculated as described above. The resulting basic transmission loss[7] are shown in Figure 94 and Figure 95, for two example frequencies, 140 and 185 GHz, which represent a case of very low and very high gaseous attenuation, respectively.

Both attenuation mechanisms are strongly dependent on frequency. For LOS, the loss is proportional to frequency squared. The frequency dependence of atmospheric attenuation, however, is dominated by spectral-line transitions of water and oxygen molecules (see Recommendation ITU-R P.676-12 [28], especially

[7] Disregarding polarisation coupling loss, scattering in the path, beam spreading loss, multipath loss (radar rays reflected from the ground), clutter loss, building entry loss.

Figure 4 for details). In the studied frequency range, oxygen produces strong attenuation at 120 GHz (with broad width of several GHz), and water vapour is responsible for an absorption at 183 GHz.

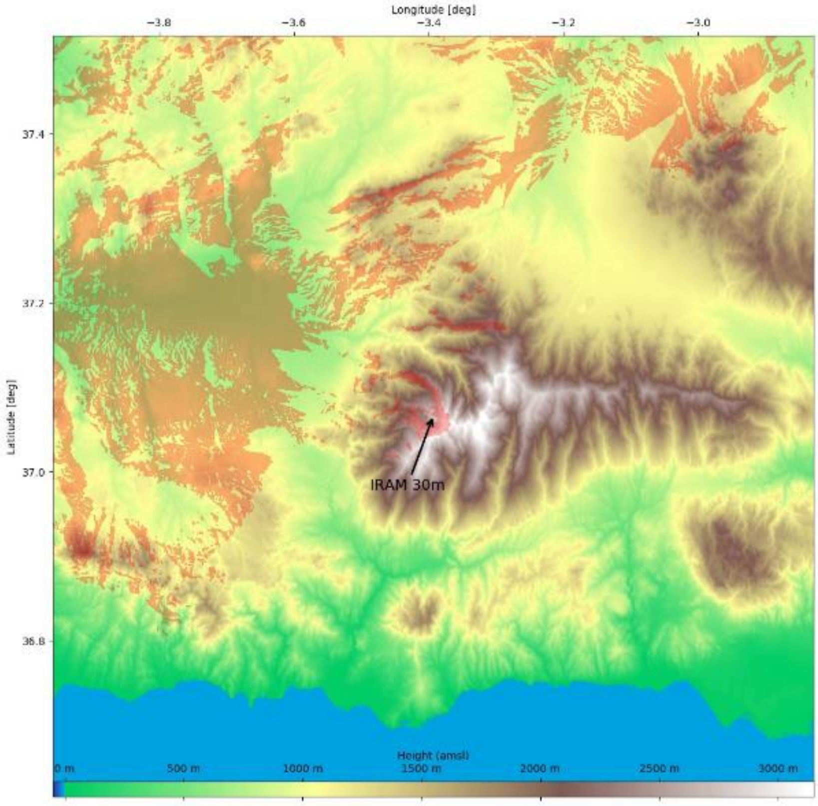


Figure 92: Topographic map of the IRAM 30 m site. The red shaded area shows the line-of-sight regions from the RAS station

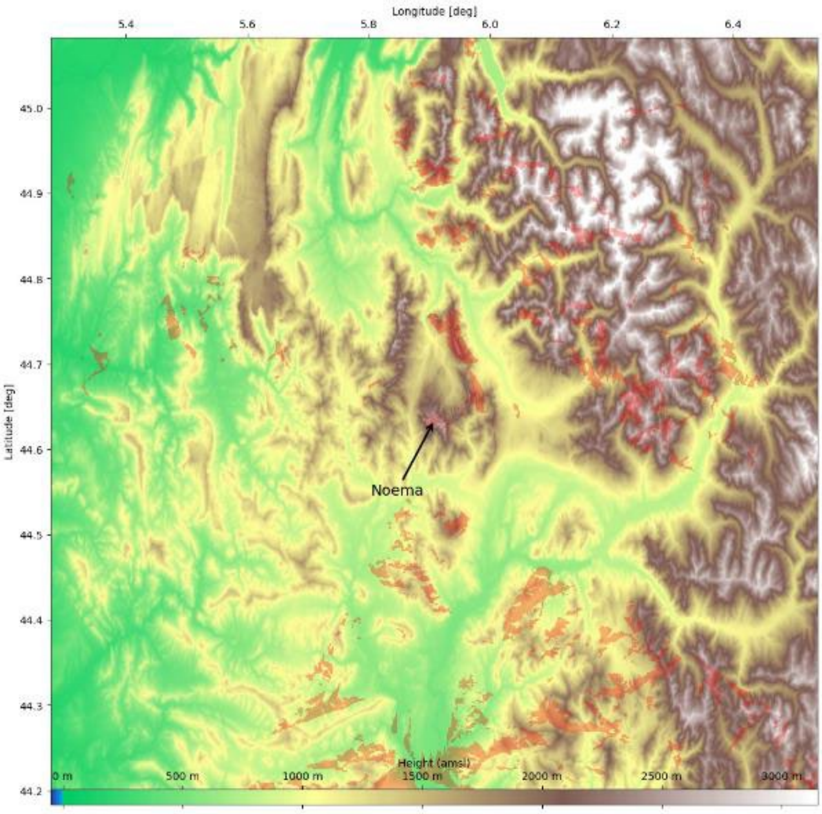


Figure 93: Topographic map of the NOEMA site. The red shaded area visualises line-of-sight regions from the RAS station

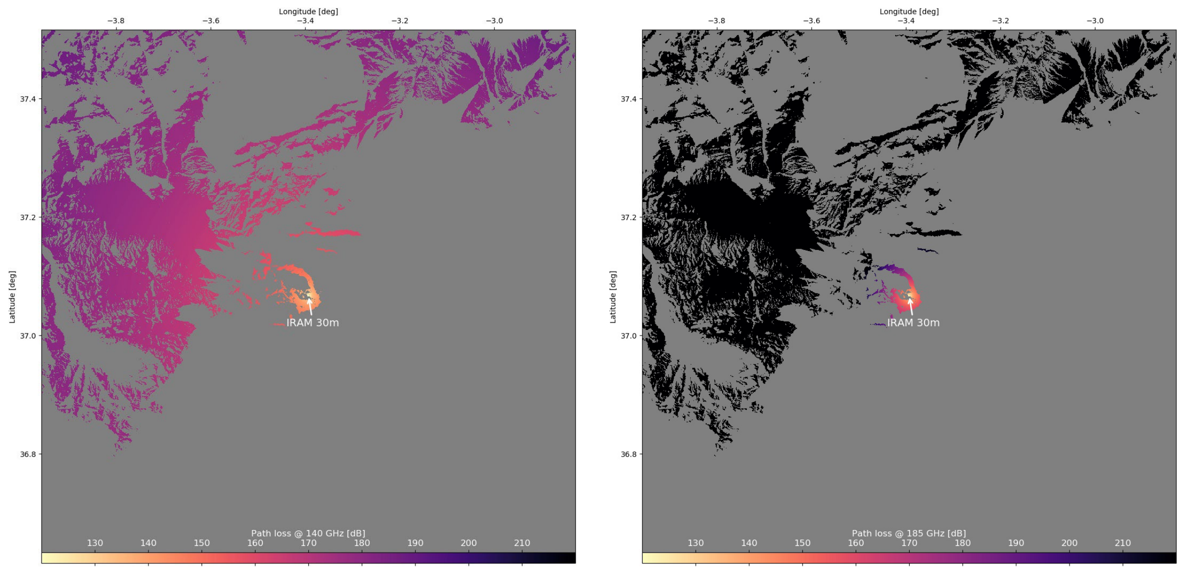


Figure 94: Path attenuation maps for LOS regions around the IRAM 30 m station at 140 and 185 GHz

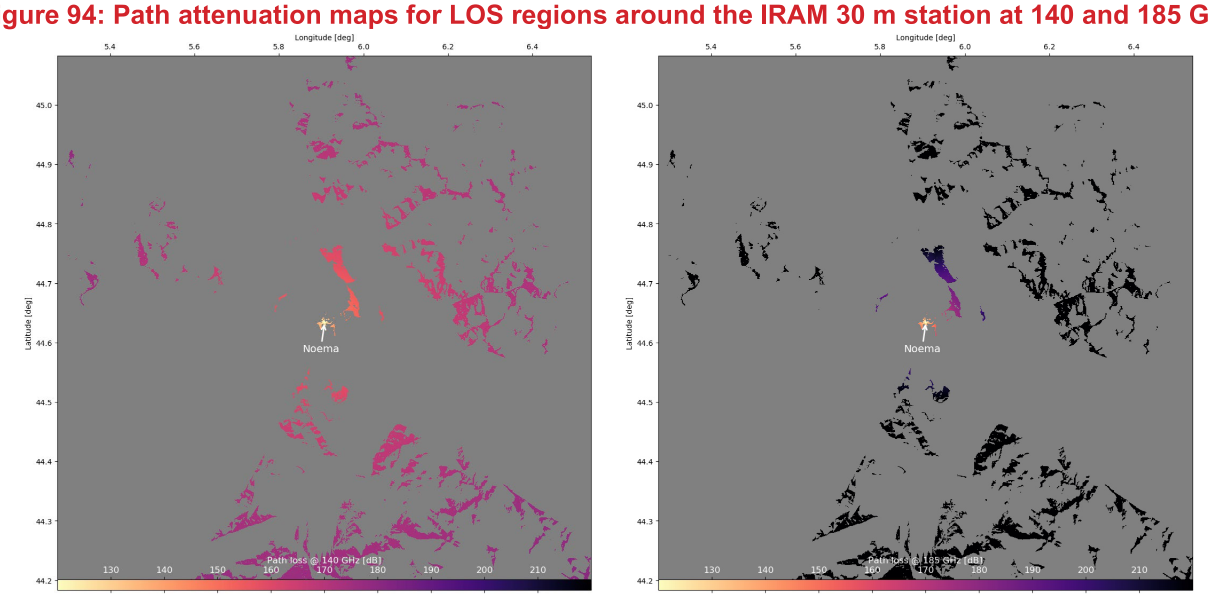


Figure 95: Path attenuation maps for LOS regions around the NOEMA station at 140 and 185 GHz

4.12 SEPARATION DISTANCES FOR SINGLE-INTERFERER SCENARIO

As discussed in section 4.10, it is possible to do the calculations in an application-agnostic manner by considering e.i.r.p. values calculated as the average power that effectively goes into the RAS antenna. This requires the transformation of the e.i.r.p. of the radiodetermination device into a value that represents the average power that would effectively reach the RAS antenna considering the propagation phenomena and the mitigation effects having an impact on the signal transmitted by the radio radiodetermination device such as, duty cycle, bandwidth correction factor, clutter loss, antenna pointing, shielding, etc. These effects represent the particularities of the different radio radiodetermination applications considered and the result of such calculation is called hereafter “the effectual e.i.r.p.” of the radio location device.

Example 1: SRD with peak power 20 dBm/MHz (e.i.r.p. forward direction) in the frequency range from 100 to 140 GHz with duty cycle of 10%. Antenna gain towards RAS station -30 dBi (with respect to forward gain). No building entry loss.

The first step would be to integrate the spectral power over the RAS continuum channel bandwidth of 8 GHz, which results in a peak e.i.r.p. (forward direction) of 59 dBm/8 GHz. Considering the duty cycle of 10%

(or -10 dB), the average power in forward direction would be 49 dBm/8 GHz. As in the example the RAS station is not in forward direction, the effective antenna gain of -30 dBi must be applied, yielding 19 dBm/8 GHz (time averaged) that is transmitted towards the RAS station.

Example 2: SRD with peak e.i.r.p. (towards RAS station) of 40 dBm over 4 GHz or 20 GHz of bandwidth, duty cycle 50%, 30 dB building entry loss.

For an SRD bandwidth of 4 GHz no conversion is necessary (i.e. the relevant e.i.r.p. is 40 dBm/8 GHz). For 20 GHz SRD bandwidth, only a fraction of the power needs to be considered (i.e., 8 GHz/20 GHz), which results in an e.i.r.p. of 36 dBm/8 GHz. Applying the duty cycle of 50% (-3 dB) and the BEL of -30 dB, on average 7 (3) dBm/8 GHz (time averaged) are transmitted towards the RAS station.

The difference between the transmitter (Tx) e.i.r.p. and the RAS threshold defines the minimal coupling loss (MCL). The difference between the MCL and the path attenuation obtained as described in section 4.11 is called the margin. A negative margin means that the RAS thresholds are exceeded (incompatibility), positive margins mean that there is still room before the thresholds are exceeded. A margin of zero indicates a case where the RAS threshold is hit exactly.

In Figure 96 and Figure 97, the zero-margin regions around the two relevant RAS stations, the IRAM 30 m observatory (Spain) and the NOEMA site (France), are shown for a range of different “effective e.i.r.p.” values between 0 dBm/8 GHz and 80 dBm/8 GHz. As this is a large dynamic range, two different map sizes were chosen. For each of the two RAS sites, the resulting separation distances are displayed as contours in Figure 96 an Figure 97 for the two example frequencies of 140 and 185 GHz. The outcome is strongly dependent on the chosen frequency, as was discussed in the previous section. It is also noted that, as the results were derived under assumption of a single interferer, some caution is needed when interpreting the results.

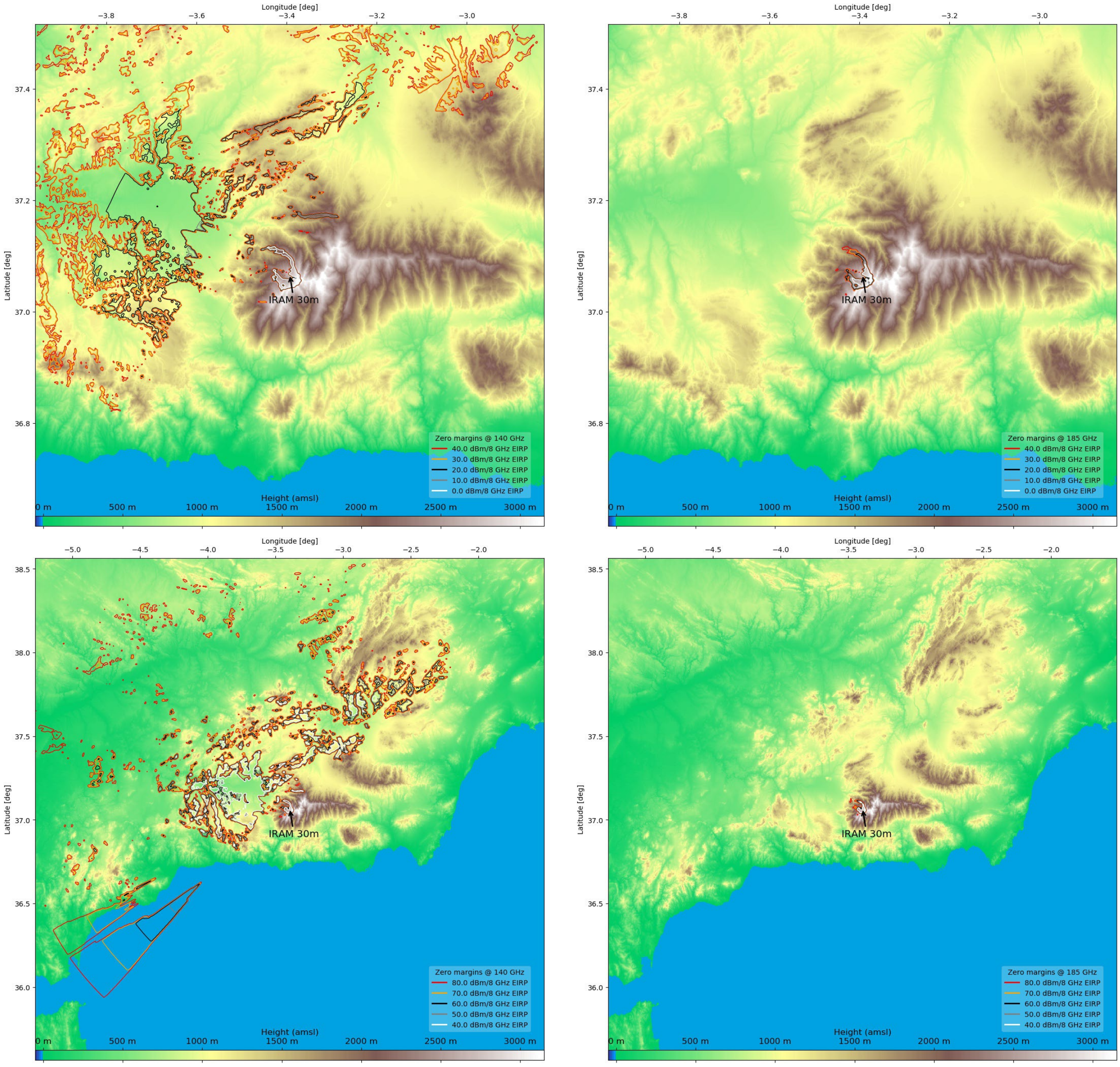


Figure 96: Regions of zero-margin around the IRAM 30 m site for different e.i.r.p. values at 140 and 185 GHz

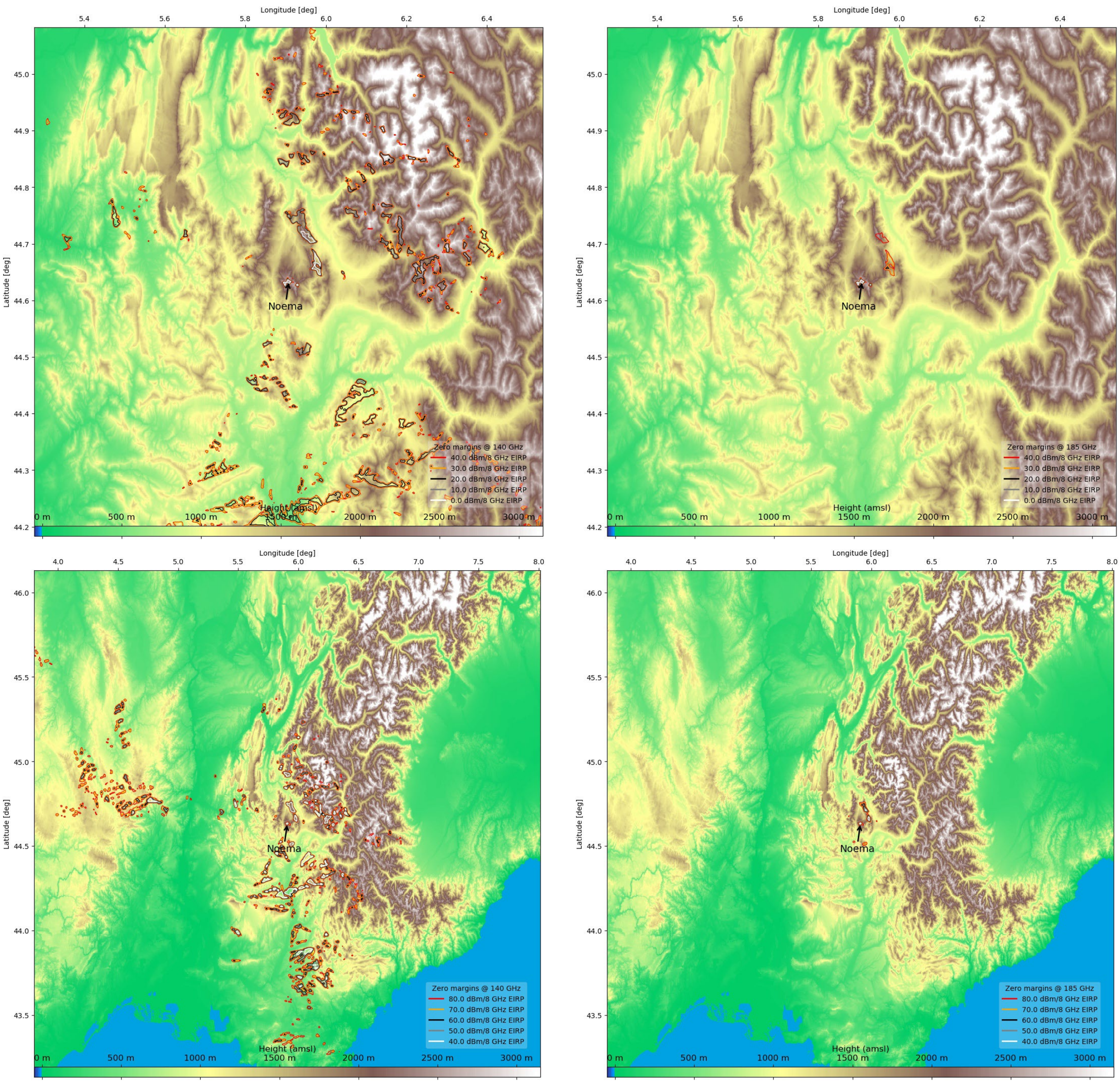


Figure 97: Regions of zero-margin around the NOEMA site for different e.i.r.p. values at 140 and 185 GHz

As an additional example, the specific case of the frequency 140 MHz with an e.i.r.p. of 55 dBm in 8 GHz is provided in Figure 98 for NOEMA site and Figure 99 for IRAM 30 m site.

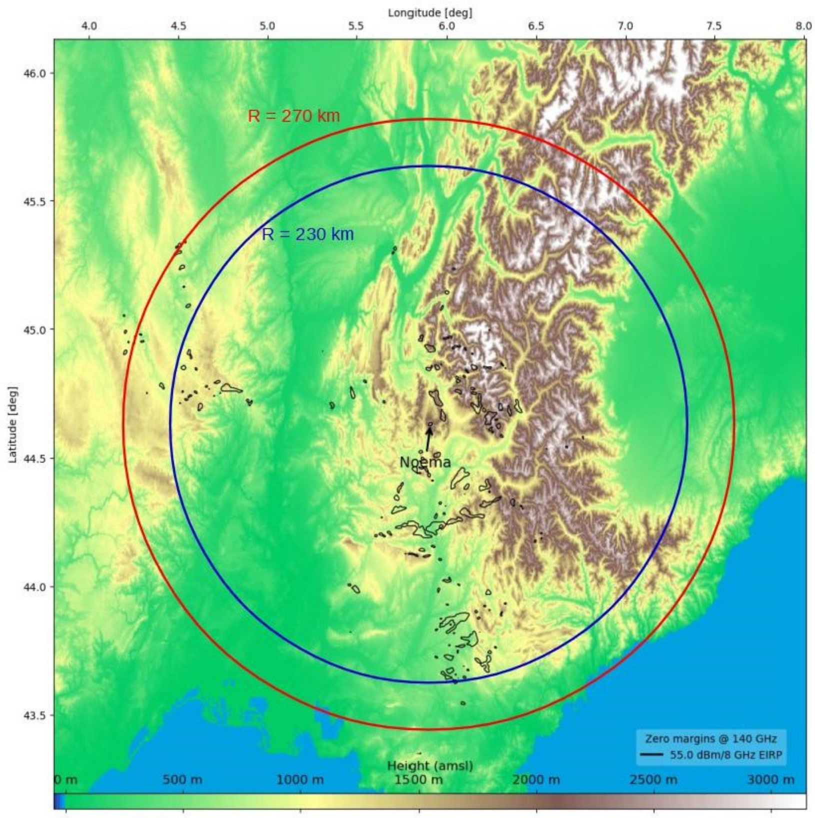


Figure 98: Regions of zero-margin around the NOEMA site for an e.i.r.p. of 55 dBm in 8 GHz at 140 GHz

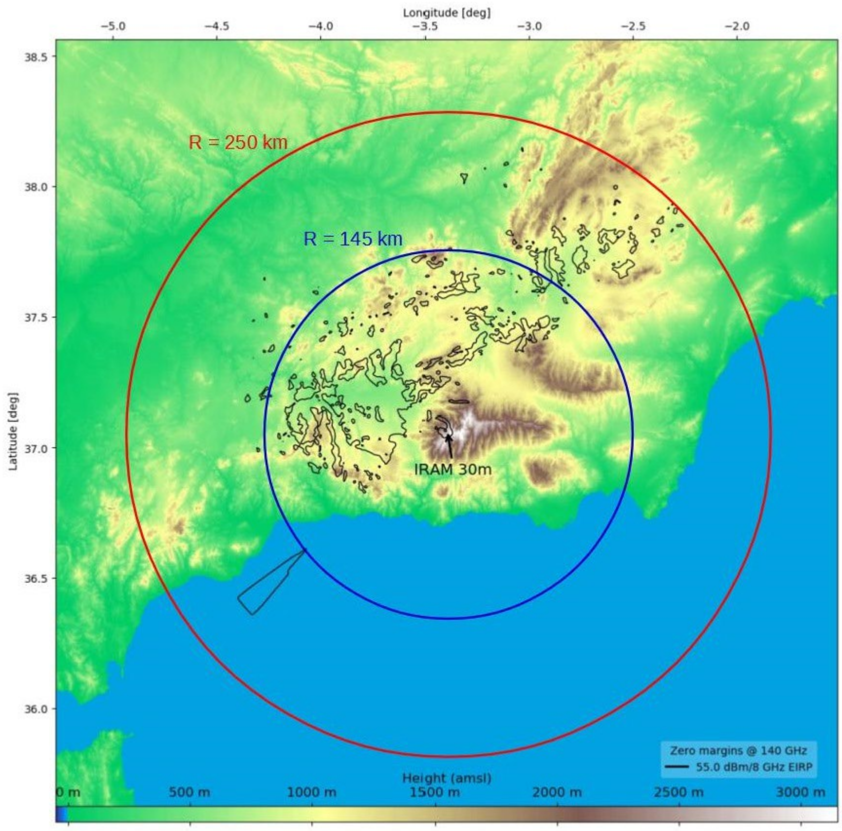


Figure 99: Regions of zero-margin around the IRAM 30 m site for an e.i.r.p. of 55 dBm in 8 GHz at 140 GHz

5 SHARING AND COMPATIBILITY STUDIES WITH FIXED SERVICE

5.1 GENERIC INDOOR SURVEILLANCE RADAR

5.1.1 Technical parameters and interference scenario considerations of generic indoor surveillance radar sensors

5.1.1.1 Technical parameters

For hand-held/mobile and fixed generic indoor surveillance radar equipment three potential frequency bands have been defined (see section 2.2.1.2). Due to the fact that in all defined frequency bands allocations for RAS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry and aggregate studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.1.3), the interference scenarios (section 2.2.1.6) and the protection requirements for FS (section 3.5.3). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the hand-held/mobile and fixed generic indoor studies (section 2.2.1.6) have been used in the studies in the different frequency ranges.

Table 66: Technical parameters of generic indoor surveillance radar used for the conducted studies in the different frequency bands

Investigated frequency range	Device type	Assumed modulation bandwidth	Duty cycle	Activity factor	Mean e.i.r.p. spectral density (Note 2)	Mean e.i.r.p. (Note 2)	OOB attenuation (Note 1)
116 to 130 GHz	Hand-held/ mobile	1 GHz	40%	50%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%		-10 dBm/MHz	20 dBm	20 dB
134 to 141 GHz	Hand-held/ mobile	1 GHz	40%	50%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%		-10 dBm/MHz	20 dBm	20 dB
141 to 148.5 GHz	Hand-held/ mobile	1 GHz	40%	50%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%		-10 dBm/MHz	20 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the generic indoor surveillance radar in adjacent bands allocated to FS.
Note 2: The duty cycles are not considered in the mean e.i.r.p. spectral density and mean e.i.r.p. values. Consequently, the given mean e.i.r.p. spectral density and mean e.i.r.p. is valid for averaging over T_{meas} (time when transmission is on, see Figure 36).

5.1.1.2 Interference scenarios-specific considerations

Due to the generic commercial nature of the devices determined for the private household, the worst-case single-entry interference scenarios were considered.

This includes the consideration of usage inside less energy efficient (traditional) buildings with low indoor-outdoor attenuation.

Single-entry assessment

The generic assumptions for the interference scenario are described in section 2.2.1.6. These considerations on potential scenarios led to four different single-entry interference cases:

1 Single-entry case 1:

- Indoor-outdoor attenuation of 12.3 dB for interference scenario 1 (see Figure 3 in section 2.2.1.6) and 11.6 dB for interference scenario 2 (see Figure 4) (Model according to ITU-R P.2109-1 [23] for P=15% with 100% traditional buildings at 100 GHz for the elevation angles derived from the two interference scenarios);
- Line of sight/main beam coupling;
- No clutter;
- Duty cycle of 10% for fixed indoor surveillance radars was considered;
- No duty-cycle mitigation for hand-held/mobile generic indoor surveillance radar since the duty cycles exceed the 20% threshold of the long-term FS interference criterion I/N=-20 dB.

2 Single-entry case 2:

- Indoor-outdoor average attenuation of 15.5 dB was considered (Model according to ITU-R P.2109-1 [23] with 70% traditional and 30% energy efficient buildings at 100 GHz and 0° elevation was used);
- Other parameters same as for Single-entry case 1.

3 Single-entry case 3

- 21.8 dB clutter loss (Model according to ITU-R P.2108-0 [25] section 3.2 for 67 GHz and a path length of 300 m. The current ITU model is only valid up to 67 GHz. At higher frequencies, also a higher clutter loss can be assumed);
- Other parameters same as for Single-entry case 1.

Note: While conducting the studies an antenna pattern mitigation was discussed and studied for fixed generic indoor surveillance radars (see section 4.1.1.2 for RAS). Here, the mean e.i.r.p. above 0° elevation shall be limited to 12 dBm (8 dB below the maximum mean e.i.r.p. of 20 dBm). This consideration led to this single-entry case 4.

4 Single-entry case 4

- Only for fixed generic indoor surveillance radar devices.
- 12 dBm mean e.i.r.p. in the direction of the victim FS receiver.
- Other parameters same as for Single-entry case 1.

Aggregate assessment

For the aggregate in-band assessment the following two cases have been distinguished.

1 Aggregate case 1:

- Only interference scenario 1 was considered as this is the worst-case scenario (see Figure 3, Table 67 and Table 68);
- Indoor-outdoor average attenuation of 15.5 dB was considered (Model according to ITU-R P.2109-1 [23] with 70% traditional and 30% energy efficient buildings at 100 GHz and 0° elevation was used);
- It was assumed that all indoor devices are in the same location inside the building, i.e. no distribution in the horizontal plane was considered and all devices are ideally aligned in the vertical plane (elevation) towards the victim FS receiver;
- No additional shielding inside the building itself (e.g. internal walls, furniture) has been considered;
- No clutter was assumed in the first step;
- Average antenna gain of 5 dBi was used in the aggregate scenario due to the arbitrary orientation in the horizontal plane and due to the antenna pattern mitigation for fixed generic indoor surveillance radars (see Single-entry case 4);
- A duty cycle of 10% was considered;
- A device density of 5 sensors per house and 3 sensors per flat is assumed (see section 2.2.1.5).

Note: To reflect the possibility that the interferer devices could be located on different floors within the building, the change in the misalignment towards the FS receiver main beam direction and the related impact on the

FS-antenna gain was assessed. This parameter was then used to calculate the necessary separation distance for a single indoor device.

2 Aggregate case 2:
- 21.8 dB clutter loss (Model according to ITU-R P.2108-0 , section 3.2 [25] for 67 GHz and a path length of 300 m. The current ITU model is only valid up to 67 GHz. At higher frequencies, also a higher clutter loss can be assumed);
- Other parameters same as for Aggregate case 1.

Based on these two aggregate cases the results for the aggregate consideration are evaluated as follows:

Step1: First, a possible floor within the building is chosen.

Step 2: Calculation of the of the separation distance of a single device with an average antenna gain of 5 dBi.

Step 3: Increase of the maximum mean e.i.r.p. of the single device with an average antenna gain of 5 dBi up to a separation distance of 300 m (border case for interference towards the FS system).

Step 4: The determined power increase in step 3 is equivalent to the aggregation of a specific number of interfering generic indoor surveillance radars. This number is calculated assuming an ideal power summation of all interfering devices.

Step 5: The obtained overall number of aggregated devices is compared to the assumption in section 2.2.1.5 (5 sensors per house and 3 sensors per flat).

5.1.2 Results

Table 67 shows the single-entry worst-case results for the generic indoor surveillance radar application for the in-band consideration within the frequency range 141 to 148.5 GHz, i.e. the largest separation distances, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 67: Required separation distances determined in a single-entry study for generic indoor surveillance radar within the frequency band 141 to 148.5 GHz (in-band case)

Device type	Single-entry case	Required separation distance for scenario 1 (Note 1)		Required separation distance for scenario 2 (Note 1)	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
Hand-held/mobile	1	290 m	53 m	34 m	2 m
Hand-held/mobile	2	203 m	37 m	22 m	1 m
Hand-held/mobile	3	11 m	4 m	1 m	0 m
Fixed	1	290 m	53 m	34 m	6 m
Fixed	2	203 m	37 m	22 m	4 m
Fixed	3	24 m	4 m	3 m	0 m
Fixed	4	118 m	21 m	14 m	2 m
Note 1: Assumed FS antenna gain based on misalignment in the individual scenario: Scenario 1: 37.5 dBi Scenario 2: 18 dBi.					

Note: In former ECC studies (e.g. ECC Report 190 [21]) an indoor-outdoor attenuation of 60 dB has been assumed.

Table 68 shows the single-entry worst-case results for the generic indoor surveillance radar application for the adjacent band interference consideration, i.e. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 68: Required separation distances determined in a single-entry study for generic indoor surveillance radar for the adjacent band interference consideration

Device type	FS frequency range	Required separation distance for scenario 1 (Note 1)		Required separation distance for scenario 2 (Note 1)	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
Hand-held/mobile	111.8 to 114.25 GHz	22 m	9 m	7 m	1 m
Hand-held/mobile	130 to 134 GHz	15 m	6 m	5 m	0 m
Hand-held/mobile	151.5 to 158.5 GHz	13 m	5 m	1 m	0 m
Fixed	111.8 to 114.25 GHz	50 m	9 m	5 m	1 m
Fixed	130 to 134 GHz	34 m	6 m	4 m	1 m
Fixed	151.5 to 158.5 GHz	28 m	5 m	3 m	1 m
Note 1: Assumed FS antenna gain based on misalignment in the individual scenario: Scenario 1: 37.5 dBi Scenario 2: 18 dBi.					

Table 69 shows the results of the necessary separation distances for a single indoor device in the interference scenario 1 based on Aggregate case 1.

Table 69: Required separation distances determined for a single indoor device in the interference scenario 1 based on Aggregate case 1.

Floor/device height	Angle β	Misalignment reference α=3.624°	Antenna gain FS receiver	Required separation distance for a single indoor device
ground floor/1 m	4.574°	0.95°	37.5 dBi	37 m
1st floor/4 m	4.004°	0.38°	43.2 dBi	71 m
2nd floor/7 m	3.433°	0.191°	43.8 dBi	76 m
3rd floor/10 m	2.862°	0.792°	40.1 dBi	50 m
4th floor/13 m	2.290°	1.334°	32.7 dBi	21 m

Table 70 shows the overall number of aggregated devices for the first four floors which are equivalent to the possible power increase by aggregation of devices based on interference scenario 1 and Aggregate case 1.

Table 70: Overall number of aggregated devices for each individual floor

Floor	Possible power increase by aggregation of devices	Overall number of aggregated devices equivalent to the possible power increase
ground floor	18.5 dB	71
1st floor	12.7 dB	19
2nd floor	12.2 dB	17
3rd floor	16 dB	40

For the Aggregate case 2 only the most critical second floor was evaluated. The result is shown in Table 71.

Table 71: Overall number of aggregated devices for the 2nd floor and Aggregate case 2

Floor	Required separation distance for a single indoor device	Possible power increase by aggregation of devices	Overall number of aggregated devices equivalent to the possible power increase
2nd floor	6 m	34 dBm	2511

The conclusions drawn from these results can be found in section 8.1.3.

5.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

5.2.1 Technical parameters of RDI

For RDI altogether five potential frequency bands have been defined (see section 2.2.2.2). However, only for the three frequency bands 116 to 130 GHz, 134 to 141 GHz and 174.8 to 182 GHz allocations for FS are indirectly affected which are located adjacent to them (please compare the figures in section 3.3). Consequently, these three bands have been investigated in single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.2.3), the antenna data (section 2.2.2.4), the defined interference scenarios (section 2.2.2.6) and the protection requirements for FS (section 3.5.3). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI application (section 2.2.2.3) have been used in the studies in the different frequency ranges.

Table 72: Technical parameters of RDI used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 130 GHz	14 GHz	5%	-23.5 dBm/MHz	31 dBm	20 dB
134 to 141 GHz	7 GHz	5%	-20.5 dBm/MHz	31 dBm	20 dB
174.8 to 182 GHz	1.5 GHz	5%	-23.8 dBm/MHz	31 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the RDI-signal in adjacent bands allocated to FS.					

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

5.2.2 Results

Table 73 shows the single-entry worst-case results for RDI, e.g. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 73: Required separation distances determined in a single-entry study for RDI

Investigated Frequency range	Allocated band for FS	Required separation distance for scenario 1		Required separation distance for scenario 2	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
116 to 130 GHz	111.8 to 114.25 GHz (OOB)	133 m	125 m	14 m	13 m
	130 to 134 GHz (OOB)	90 m	85 m	10 m	9 m
134 to 141 GHz	130 to 134 GHz (OOB)	127 m	85 m	14 m	9 m
	141 to 148.5 GHz (OOB)	116 m	77 m	12 m	8 m
174.8 to 182 GHz	167 to 174.8 GHz (OOB)	205 m	65 m	23 m	7 m

The conclusions drawn from these results can be found in section 8.2.3.

5.3 SHORT RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

No study has been conducted to evaluate the compatibility between short-range assist and surrounding monitoring for vehicles and autonomous systems and Fixed Service (see section 8.3.3).

5.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

No study has been conducted to evaluate the compatibility between GBSAR and Fixed Service (see section 8.4.3).

5.5 LEVEL PROBING RADAR (LPR)

5.5.1 Technical parameters of LPR

For LPR altogether three potential frequency bands have been defined (see section 2.2.5.2). However, only for the two frequency bands 116 to 148.5 GHz and 167 to 182 GHz allocations for FS are affected either within these bands or adjacent to them. Consequently, these two bands have been investigated in single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.5.3), the antenna data (section 2.2.5.4), the defined interference scenarios (section 2.2.5.6) and the protection requirements for FS (section 3.5.3). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the LPR application (section 2.2.5.3) have been used in the studies in the different frequency ranges.

Table 74: Technical parameters of LPR used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1.6 GHz	5%	-8 dBm/MHz	37 dBm	20 dB
167 to 182 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the LPR-signal in adjacent bands allocated to FS.
Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).

5.5.2 Results

Table 75 shows the single-entry worst-case results for LPR, e.g. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 75: Required separation distances determined in a single-entry study for LPR

Investigated Frequency range	Allocated band for FS	Required separation distance for scenario 1		Required separation distance for scenario 2	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
116 to 148.5 GHz	111.8 to 114.25 GHz (OOB)	40 m	13 m	4 m	1 m
	130 to 134 GHz (In-band)	263 m	85 m	24 m	8 m
	141 to 148.5 GHz (In-band)	237 m	77 m	22 m	7 m
167 to 182 GHz	167 to 174.8 GHz (In-band)	240 m	63 m	23 m	6 m

The conclusions drawn from these results can be found in section 8.5.3.

5.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

5.6.1 Technical parameters of CDR

For contour determination radar (CDR) altogether three potential frequency bands have been defined (see section 2.2.6.2). However, only for the two frequency bands 116 to 148.5 GHz and 167 to 182 GHz allocations for FS are affected within these bands or adjacent to them. Consequently, these two bands have been investigated in single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.6.3), the antenna data (section 2.2.6.4), the defined interference scenarios (section 2.2.6.6) and the protection requirements for FS (section 3.5.3). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the CDR application (section 2.2.6.3) have been used in the studies in the different frequency ranges.

Table 76: Technical parameters of CDR used for the conducted studies in the different frequency bands

Investigated frequency range	CDR-type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	DBF-CDR	5.7 GHz	10%	-32.6 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-12 dBm/MHz	28.6 dBm	20 dB
167 to 182 GHz	DBF-CDR	2.5 GHz	10%	-29 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-9 dBm/MHz	34.6 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the CDR-signal in adjacent bands allocated to FS.
Note 2: The duty cycle of 10% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).

5.6.2 Results

Table 77 shows the single-entry worst-case results for digital beamforming contour determination radar (DBF-CDR), e.g. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 77: Required separation distances determined in a single-entry study for DBF-CDR

Investigated Frequency range	Allocated band for FS	Required separation distance for scenario 1		Required separation distance for scenario 2	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
116 to 148.5 GHz	111.8 to 114.25 GHz (OOB)	28 m	12 m	3 m	1 m
	130 to 134 GHz (In-band)	179 m	77 m	18 m	7 m
	141 to 148.5 GHz (In-band)	156 m	67 m	15 m	7 m
167 to 182 GHz	167 to 174.8 GHz (In-band)	164 m	47 m	15 m	4 m

shows the single-entry worst-case results for mechanical- and phased-array contour determination radar (M- & PA-CDR), e.g. the largest separation distances for the individual frequency ranges and FS victim receivers distinguished between the long term objective and the peak power objective.

Table 78: Required separation distances determined in a single-entry study for M- & PA-CDR

Investigated Frequency range	Allocated band for FS	Required separation distance for scenario 1		Required separation distance for scenario 2		Required separation distance for scenario 3		Required separation distance for scenario 4	
		Long term	Peak power	Long term	Peak power	Long term	Peak power	Long term	Peak power
116 to 148.5 GHz	111.8 to 114.25 GHz (OOB)	25 m	45 m	2 m	5 m	25 m	127 m	3 m	16 m
	130 to 134 GHz (In-band)	169 m	300 m	15 m	31 m	166 m	804 m	21 m	108 m
	141 to 148.5 GHz (In-band)	154 m	278 m	14 m	28 m	151 m	726 m	19 m	98 m
167 to 182 GHz	167 to 174.8 GHz (In-band)	174 m	299 m	16 m	28 m	176 m	1.05 km	23 m	162 m

The conclusions drawn from these results can be found in section 8.6.3.

5.7 TANK LEVEL PROBING RADAR (TLPR)

5.7.1 Technical parameters of TLPR

For TLPR altogether three potential frequency bands have been defined (see section 2.2.7.2). However, only for the two frequency bands 116 to 148.5 GHz and 167 to 182 GHz allocations for FS are affected either within these bands or adjacent to them. Consequently, these two bands have been investigated in single-entry studies. In these studies the individually required separation distances (section 3.4.2) is determined by means of the technical parameters (section 2.2.7.3), the antenna data (section 2.2.7.4), the defined interference scenarios (section 2.2.7.6) and the protection requirements for FS (section 3.5.3). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the TLPR application (section 2.2.7.3) have been used in the studies in the different frequency ranges.

Table 79: Technical parameters of TLPR used for the conducted studies in the different frequency bands

Investigated frequency range	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
167 to 182 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the TLPR-signal in adjacent bands allocated to FS.					

5.7.2 Results

Table 80 shows the single-entry worst-case results for tank level probing radar, e.g. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 80: Required separation distances determined in a single-entry study for TLPR

Investigated Frequency range	Allocated band for FS	Required separation distance for scenario 1		Required separation distance for scenario 2	
		Long-term objective	Peak-power objective	Long-term objective	Peak-power objective
116 to 148.5 GHz	111.8 to 114.25 GHz (OOB)	19 m	1 m	2 m	0 m
	130 to 134 GHz (In-band)	101 m	6 m	9 m	1 m
	141 to 148.5 GHz (In-band)	79 m	4 m	7 m	0 m
167 to 182 GHz	167 to 174.8 GHz (In-band)	50 m	3 m	5 m	0 m

The conclusions drawn from these results can be found in section 8.7.3.

5.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

5.8.1 Technical parameters of RDI-S

For RDI-S the whole frequency range from 116 to 260 GHz has been defined (see section 2.2.8.2). In this band several allocations for FS are affected (see section 3.3). All these identified bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.8.3), the antenna data (section 2.2.8.4), the defined interference scenarios (section 2.2.8.6) and the protection requirements for FS (section 3.5.2). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI-S application (section 2.2.8.3) have been used in the studies in the different frequency ranges.

Table 81: Technical parameters of RDI-S used for the conducted studies at the different centre frequencies

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 260 GHz	113.025 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	10 dB
	132 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
	144.75 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
	157.75 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
	170.75 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to FS.						

5.8.2 Results

Table 82 shows the single-entry worst-case results for RDI-S, e.g. the largest separation distances for the individual frequency ranges, and FS victim receivers distinguished between the long-term objective and the peak power objective.

Table 82: Required separation distances determined in a single-entry study for RDI-S

Investigated Frequency range	Allocated band for FS	Investigated centre frequency	Required separation distance for scenario 1		Required separation distance for scenario 2	
			Long term objective	Peak power objective	Long term objective	Peak power objective
116 to 260 GHz	111.8 to 114.25 GHz (OOB)	113.025 GHz	11 m	6 m	1 m	1 m
	130 to 134 GHz (In-band)	132 GHz	24 m	14 m	3 m	1 m
	141 to 148.5 GHz (In-band)	144.75 GHz	22 m	12 m	2 m	1 m
	151.5 to 164 GHz (In-band)	157.75 GHz	20 m	11 m	2 m	1 m
	167 to 174.8 GHz (In-band)	170.75 GHz	19 m	10 m	2 m	1 m

The conclusions drawn from these results can be found in section 8.8.3.

6 SHARING AND COMPATIBILITY STUDIES WITH EESS (PASSIVE)

6.1 GENERIC INDOOR SURVEILLANCE RADAR

6.1.1 Technical parameters of generic indoor surveillance radar sensors

For generic indoor surveillance radar sensors altogether three potential frequency bands have been defined (see section 2.2.1.2). However, only for the two frequency bands 116 to 130 GHz and 141 to 148.5 GHz allocations for EESS are affected which are located within these bands or adjacent to them (please compare the figures in section 3.3). Consequently, these two bands have been investigated in single-entry and aggregate studies. In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.1.3), the antenna data (section 2.2.1.4), the defined interference scenarios (section 2.2.1.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the hand-held/mobile and fixed generic indoor surveillance application (section 2.2.1.3) have been used in the studies in the different frequency ranges.

Table 83: Technical parameters of generic indoor surveillance radars used for the conducted single-entry and aggregate studies in the different frequency bands

Investigated frequency range	Device type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Mean e.i.r.p. (Note 2)	OOB attenuation (Note 1)
116 to 130 GHz	Hand-held/mobile	1 GHz	20%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%	-10 dBm/MHz	20 dBm	20 dB
141 to 148.5 GHz	Hand-held/mobile	1 GHz	20%	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10%	-10 dBm/MHz	20 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the generic indoor surveillance radar in adjacent bands allocated to EESS. Note 2: The duty cycles are not considered in the mean e.i.r.p. spectral density and mean e.i.r.p. values. Consequently, the given mean e.i.r.p. spectral density and mean e.i.r.p. is valid for averaging over T_{meas} (time when transmission is on, see Figure 36).						

For the aggregate studies the total numbers of fixed and hand-held/mobile devices in the IFOV of the satellite were combined, and it was assumed that 2% of the devices are abusively operated outdoors. In this case the proposed installation requirement to fixed generic indoor surveillance equipment was not considered. In addition, for the aggregate scenario an average gain of all devices (fixed and hand-held/mobile) in the footprint of the satellite of 0 dBi has been agreed and used.

6.1.2 Results

Table 84 shows the single-entry and Table 85 the aggregate worst-case results for generic indoor surveillance radar sensors, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 84: Margins to the EESS interference criterion determined in a single-entry study for generic indoor surveillance radar sensors

Investigated Frequency range	Device type	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	Hand-held/ mobile	114.25 to 122.25 GHz (in-band)	119.125 GHz	MWI conical scanner	33.6 dB
116 to 130 GHz	Fixed	114.25 to 122.25 GHz (in-band)	119.125 GHz	MWI conical scanner	26.6 dB
122.25 to 130 GHz	Hand-held/ mobile	114.25 to 122.25 GHz (in adjacent)	119.125 GHz	MWI conical scanner	53.6 dB
122.25 to 130 GHz	Fixed	114.25 to 122.25 GHz (in adjacent)	119.125 GHz	MWI conical scanner	46.6 dB
116 to 130 GHz	Hand-held/ mobile	114.25 to 116 GHz (5.340 in adjacent)	115.125 GHz	MWI conical scanner	56.0 dB
116 to 130 GHz	Fixed	114.25 to 116 GHz (5.340 in adjacent)	115.125 GHz	MWI conical scanner	46.0 dB
141 to 148.5 GHz	Hand-held/ mobile	148.5 to 151.5 GHz (5.340 in adjacent)	150 GHz	System N1 (Nadir)	62.4 dB
				System N1 (Outer)	69.0 dB
141 to 148.5 GHz	Fixed	148.5 to 151.5 GHz (5.340 in adjacent)	150 GHz	System N1 (Nadir)	55.8 dB
				System N1 (Outer)	62.0 dB

Table 85: Margins to the EESS interference criterion determined in an aggregate study for generic indoor surveillance radar sensors

Investigated Frequency range	Device type	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	Hand-held/mobile + fixed	114.25 to 122.25 GHz (in-band)	119.125 GHz	MWI conical scanner	-21.0 dB
116 to 130 GHz	Hand-held/mobile + fixed	114.25 to 122.25 GHz (in adjacent)	119.125 GHz	MWI conical scanner	-0.9 dB
122.25 to 130 GHz	Hand-held/mobile + fixed	114.25 to 116 GHz (5.340 in adjacent)	115.125 GHz	MWI conical scanner	-1.2 dB
141 to 148.5 GHz	Hand-held/mobile + fixed	148.5 to 151.5 GHz (5.340 in adjacent)	150 GHz	System N1 (Nadir)	3.8 dB
				System N1 (Outer)	5.1 dB

The conclusions drawn from these results can be found in section 8.1.4.

6.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

6.2.1 Technical parameters of RDI

For RDI altogether five potential frequency bands have been defined (see section 2.2.2.2). However, only for the four frequency bands 116 to 130 GHz, 174.8 to 182 GHz, 185 to 190 GHz and 231.5 to 250 GHz allocations for EESS are affected which are located within these bands or adjacent to them (please compare the figures in section 3.3). Consequently, these four bands have been investigated in single-entry and aggregate studies. In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.2.3), the antenna data (section 2.2.2.4), the defined interference scenarios (section 2.2.2.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI application (section 2.2.2.3) have been used in the studies in the different frequency ranges.

Table 86: Technical parameters of RDI used for the conducted single-entry and aggregate studies in the different frequency bands

Investigated Frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 130 GHz	14 GHz	5%	-23.5 dBm/MHz	31 dBm	20 dB
174.8 to 182 GHz	1.5 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
185 to 190 GHz	1.5 GHz	5%	-13.8 dBm/MHz	31 dBm	20 dB
231.5 to 250 GHz	15 GHz	5%	-25.6 dBm/MHz	31 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the RDI-signal in adjacent bands allocated to EESS. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

6.2.2 Results

Table 87 shows the single entry and Table 88 the aggregate worst-case results for RDI, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 87: Margins to the EESS interference criterion determined in a single-entry study for RDI

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	-0.8 dB
174.8 to 182 GHz	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	0.1 dB
185 to 190 GHz	174.8 to 191.8 GHz (In-band)	187.5 GHz	AWS nadir scanner (at nadir)	0.5 dB
231.5 to 250 GHz	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	14.6 dB

Table 88: Margins to the EESS interference criterion determined in an aggregate study for RDI

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	5.5 dB
174.8 to 182 GHz	174.8 to 191.8 GHz (In-band)	178.4 GHz	MWS nadir scanner (at nadir)	13.4 dB
185 to 190 GHz	174.8 to 191.8 GHz (In-band)	187.5 GHz	MHS nadir scanner (at nadir)	16.8 dB
231.5 to 250 GHz	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	31.6 dB

The conclusions drawn from these results can be found in section 8.2.4.

6.3 SHORT RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

6.3.1 Technical parameters of short-range assist

For short-range assist altogether three potential frequency bands have been defined (see section 2.2.3.2). For all three frequency bands 116 to 130 GHz, 134 to 141 GHz and 141 to 148.5 GHz allocations for EESS are affected which are located within these bands or adjacent to them (please compare the figures in section 3.3). Consequently, these three bands have been investigated in aggregate studies for the two different vehicle density cases "urban/suburban" and "highway". For the urban/suburban case a density of 330 vehicles/km² and for the highway case a density of 123 vehicles/km² have been assumed, respectively.

In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.3.3), the antenna data (section 2.2.3.4), the defined interference scenarios (section 2.2.3.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the SR-assist application (section 2.2.3.3) have been used in the studies in the different frequency ranges.

Table 89: Technical parameters of short-range assist used for the conducted single-entry and aggregate studies in the different frequency bands

Investigated Frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 130 GHz	1 GHz	50%	14 dBm/MHz	47 dBm	20 dB
134 to 141 GHz	1 GHz	50%	14 dBm/MHz	47 dBm	20 dB
141 to 148.5 GHz	1 GHz	50%	14 dBm/MHz	47 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the SR-assist-signal in adjacent bands allocated to EESS.
Note 2: The duty cycle of 50% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).

In addition, calculations have also been performed with a peak e.i.r.p. of 40 dBm and 26 dBm.

6.3.2 Results

Table 90 shows the aggregate worst-case results for short-range assist in the urban/suburban scenario and Table 91 in the highway scenario, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 90: Margins to the EESS interference criterion determined in an aggregate study for SR-assist in the urban/suburban scenario

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	114.25 to 122.25 GHz	116 GHz (In-band)	MWI	-85.7 dB
		114.25 GHz (OOB)	MWI	-65.7 dB
134 to 141 GHz	148.5 to 151.5 GHz	148.5 GHz (OOB)	System N1 (Outer)	-59.7 dB
141 to 148.5 GHz	148.5 to 151.5 GHz	148.5 GHz (OOB)	System N1 (Outer)	-59.7 dB

Table 91: Margins to the EESS interference criterion determined in an aggregate study for SR-assist in the highway scenario

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 130 GHz	114.25 to 122.25 GHz	116 GHz (In-band)	MWI	-81.5 dB
		114.25 GHz (OOB)	MWI	-61.5 dB
134 to 141 GHz	148.5 to 151.5 GHz	148.5 GHz (OOB)	System N1 (Outer)	-55.4 dB
141 to 148.5 GHz	148.5 to 151.5 GHz	148.5 GHz (OOB)	System N1 (Outer)	-55.4 dB

In addition, calculations performed with the peak e.i.r.p. of 40 dBm and 26 dBm are still depicting large negative margins:

- For the 40 dBm peak e.i.r.p. scenario: -54.7 to -78.7 dB (in-band) and -34.7 to -58.7 dB (adjacent-band);
- For 26 dBm peak e.i.r.p. scenario: -40.7 to -64.7 dB (in-band) and -20.7 to -44.7 dB (adjacent-band).

The conclusions drawn from these results can be found in section 8.3.4.

6.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

6.4.1 Technical parameters of GBSAR

For GBSAR only one frequency band have been defined (see section 2.2.4.2). Due to the fact that in this defined frequency bands no allocation to EESS is affected, the out-of-band compatibility has been investigated by a single-entry and an aggregate study (please compare the figures in section 3.3). In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters, the antenna data (section 2.2.4.3), the defined interference scenarios (section 2.2.4.5) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the GBSAR application (section 2.2.4.3) have been used in the studies.

Table 92: Technical parameters of GBSAR used for the conducted study

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB mean e.i.r.p. spectral density
134 to 141 GHz	7 GHz	100%	9.55 dBm/MHz	48 dBm	-21.8 dBm/MHz

6.4.2 Results

Table 93 shows the single-entry and Table 94 the aggregate worst-case results for GBSAR, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 93: Margins to the EESS interference criterion determined in a single-entry study for GBSAR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
134 to 141 GHz	148.5 to 151.5 GHz (OOB)	148.5 GHz	Sensor N1 nadir scanner (at nadir)	13 dB

Table 94: Margins to the EESS interference criterion determined in an aggregate study for GBSAR

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
134 to 141 GHz	148.5 to 151.5 GHz (OOB)	148.5 GHz	Sensor N1 nadir scanner (at outer)	0 dB

The conclusions drawn from these results can be found in section 8.4.4.

6.5 LEVEL PROBING RADAR (LPR)

6.5.1 Technical parameters of LPR

For LPR altogether three potential frequency bands have been defined (see section 2.2.5.2). Due to the fact that in all defined frequency bands allocations for EESS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry and aggregate studies (please compare the figures in section 3.3). In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.5.3), the antenna data (section 2.2.5.4), the defined interference scenarios (section 2.2.5.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the LPR application (section 2.2.5.3) have been used in the studies in the different frequency ranges.

Table 95: Technical parameters of LPR used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1.6 GHz	5%	-8 dBm/MHz	37 dBm	20 dB
167 to 182 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB
231.5 to 250 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the LPR-signal in adjacent bands allocated to EESS. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

6.5.2 Results

Table 96 shows the single-entry and Table 97 the aggregate worst-case results for LPR, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 96: Margins to the EESS interference criterion determined in a single-entry study for LPR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	0.1 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	29.3 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	28.2 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	8.6 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	30.3 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	11.4 dB

Table 97: Margins to the EESS interference criterion determined in an aggregate study for LPR

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	6.9 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at outer)	33.4 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	35.0 dB

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	20.2 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	41.8 dB
	239 to 248 GHz (In-band)	234.5 GHz	AWS nadir scanner (at nadir)	25.3 dB

The conclusions drawn from these results can be found in section 8.5.4.

6.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

6.6.1 Technical parameters of CDR

For CDR altogether three potential frequency bands have been defined (see section 2.2.6.2). Due to the fact that in all defined frequency bands allocations for EESS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry and aggregate studies (please compare the figures in section 3.3). In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.6.3), the antenna data (section 2.2.6.4), the defined interference scenarios (section 2.2.6.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the CDR application (section 2.2.6.3) have been used in the studies in the different frequency ranges.

Table 98: Technical parameters of CDR used for the conducted studies in the different frequency bands

Investigated frequency range	CDR-type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	DBF-CDR	5.7 GHz	10%	-32.6 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-12 dBm/MHz	28.6 dBm	20 dB
167 to 182 GHz	DBF-CDR	2.5 GHz	10%	-29 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-9 dBm/MHz	34.6 dBm	20 dB
231.5 to 250 GHz	DBF-CDR	0.63 GHz	10%	-23 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-6 dBm/MHz	37 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the CDR-signal in adjacent bands allocated to EESS. Note 2: The duty cycle of 10% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).						

6.6.2 Results

Table 99 shows the single-entry and Table 100 the aggregate worst-case results for DBF-CDR, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 99: Margins to the EESS interference criterion determined in a single-entry study for DBF-CDR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	14.1 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	43.5 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	40.8 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	21.3 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	36.7 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	17.7 dB

Table 100: Margins to the EESS interference criterion determined in an aggregate study for DBF-CDR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	22.8 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	53.9 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P2 nadir scanner	53.4 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	30.9 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	44.6 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	25.8 dB

Table 101 shows the single-entry and Table 102 the aggregate worst-case results for M- and PA-CDR, e.g. the residual margins for the individual frequency ranges and EESS victim sensors.

Table 101: Margins to the EESS interference criterion determined in a single-entry study for M- and PA-CDR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	15.0 dB

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	44.2 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	42.1 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	22.6 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	41.2 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	22.3 dB

Table 102: Margins to the EESS interference criterion determined in an aggregate study for M- and PA-CDR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	15.8 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	45.0 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	42.9 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	23.4 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	42.0 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	23.1 dB

The conclusions drawn from these results can be found in section 8.6.4.

6.7 TANK LEVEL PROBING RADAR (TLPR)

6.7.1 Technical parameters of TLPR

For TLPR altogether three potential frequency bands have been defined (see section 2.2.7.2). Due to the fact that in all defined frequency bands allocations for EESS are affected-either within these bands or adjacent to them – all three bands have been investigated by single-entry and aggregate studies (please compare the figures in section 3.3). In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.7.3), the antenna data (section 2.2.7.4), the defined interference scenarios (section 2.2.7.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the TLPR application (section 2.2.7.3) have been used in the studies in the different frequency ranges.

Table 103: Technical parameters of TLPR used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
167 to 182 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
231.5 to 250 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the TLPR-signal in adjacent bands allocated to EESS.					

6.7.2 Results

Table 104 shows the single-entry and Table 105 the aggregate worst-case results for TLPR, e.g. the residual margins for the individual frequency ranges, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 104: Margins to the EESS interference criterion determined in a single-entry study for TLPR

Investigated Frequency range	Allocated band for EESS	Evaluated frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	12.1 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at nadir)	54.8 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	57.2 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	38.8 dB
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	64.3 dB
	239 to 248 GHz (In-band)	243.5 GHz	AWS nadir scanner (at nadir)	46.3 dB

Table 105: Margins to the EESS interference criterion determined in an aggregate study for TLPR

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
116 to 148.5 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	18.6 dB
	148.5 to 151.5 GHz (OOB)	150 GHz	Sensor N1 nadir scanner (at outer)	57.8 dB
167 to 182 GHz	164 to 167 GHz (OOB)	165.5 GHz	Sensor P1 conical scanner	57.2 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	38.8 dB

Investigated Frequency range	Allocated band for EESS	Evaluated Frequency	EESS victim sensor	Margin to interference criterion
231.5 to 250 GHz	226 to 231.5 GHz (OOB)	228.75 GHz	AWS nadir scanner (at nadir)	79.3 dB
	239 to 248 GHz (In-band)	234.5 GHz	AWS nadir scanner (at nadir)	61.3 dB

The conclusions drawn from these results can be found in section 8.7.4.

6.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

6.8.1 Technical parameters of RDI-S

For RDI-S the whole frequency range from 116 to 260 GHz has been defined (see section 2.2.8.2). In this band several allocations for EESS are affected (see section 3.3). In addition to that altogether eight bands are affected which are protected by article 5.340 in the ITU Radio Regulations (compare section 3.4). In the protected bands there are also allocations of EESS. All these identified bands have been investigated by single-entry and aggregate studies (please compare the figures in section 3.3). In these studies the individual residual margin (section 3.4.4) to the interference criterion is determined by means of the technical parameters (section 2.2.8.3), the antenna data (section 2.2.8.4), the defined interference scenarios (section 2.2.8.6) and the protection requirements for EESS (section 3.5.4). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI-S application (section 2.2.8.3) have been used in the studies in the different frequency ranges.

Table 106: Technical parameters of RDI-S used for the conducted studies in EESS frequency allocations outside RR article 5.340 protected bands

Investigated frequency range	Investigated centre frequency	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
114.25 to 122.25 GHz	119.125 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	10 dB
174.8 to 191.8 GHz	178.4 GHz	100 GHz	100%	10 dBm/MHz	60 dBm	
	187.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
235 to 238 GHz	236.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
239 to 248 GHz	239 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to EESS.						

Table 107: Technical parameters of RDI-S used for the conducted studies in EESS frequency allocations inside RR article 5.340 protected bands

Investigated frequency range	Investigated centre frequency	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
114.25 to 116 GHz	115.125 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	10 dB

Investigated frequency range	Investigated centre frequency	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
148.5 to 151.5 GHz	150 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
164 to 167 GHz	165.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
182 to 185 GHz	183.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
190 to 191.8 GHz	190.9 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
200 to 209 GHz	204.5 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
226 to 231.5 GHz	228.75 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
250 to 252 GHz	251 GHz	100 GHz	100%	-15 dBm/MHz	35 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to EESS.						

6.8.2 Results

Table 108 shows the single-entry and Table 109 the aggregate worst-case results for RDI-S, e.g. the residual margins for the individual frequency ranges outside RR article 5.340 protected bands, and EESS victim sensors. A positive margin indicates that the interference criterion is fulfilled and a negative margin that the criterion is violated.

Table 108: Margins to the EESS interference criterion determined in a single-entry study for RDI-S in frequency ranges outside RR article 5.340 protected bands

Investigated Frequency range	Allocated band for EESS	Investigated centre frequency	EESS victim sensor	Margin to interference criterion
116 to 260 GHz	114.25 to 122.25 GHz (in-band)	119.125 GHz	MWI conical scanner	30.7 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	AWS nadir scanner (at nadir)	26.3 dB
		187.5 GHz	AWS nadir scanner (at nadir)	41.8 dB
	235 to 238 GHz (In-band)	236.5 GHz	MWI conical scanner	43.1 dB
	239 to 248 GHz (In-band)	239 GHz	AWS nadir scanner (at nadir)	43.9 dB

Table 109: Margins to the EESS interference criterion determined in an aggregate study for RDI-S in frequency ranges outside RR article 5.340 protected bands

Investigated Frequency range	Allocated band for EESS	Investigated centre frequency	EESS victim sensor	Margin to interference criterion
116 to 260 GHz	114.25 to 122.25 GHz (In-band)	119.125 GHz	MWI conical scanner	12.3 dB
	174.8 to 191.8 GHz (In-band)	178.4 GHz	MWI conical scanner	14.3 dB
		187.5 GHz	MWI conical scanner	29.7 dB
	235 to 238 GHz (In-band)	236.5 GHz	ICI conical scanner	25.6 dB
	239 to 248 GHz (In-band)	239 GHz	ICI conical scanner	30.5 dB

Table 110 shows the single-entry and Table 111 the aggregate worst-case results for RDI-S, e.g. the residual margins for the individual frequency ranges inside RR article 5.340 protected bands, and EESS victim sensors.

Table 110: Margins to the EESS interference criterion determined in a single-entry study for RDI-S in frequency ranges inside RR article 5.340 protected bands

Investigated Frequency range	Allocated band for EESS	Investigated centre frequency	EESS victim sensor	Margin to interference criterion
116 to 260 GHz	114.25 to 116 GHz (OOB)	115.125 GHz	MWI conical scanner	40.4 dB
	148.5 to 151.5 GHz (In-band)	150 GHz	Sensor N1 nadir scanner (at nadir)	49.9 dB
	164 to 167 GHz (In-band)	165.5 GHz	Sensor P1 conical scanner	50.9 dB
	182 to 185 GHz (In-band)	183.5 GHz	AWS nadir scanner (at nadir)	51.6 dB
	190 to 191.8 GHz (In-band)	190.9 GHz	AWS nadir scanner (at nadir)	51.9 dB
	200 to 209 GHz (In-band)	204.5 GHz	MWI conical scanner	48.8 dB
	226 to 231.5 GHz (In-band)	228.75 GHz	MWI conical scanner	52.3 dB
	250 to 252 GHz (In-band)	251 GHz	MWI conical scanner	54.1 dB

Table 111: Margins to the EESS interference criterion determined in an aggregate study for RDI-S in frequency ranges inside RR article 5.340 protected bands

Investigated Frequency range	Allocated band for EESS	Investigated centre frequency	EESS victim sensor	Margin to interference criterion
116 to 260 GHz	114.25 to 116 GHz (OOB)	115.125 GHz	MWI conical scanner	22.0 dB
	148.5 to 151.5 GHz (In-band)	150 GHz	Sensor N1 nadir scanner (at nadir)	28.2 dB
	164 to 167 GHz (In-band)	165.5 GHz	Sensor P1 conical scanner	31.2 dB
	182 to 185 GHz (In-band)	183.5 GHz	MWI conical scanner	39.5 dB
	190 to 191.8 GHz (In-band)	190.9 GHz	MWI conical scanner	39.9 dB
	200 to 209 GHz (In-band)	204.5 GHz	MWI conical scanner	31.7 dB
	226 to 231.5 GHz (In-band)	228.75 GHz	MWI conical scanner	35.2 dB
	250 to 252 GHz (In-band)	251 GHz	MWI conical scanner	37.0 dB

The conclusions drawn from these results can be found in section 8.8.4.

7 SHARING AND COMPATIBILITY STUDIES WITH AMATEUR SERVICE

7.1 GENERIC INDOOR SURVEILLANCE RADAR

For generic indoor surveillance radar sensors altogether three potential frequency bands have been defined (see section 2.2.1.2). Due to the fact that in all defined frequency bands allocations for Amateur are affected- either within these bands or adjacent to them – all three bands have been investigated by single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.1.3), the antenna data (section 2.2.1.4), the defined interference scenarios (section 2.2.1.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the generic hand-held/mobile and fixed indoor studies (section 2.2.1.3) have been used in the studies in the different frequency ranges.

Table 112: Technical parameters of the generic indoor surveillance radars used for the conducted studies in the different frequency bands

Investigated frequency range	Device type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Mean e.i.r.p. (Note 2)	OOB attenuation (Note 1)
116 to 130 GHz	Hand-held/mobile	1 GHz	20 %	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10 %	-10 dBm/MHz	20 dBm	20 dB
134 to 141 GHz	Hand-held/mobile	1 GHz	20 %	-20 dBm/MHz	10 dBm	20 dB
	Fixed	1 GHz	10 %	-10 dBm/MHz	20 dBm	20 dB

Note 1: Assumed out-of-band attenuation of the generic indoor surveillance radar in adjacent bands allocated to Amateur.
Note 2: The duty cycles are not considered in the mean e.i.r.p. spectral density and mean e.i.r.p. values. Consequently, the given mean e.i.r.p. spectral density and mean e.i.r.p. is valid for averaging over T_{meas} (time when transmission is on, see Figure 36).

7.1.1 Results

Table 113 shows the single-entry worst-case results for generic indoor surveillance radar sensors, e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 113: Required separation distances determined in a single-entry study for generic indoor surveilance radar sensors

Device type	Single-entry case (see section 4.1)	Required separation distances	
		Allocated Amateur band: 122.25 GHz to 123 GHz (in-band)	Allocated Amateur band: 134 to 141 GHz (in-band)
		Evaluated frequency: 122.625 GHz	Evaluated frequency: 137.5 GHz
Hand-held/mobile	1	73 m	65 m
Hand-held/mobile	2	51 m	45 m
Hand-held/mobile	3	6 m	5 m

Device type	Single-entry case (see section 4.1)	Required separation distances	
		Allocated Amateur band: 122.25 GHz to 123 GHz (in-band)	Allocated Amateur band: 134 to 141 GHz (in-band)
		Evaluated frequency: 122.625 GHz	Evaluated frequency: 137.5 GHz
Fixed	1	163 m	145 m
Fixed	2	113 m	101 m
Fixed	3	13 m	12 m
Fixed	4	5 m	5 m

Note: In former ECC studies (e.g. ECC Report 190 [21]) an indoor-outdoor attenuation of 60 dB has been assumed.

The conclusions drawn from these results can be found in section 8.1.5.

7.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

7.2.1 Technical parameters of RDI

For RDI altogether five potential frequency bands have been defined (see section 2.2.2.2). However, only for the three frequency bands 116 to 130 GHz, 134 to 141 GHz and 231.5 to 250 GHz allocations for Amateur Service are affected which are located within these bands (please compare the figures in section 3.3). Consequently, these three bands have been investigated in single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.2.3), the antenna data (section 2.2.2.4), the defined interference scenarios (section 2.2.2.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI application (section 2.2.2.3) have been used in the studies in the different frequency ranges.

Table 114: Technical parameters of RDI used for the conducted studies in the different frequency bands

Investigated frequency range	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 130 GHz	14 GHz	5%	-23.5 dBm/MHz	31 dBm	20 dB
134 to 141 GHz	7 GHz	5%	-20.5 dBm/MHz	31 dBm	20 dB
231.5 to 250 GHz	15 GHz	5%	-25.6 dBm/MHz	31 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the RDI-signal in adjacent bands allocated to Amateur. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

7.2.2 Results

Table 115 shows the single-entry worst-case results for RDI, e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 115: Required separation distances determined in a single-entry study for radiodetermination systems for industry automation (RDI)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 130 GHz	122.25 to 123 GHz (In-band)	446 m
134 to 141 GHz	134 to 141 GHz (In-band)	546 m
231.5 to 250 GHz	241 to 250 GHz (In-band)	121 m

The conclusions drawn from these results can be found in section 8.2.5.

7.3 SHORT RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

No study has been conducted to evaluate the compatibility between short-range assist and surrounding monitoring for vehicles and autonomous systems and Amateur Service (see section 8.3.5).

7.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

No study has been conducted to evaluate the compatibility between GBSAR and Amateur Service (see section 8.4.5).

7.5 LEVEL PROBING RADAR (LPR)

7.5.1 Technical parameters of LPR

For LPR altogether three potential frequency bands have been defined (see section 2.2.5.2). However, only for the two frequency bands 116 to 148.5 GHz and 231.5 to 250 GHz allocations for Amateur Service are affected which are located within these bands (please compare the figures in section 3.3). Consequently, these two bands have been investigated in single-entry studies. In these studies the individually required separation distance (section 3.4.2) is determined by means of the technical parameters (section 2.2.5.3), the antenna data (section 2.2.5.4), the defined interference scenarios (section 2.2.5.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the LPR application (section 2.2.5.3) have been used in the studies in the different frequency ranges.

Table 116: Technical parameters of LPR used for the conducted studies in the different frequency bands

Investigated frequency range	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1.6 GHz	5%	-8 dBm/MHz	37 dBm	20 dB
231.5 to 250 GHz	1 GHz	5%	-6 dBm/MHz	37 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the LPR-signal in adjacent bands allocated to Amateur. Note 2: The duty cycle of 5% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).					

7.5.2 Results

Table 117 shows the single-entry worst-case results for LPR, e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 117: Required separation distances determined in a single-entry study for level probing radar (LPR)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 148.5 GHz	122.25 to 123 GHz (In-band)	69 m
	134 to 141 GHz (In-band)	61 m
231.5 to 250 GHz	241 to 250 GHz (In-band)	27 m

The conclusions drawn from these results can be found in section 8.5.5.

7.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

7.6.1 Technical parameters of CDR

For contour determination radar (CDR) altogether three potential frequency bands have been defined (see section 2.2.6.2). However, only for the two frequency bands 116 to 148.5 GHz and 231.5 to 250 GHz allocations for Amateur are affected within these bands. Consequently, these two bands have been investigated in single-entry studies. In these studies the individual required interference range (section 3.4.2) (also known as separation distance) is determined by means of the technical parameters (section 2.2.6.2), the antenna data (section 2.2.6.4), the defined interference scenarios (section 2.2.6.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the CDR application (section 2.2.6.3) have been used in the studies in the different frequency ranges.

Table 118: Technical parameters of CDR used for the conducted studies in the different frequency bands

Investigated frequency range	CDR-type	Assumed modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density (Note 2)	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	DBF-CDR	5.7 GHz	10%	-32.6 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-12 dBm/MHz	28.6 dBm	20 dB
231.5 to 250 GHz	DBF-CDR	0.63 GHz	10%	-23 dBm/MHz	15 dBm	20 dB
	M-/PA-CDR	8 GHz	10%	-9 dBm/MHz	34.6 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the CDR-signal in adjacent bands allocated to Amateur. Note 2: The duty cycle of 10% is already considered in this mean e.i.r.p. spectral density value. Consequently, the given mean e.i.r.p. spectral density is valid for averaging over the whole measurement cycle T_{meas_cycle} of the device including any T_{off} times (see Figure 36).						

7.6.2 Results

Table 119 shows the single-entry worst-case results for digital beamforming contour determination radar (DBF-CDR), e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 119: Required separation distances determined in a single-entry study for digital beamforming contour determination radar (DBF-CDR)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 148.5 GHz	122.25 to 123 GHz (In-band)	114 m
	134 to 141 GHz (In-band)	101 m
231.5 to 250 GHz	241 to 250 GHz (In-band)	116 m

Table 120 shows the single-entry worst-case results for mechanical- and phased-array contour determination radar (M- & PA-CDR), e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 120: Required separation distances determined in a single-entry study for mechanical- and phased-array contour determination radar (M- & PA-CDR)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 148.5 GHz	122.25 to 123 GHz (In-band)	76 m
	134 to 141 GHz (In-band)	68 m
231.5 to 250 GHz	241 to 250 GHz (In-band)	53 m

The conclusions drawn from these results can be found in section 8.6.5.

7.7 TANK LEVEL PROBING RADAR (TLPR)

7.7.1 Technical parameters of TLPR

For TLPR altogether three potential frequency bands have been defined (see section 2.2.7.2). However, only for the two frequency bands 116 to 148.5 GHz and 231.5 to 250 GHz allocations for Amateur Service are affected which are located within these bands (please compare the figures in section 3.3). Consequently, these two bands have been investigated in single-entry studies. In these studies the individually required separation distances (section 3.4.2) is determined by means of the technical parameters (section 2.2.7.3), the antenna data (section 2.2.7.4), the defined interference scenarios (section 2.2.7.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the TLPR application (section 2.2.7.3) have been used in the studies in the different frequency ranges.

Table 121: Technical parameters of TLPR used for the conducted studies in the different frequency bands

Investigated frequency range	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
116 to 148.5 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
231.5 to 250 GHz	1 GHz	100%	12 dBm/MHz	42 dBm	20 dB
Note 1: Assumed out-of-band attenuation of the TLPR-signal in adjacent bands allocated to Amateur.					

7.7.2 Results

Table 122 shows the single-entry worst-case results for TLPR, e.g. the largest separation distances for the individual frequency ranges and Amateur victim receivers.

Table 122: Required separation distances determined in a single-entry study for tank level probing radar (TLPR)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 148.5 GHz	122.25 to 123 GHz (In-band)	31 m
	134 to 141 GHz (In-band)	22 m
231.5 to 250 GHz	241 to 250 GHz (In-band)	3 m

The conclusions drawn from these results can be found in section 8.7.5.

7.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

7.8.1 Technical parameters of RDI-S

For RDI-S the whole frequency range from 116 to 260 GHz has been defined (see section 2.2.8.2). In this band three allocations for Amateur Service are affected (see section 3.3). All these identified bands have been investigated by single-entry studies. In these studies the individually required interference range (section 3.4.2) is determined by means of the technical parameters (section 2.2.8.3), the antenna data (section 2.2.8.4), the defined interference scenarios (section 2.2.8.6) and the protection requirements for Amateur Service (section 3.5.5). The exact calculations can be found in an Excel-spreadsheet which is attached to this Report.

The following technical parameters of the RDI-S application (section 2.2.8.3) have been used in the studies in the different frequency ranges.

Table 123: Technical parameters of RDI-S used for the conducted studies in the different frequency bands

Investigated frequency range	Investigated centre frequency	Modulation bandwidth	Duty cycle	Mean e.i.r.p. spectral density	Peak e.i.r.p.	OOB attenuation (Note 1)
122.25 to 123 GHz	122.625 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	10 dB
134 to 141 GHz	137.5 GHz	100 GHz	100%	10 dBm/MHz	60 dBm	
241 to 250 GHz	245.5 GHz	100 GHz	100%	-5 dBm/MHz	45 dBm	
Note 1: Assumed out-of-band attenuation of the RDI-S-signal in adjacent bands allocated to Amateur.						

7.8.2 Results

Table 124 shows the single-entry worst-case results for RDI-S, e.g. the largest separation distances for the individual frequency ranges and Amateur Service victim receivers.

Table 124: Required separation distances determined in a single-entry study for radiodetermination systems for industry automation in shielded environments (RDI-S)

Investigated Frequency range	Allocated band for Amateur Service	Required separation distance for all Amateur Services
116 to 260 GHz	122.25 to 123 GHz (In-band)	12 m
	134 to 141 GHz (In-band)	60 m
	241 to 250 GHz (In-band)	4 m

The conclusions drawn from these results can be found in section 8.8.5.

8 CONCLUSIONS

8.1 GENERIC INDOOR SURVEILLANCE RADAR

8.1.1 Summary

For generic indoor surveillance radar the candidate frequency bands 116 to 130 GHz, 134 to 141 GHz and 141 to 148.5 GHz have been studied for both categories of such devices, hand-held/mobile and fixed. It turned out that only in the bands 122.25 to 130 GHz, 134 to 141 GHz and 141 to 148.5 GHz compatibility between generic indoor surveillance radars and all investigated Radio Services can be ensured.

The lower portion, 116 to 122.25 GHz, of the whole candidate band 116 to 130 GHz has also been investigated. However, compatibility between generic indoor surveillance radar sensors and EESS (passive) cannot be ensured in this band portion assuming the power levels given in section 6.1.1.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km
- Fixed Service and Amateur Service: Separation distance smaller than 300 m
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All fixed generic indoor surveillance radars should comply with the following (installation) requirements:

- Fixed generic indoor surveillance radars shall only be installed and operated inside buildings.
- Users and installers have to ensure that fixed generic indoor surveillance radars, although installed inside a building, do not perform a function outside the building structure, such as for example the detection of persons outside the building (e.g. through wall imaging).
- The provider is required to inform the users and installers of fixed generic indoor surveillance equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is proposed:

- For fixed generic indoor surveillance radars, the mean e.i.r.p. above 0° elevation shall be limited to 12 dBm (8 dB below the maximum mean e.i.r.p. of 20 dBm).

8.1.2 Radio Astronomy

The separation distances in the lower frequency range 123 GHz to 158.5 GHz obtained in the single-entry study are for the fixed generic indoor surveillance radar devices 35.2 km for the outdoor consideration and 10.7 km for the indoor case. For the hand-held/mobile generic indoor surveillance equipment the separation distances are 19 km for the outdoor consideration and 1.6 km for the indoor case.

Therefore, to reach compatibility for the fixed indoor equipment an installation requirement limiting the related mean e.i.r.p. to a maximal value of 12 dBm for elevation angles larger than 0° could be requested. In this case the separation distance would drop to 17.5 km for the outdoor consideration.

For the frequency bands 76 GHz to 116 GHz, 148.5 GHz to 151.5 GHz (adjacent frequency situation) compatibility can be ensured between both types of generic indoor surveillance radar equipment and RAS without the implementation of additional mitigation techniques. The separation distances obtained in the MCL calculations are all below 5 km.

Operational solutions to implement these separation distances were not studied in this Report.

8.1.3 Fixed Service

For evaluating the compatibility between generic indoor surveillance radar and FS the two worst-case interference scenarios in Figure 3 and Figure 4 have been defined (see section 2.2.1.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between RDI and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

For the hand-held/mobile and fixed generic indoor surveillance equipment the largest separation distance in the in-band interference situation was determined to be 290 m. For the adjacent band situation, the separation distance was determined to be 50 m.

If in addition the antenna pattern (8 dB below the maximum mean e.i.r.p above an elevation of larger than 0°) was considered for the fixed generic indoor surveillance radar a smaller separation distance and thus a lower probability of interference would result. The same would apply to both generic indoor surveillance device categories if a clutter loss was considered in the terrestrial path.

In the aggregate consideration the number of required devices in order to interfere with the FS receiver (in the worst-case 17 per floor) would by far outnumber the expected device numbers per house (5) or per flat (3).

8.1.4 Earth Exploration Satellite Service (Passive)

For the single-entry consideration In all investigated frequency bands ample margins to the interference criteria can be ensured without the implementation of additional mitigation techniques (see Table 84 in section 6.1.2).

For the aggregate scenario, however, in the lower portion 116 to 122.25 GHz of the candidate band 116 to 130 GHz compatibility between generic indoor surveillance radar sensors and EESS (passive) (in-band scenario) cannot be ensured assuming the conditions shown in Table 83 without the implementation of additional mitigation techniques. In the remaining portion 122.25 to 130 GHz of this band and in the bands 134 to 141 GHz and 141 to 148.5 GHz only an adjacent band situation occurs to EESS (passive). Under these circumstances the aggregate studies have shown that compatibility could be reached without the implementation of additional mitigation techniques. The margins in Table 85 are only exceeded by 0.9 and 1.2 dB, respectively.

It is however important that the generated interference in the out-of-band domain is at least 20 dB below the in-band emission. That means the maximum mean e.i.r.p and the maximum mean e.i.r.p spectral density should be reduced in adjacent bands allocated to EESS (passive) by at least 20 dB.

If in addition an installation requirement limiting the related mean e.i.r.p. to a maximal value of 12 dBm for elevation angles larger than 0° for the fixed indoor equipment was applied, the margin for the aggregate interference would rise to 0.1 dB in the band 114.25 to 122.25 GHz.

8.1.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 113 suggest that compatibility between generic indoor surveillance radar sensors for both types, hand-held/mobile and fixed, and Amateur can be asserted in all investigated frequency bands without the implementation of additional mitigation techniques (see section 7.1.1).

8.2 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION (RDI)

8.2.1 Summary

For RDI the candidate frequency bands 116 to 130 GHz, 134 to 141 GHz, 174.8 to 182 GHz, 185 to 190 GHz and 231.5 to 250 GHz have been studied. It turned out that only in the upper three frequency ranges 174.8 to

182 GHz, 185 to 190 GHz and 231.5 to 250 GHz compatibility between RDI and all investigated Radio Services can be ensured.

The candidate bands 116 to 130 GHz and 134 to 141 GHz have also been investigated. However, compatibility between RDI and RAS cannot be ensured in these bands assuming the power levels given in section 4.2.1 without the implementation of additional mitigation techniques.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km
- Fixed Service and Amateur Service: Separation distance smaller than 300 m
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All RDI sensors should furthermore comply with the following (installation) requirements:

- The operation of RDI sensors is envisaged for industrial purposes only;
- Installation and maintenance of RDI equipment shall be performed by professionally trained individuals only;
- RDI equipment shall not be marketed to private end customers;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- All outdoor RDI sensors under consideration shall be installed in heights from 0 m to 3 m above ground;
- In order to protect the Radio Astronomy Service, inside a radius of 20 km around the stations of NOEMA and IRAM 30 m, the installation and operation of RDI devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of RDI equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is proposed:

- For RDI devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

8.2.2 Radio Astronomy

The required separation distances in the lower frequency ranges 116 GHz to 130 GHz and 134 GHz to 141 GHz obtained in the single-entry study are 53.3 km and 63.0 km, respectively. These relatively large impact ranges increase the probability of interference to the affected Radio Astronomy Stations. Therefore, compatibility between RDI and RAS cannot be ensured in these bands assuming the power levels given in Table 52 without the implementation of additional mitigation techniques (see section 4.2.1).

For the frequency bands 174.8 GHz to 182 GHz, 185 GHz to 190 GHz and 231.5 GHz to 250 GHz compatibility can be ensured between RDI and RAS when separation distances of 15.3 km, 9.6 km and 19.9 km, respectively, are respected without the implementation of additional mitigation techniques (see section 4.2.2).

8.2.3 Fixed Service

For evaluating the compatibility between RDI and FS the two worst-case interference scenarios in Figure 12 and Figure 13 have been defined (see section 2.2.2.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between RDI and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for RDI in Table 73 are smaller than 300 m (see section 5.2.2). Therefore, compatibility between RDI and FS can always be asserted for all investigated frequency bands, for both scenarios and both protection objectives without the implementation of additional mitigation techniques.

8.2.4 Earth Exploration Satellite Service (Passive)

For the frequency band 116 to 130 GHz the protection criterion is exceeded for the single-entry case by 0.8 dB under the assumed conditions shown in Table 86 in section 6.2.1. However, a reduction of the mean power spectral density of at least 0.8 dB could be considered in order to ensure compatibility. In all other frequency bands and in particular for the aggregate consideration ample margins to the interference criteria can be ensured without the implementation of additional mitigation techniques (see Table 88).

8.2.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 115 suggest that compatibility between RDI and Amateur can only be asserted in the investigated frequency band 231.5 to 250 GHz without the implementation of additional mitigation techniques (see section 7.2.2).

8.3 SHORT-RANGE ASSIST AND SURROUNDING MONITORING FOR VEHICLES AND AUTONOMOUS SYSTEMS

8.3.1 Summary

For short-range assist and surrounding monitoring for vehicles and autonomous systems the candidate frequency bands 116 to 130 GHz, 134 to 141 GHz and 141 to 148.5 GHz have been studied. It turned out that in none of the mentioned frequency ranges compatibility between short-range assist and the investigated Radio Services can be ensured under the technical assumptions used in the studies (see section 2.2.3.3 and Table 89).

Further studies have been conducted which resulted in ECC Report 351 [72] in order to address the latest insight in the technical assumptions in bands adjacent to EESS (passive) bands.

The following protection requirement has been assumed:

- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

8.3.2 Radio Astronomy

A single-interferer scenario compatibility study between Radio Astronomy Service and radiodetermination devices for short-range assist and surrounding monitoring for vehicles and autonomous systems has been conducted.

The study shows that separation distances are needed between the short-range devices and the observatories of NOEMA in France and IRAM 30 m in Spain in order to protect the RAS. These separation distances are dependent on the frequency and on the e.i.r.p. of the interfering short-range devices. The effectual e.i.r.p. of the SRDs which has been considered for this single-interferer study was 55 dBm in a bandwidth of 8 GHz.

The study shows that separation distances around the radioastronomy sites of NOEMA in France and IRAM 30 m in Spain have to be respected for the emissions of the radio determination devices for short-range assist and surrounding monitoring for vehicles and autonomous systems. By considering an effectual e.i.r.p. of 55 dBm, these zones cover distances up to 270 km for the NOEMA site and up to 250 km for the IRAM 30 m site. The circles in Figure 98 and Figure 99 show the separation distances for the NOEMA site and the IRAM 30 m site, respectively (see section 4.12).

An implementation of an automatic system to switch-off the short-range device coupled with geo-positioning of the vehicle should be considered in order to overcome compatibility issues.

Interference studies considering an aggregate scenario have been invited but not performed for short-range assist devices. Therefore, no conclusion can be drawn whether short-range assist can ensure compatibility with Radio Astronomy Service in such an aggregate scenario.

8.3.3 Fixed Service

No study has been conducted to evaluate the compatibility between short-range assist and surrounding monitoring for vehicles and autonomous systems and Fixed Service. Therefore, no conclusion can be drawn whether short-range assist can ensure compatibility with FS.

8.3.4 Earth Exploration Satellite Service (Passive)

For all investigated frequency ranges, the protection criterion is exceeded for the two distinguished aggregate scenarios by large amounts, no matter if an in-band or out-of-band interference is considered. Under the assumed conditions illustrated in Table 89 in section 6.3.1, compatibility of short-range assist and surrounding monitoring for vehicles and autonomous systems cannot be ensured with EESS (passive).

Additional calculations with a decreased peak e.i.r.p. (40 dBm and 26 dBm instead of 47 dBm) have shown that the conclusions remain the same, i.e. that the EESS (passive) protection criterion is exceeded for the two distinguished aggregate scenarios by large amounts, no matter if an in-band or out-of-band interference is considered.

8.3.5 Amateur Service

No study has been conducted to evaluate the compatibility between short-range assist and surrounding monitoring for vehicles and autonomous systems and Amateur Service. Therefore, no conclusion can be drawn whether short-range assist can ensure compatibility with Amateur.

8.4 GROUND BASED SYNTHETIC APERTURE RADAR (GBSAR)

8.4.1 Summary

For GBSAR the candidate frequency band 134 to 141 GHz has been studied only for Earth Exploration Satellite Service (passive) which is located adjacent to this band. Compatibility can be ensured if the maximum out-of-band mean e.i.r.p. spectral density is limited to -21.8 dBm/MHz in adjacent EESS-bands.

The following protection requirement has been assumed:

- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

However, studies for the other relevant Radio Services, like RAS, FS and Amateur, have not been conducted. A conclusion whether compatibility to these services can also be ensured can hence not be drawn.

8.4.2 Radio Astronomy

No study has been conducted to evaluate the compatibility between GBSAR and Radio Astronomy Service. Therefore, no conclusion can be drawn whether GBSAR can ensure compatibility with RAS.

8.4.3 Fixed Service

No study has been conducted to evaluate the compatibility between GBSAR and Fixed Service. Therefore, no conclusion can be drawn whether GBSAR can ensure compatibility with FS.

8.4.4 Earth Exploration Satellite Service (Passive)

For the aggregate consideration a maximum out-of-band mean power spectral density (e.i.r,p.) of -21.8 dBm/MHz can be tolerated in order to establish a zero margin to the interference criterion without the implementation of additional mitigation techniques. In addition to that with this power spectral density a positive margin of 13 dB can be achieved to the interference criterion in the single-entry study (see sections 6.4.1 and 6.4.2).

8.4.5 Amateur Service

No study has been conducted to evaluate the compatibility between GBSAR and Amateur Service. Therefore, no conclusion can be drawn whether GBSAR can ensure compatibility with Amateur.

8.5 LEVEL PROBING RADAR (LPR)

8.5.1 Summary

For LPR the candidate frequency bands 116 to 148.5 GHz, 167 to 182 GHz and 231.5 to 250 GHz have been studied. It turned out that in all three frequency ranges compatibility between LPR and all investigated Radio Services can be ensured.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km;
- Fixed Service and Amateur Service: Separation distance smaller than 300 m;
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All level probing radars should furthermore comply with the following (installation) requirements:

- The operation of LPR sensors is envisaged for industrial purposes only;
- Installation and maintenance of LPR equipment shall be performed by professionally trained individuals only;
- LPR equipment shall not be marketed to private end customers;
- Level probing radars are required to be installed at a permanent fixed position pointing in a downwards direction towards the ground. The equipment shall not operate while being moved, or while inside a moving container;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- In order to protect the Radio Astronomy Service, inside a radius of 13 km around the stations of NOEMA and IRAM 30 m, the installation and operation of LPR devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of LPR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following two requirements are proposed:

- For LPR devices, the peak e.i.r.p. for elevations above 0° shall be limited to 0 dBm.
- For LPR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

8.5.2 Radio Astronomy

For the frequency bands 116 GHz to 148.5 GHz, 167 GHz to 182 GHz and 231.5 GHz to 250 GHz compatibility can be ensured between LPR and RAS when separation distances of 13 km, 10 km and 6.4 km, respectively, are respected without the implementation of additional mitigation techniques (see section 4.5.2).

8.5.3 Fixed Service

For evaluating the compatibility between LPR and FS the two worst-case interference scenarios in Figure 38 and Figure 39 have been defined (see section 2.2.5.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between LPR and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for LPR in Table 75 are smaller than 300 m (see section 5.5.2). Therefore, compatibility between LPR and FS can always be asserted for both scenarios and both investigated protection objectives without the implementation of additional mitigation techniques.

In order to restrict the interference in unwanted directions, e.g. over sidelobes of the antenna, a limitation of the peak e.i.r.p. to 0 dBm is proposed for elevations above 0°.

8.5.4 Earth Exploration Satellite Service (Passive)

For the frequency band 116 to 148.5 GHz under the assumed conditions illustrated in Table 95 in section 6.5.1 only a margin of 0.1 dB to the protection criterion can be ensured for the single-entry case. However, for all other frequency bands and in particular for the aggregate consideration in all bands, ample margins to the interference criteria can be ensured without the implementation of additional mitigation techniques (see section 6.5.2).

8.5.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 117 suggest that compatibility between LPR and Amateur can be asserted in all investigated frequency bands without the implementation of additional mitigation techniques (see section 7.5.2).

8.6 CONTOUR DETERMINATION AND ACQUISITION (CDR)

8.6.1 Summary

For CDR the candidate frequency bands 116 to 148.5 GHz, 167 to 182 GHz and 231.5 to 250 GHz have been studied for both categories of CDR devices, DBF-CDR and M- and PA-CDR. It turned out that in all three frequency ranges compatibility between both CDR categories and all investigated Radio Services can be ensured.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km
- Fixed Service and Amateur Service: Separation distance smaller than 300 m
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All contour determination and acquisition sensors should furthermore comply with the following (installation) requirements:

- The operation of CDR sensors is envisaged for industrial purposes only.
- Installation and maintenance of CDR equipment shall be performed by professionally trained individuals only.

- CDR equipment shall not be marketed to private end customers.
- CDR equipment is required to be installed at a permanent fixed position. The equipment shall not operate while being moved.
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering.
- In order to protect the Radio Astronomy Service, inside a radius of 20 km around the stations of NOEMA and IRAM 30 m, the installation and operation of CDR devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz.
- The provider is required to inform the users and installers of CDR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is proposed:

- For CDR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

In addition to the installation and antenna requirements above, applicable to all CDRs, the following condition is proposed to be met only for the subclass of DBF-CDR:

- DBF-CDRs are required to be pointing vertically downwards towards the ground.

In addition to the installation and antenna requirements above, applicable to all CDRs, the following conditions are proposed to be met only for the subclass of M-CDRs and PA-CDRs:

- M-CDRs and PA-CDRs shall have a permanent spatially scanning behaviour of the antenna main beam direction at any time during operation.
- The maximum tilting angle of the antenna main beam direction in relation to the vertical axis towards the ground shall never exceed 60°.
- The peak e.i.r.p. for elevations above 0° shall be limited to 0 dBm.

8.6.2 Radio Astronomy

For the frequency bands 116 GHz to 148.5 GHz, 167 GHz to 182 GHz and 231.5 GHz to 250 GHz compatibility can be ensured between both CDR systems and RAS when separation distances of 19.9 km, 18.3 km and 19.3 km, respectively, are respected without the implementation of additional mitigation techniques (see section 4.6.2).

8.6.3 Fixed Service

For evaluating the compatibility between DBF-CDR and FS the same two worst-case interference scenarios as for LPR (see Figure 38 and Figure 39) have been used (see section 2.2.5.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between DBF-CDR and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for DBF-CDR in Table 77 are smaller than 300 m (see section 5.6.2). Therefore, compatibility between DBF-CDR and FS can always be asserted for both scenarios and both investigated protection objectives without the implementation of additional mitigation techniques.

For evaluating the compatibility between M- and PA-CDR and FS the four different worst-case interference scenarios in Figure 44 to Figure 47 have been defined (see section 2.2.6.6). In all scenarios it is valid that separation distances smaller than 300 m result in compatibility between M- and PA-CDR and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for M- and PA-CDR for the long-term interference criterion in Table 78 are smaller than 300 m (see section 5.6.2). Therefore, compatibility between M- and PA-CDR and FS can always be asserted for all four scenarios and the long-term interference criterion without the implementation of additional mitigation techniques.

For the peak power objective, however, for scenario 3 in Figure 46, separation distances larger than 300 m result for both evaluated frequency ranges (see Table 78 in section 5.6.2). In this scenario a separation distance of 1.05 km is required. Consequently, the protection requirements identified in section 3.5.3 are not fulfilled.

In order to eliminate this incompatibility in the peak power objective, the occurrence of scenario 3 must be prevented. This could be accomplished by the limitation of the maximum tilting angle of the M- and PA-CDR main beam direction to angles in the range smaller than 60° in relation to the vertical downward direction towards the ground. Such a measure is suggested and would eliminate the critical scenario 3, defined in Figure 46, "CDR main beam direction in horizontal direction" completely.

In order to further restrict the interference in unwanted directions, e.g. over sidelobes of the antenna, a limitation of the peak e.i.r.p. to 0 dBm for M- and PA-CDR equipment is proposed for elevations above 0°.

8.6.4 Earth Exploration Satellite Service (Passive)

For all investigated frequency bands and both CDR categories, in the single-entry and in particular in the aggregate consideration, ample margins to the interference criteria can be ensured without the implementation of additional mitigation techniques (see section 6.6.2).

8.6.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 119 and Table 120 suggest that compatibility between both CDR systems and Amateur can be asserted in all investigated frequency bands without the implementation of additional mitigation techniques (see section 7.6.2).

8.7 TANK LEVEL PROBING RADAR (TLPR)

8.7.1 Summary

For TLPR the candidate frequency bands 116 to 148.5 GHz, 167 to 182 GHz and 231.5 to 250 GHz have been studied. It turned out that in all three frequency ranges compatibility between TLPR and all investigated Radio Services can be ensured.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km
- Fixed Service and Amateur Service: Separation distance smaller than 300 m
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All tank level probing radars should furthermore comply with the following (installation) requirements:

- The operation of TLPR sensors is envisaged for industrial purposes only.
- Installation and maintenance of TLPR equipment shall be performed by professionally trained individuals only.
- TLPR equipment shall not be marketed to private end customers.

- TLPRs shall be installed at a permanent fixed position at a closed metallic tank or concrete tank, or a similar enclosure structure made of comparable attenuating material.
- Flanges and attachments of the TLPR equipment shall provide the necessary microwave sealing by design.
- Sight glasses shall be coated with a microwave-proof coating when necessary (i.e. electrically conductive or microwave absorbing coating).
- Manholes or connection flanges attached to the tank shall be closed while the TLPR equipment is in operation to ensure a low-level leakage of the signal into the free space outside the tank.
- The provider is required to inform the users and installers of TLPR equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is proposed:

- For TLPR devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

8.7.2 Radio Astronomy

For the frequency bands 116 GHz to 148.5 GHz, 167 GHz to 182 GHz and 231.5 GHz to 250 GHz compatibility can be ensured between TLPR and RAS when separation distances of 5.3 km, 2.7 km and 1 km, respectively, are respected without the implementation of additional mitigation techniques (see section 4.7.2). Industrial areas where TLPR sensors are usually installed and operated are not located in such close proximity to radio astronomy stations. Therefore, the implementation of specific exclusion zones around radio astronomy stations is not suggested.

8.7.3 Fixed Service

For evaluating the compatibility between TLPR and FS the two worst-case interference scenarios in Figure 53 and Figure 54 have been defined (see section 2.2.7.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between TLPR and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for TLPR in Table 80 are smaller than 300 m (see section 5.7.2). Therefore, compatibility between TLPR and FS can always be asserted for both scenarios and both investigated protection objectives without the implementation of additional mitigation techniques.

8.7.4 Earth Exploration Satellite Service (Passive)

For all investigated frequency bands in particular for the aggregate consideration ample margins to the interference criteria can be ensured without the implementation of additional mitigation techniques (see section 6.7.2).

8.7.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 122 suggest that compatibility between TLPR and Amateur can be asserted in all investigated frequency bands without the implementation of additional mitigation techniques (see section 7.7.2).

8.8 RADIODETERMINATION SYSTEMS FOR INDUSTRY AUTOMATION IN SHIELDED ENVIRONMENTS (RDI-S)

8.8.1 Summary

For RDI-S the candidate frequency band 116 to 260 GHz has been studied. It turned out that in the whole frequency range compatibility between RDI-S and all investigated Radio Services can be ensured.

The following protection requirements have been assumed:

- Radio Astronomy: Separation distance smaller than 20 km;
- Fixed Service and Amateur Service: Separation distance smaller than 300 m;
- Earth Exploration Satellite Service (passive): positive margin to the maximum interference level in the victim receiver (see section 3.5.4.2).

All RDI-S sensors should furthermore comply with the following (installation) requirements:

- The operation of RDI-S sensors is envisaged for industrial purposes only;
- Installation and maintenance of RDI-S equipment shall be performed by professionally trained individuals only;
- RDI-S equipment shall not be marketed to private end customers;
- Installers have to ensure that the device main beam is not pointing towards windows or other weak shielded parts of the shielded environment. The direction of main radiation shall be indicated on the device;
- Installers have to ensure that there are no unwanted obstacles in the main beam of the antenna in order to minimise unintentional reflections and scattering;
- For RDI-S, the 10 dB contiguous bandwidth shall be equal to or higher than 35 GHz;
- Slow sweeping RDI-S devices with sweep slopes smaller than 2.5 GHz/ms shall notch out the ITU-RR FN 5.340 bands by at least 10 dB reduction in mean and peak power;
- In order to protect the Radio Astronomy Service, inside a radius of 13.2 km around the stations of NOEMA and IRAM 30 m the installation and operation of RDI-S devices should be prohibited, unless a special authorisation has been provided by the responsible national administration. Table 3 shows the locations of the two European observatories operating in the frequency range from 116 GHz to 260 GHz;
- The provider is required to inform the users and installers of RDI-S equipment about the installation requirements and the additional special mounting instructions.

In addition, the following antenna requirement is proposed:

- For RDI-S devices using an antenna gain smaller than 20 dBi, the maximum conducted peak output power shall be limited to 15 dBm.

8.8.2 Radio Astronomy

For the whole investigated frequency band 116 GHz to 260 GHz compatibility can be ensured between RDI-S and RAS when a separation distance of 13.2 km is respected without the implementation of additional mitigation techniques (see section 4.8.2).

8.8.3 Fixed Service

For evaluating the compatibility between RDI-S and FS the two worst-case interference scenarios in Figure 60 and Figure 61 have been defined (see section 2.2.8.6). In both scenarios it is valid that separation distances smaller than 300 m result in compatibility between RDI-S and FS such that a coexistence of both systems is always given. Separation distances larger than 300 m in contrast produce interference to the FS receiver such that the protection requirements identified in section 3.5.3 are not fulfilled. In this case the coexistence of both systems is not possible in the respective scenario without further protection measures.

All calculated separation distances for RDI-S in Table 82 are smaller than 300 m (see section 5.8.2). Therefore, compatibility between RDI-S and FS can always be asserted for both scenarios and both investigated protection objectives without the implementation of additional mitigation techniques.

8.8.4 Earth Exploration Satellite Service (Passive)

For the whole investigated frequency band 116 GHz to 260 GHz and for both, the single-entry and the aggregate consideration, ample margins to the interference criteria and therefore compatibility can be ensured without the implementation of additional mitigation techniques (see section 6.8.2).

8.8.5 Amateur Service

For the Amateur Service the same criterion as for the Fixed Service has been consulted. In this interference scenario, separation distances smaller than 300 m result in compatibility between the interfering device and Radio Service such that a coexistence of both systems can be ensured. For separation distances larger than 300 m the probability of interference increases such that a compatibility cannot be ensured in all cases.

The results illustrated in Table 124 suggest, that compatibility between RDI-S and Amateur can be asserted in the whole investigated frequency band without the implementation of additional mitigation techniques (see section 7.8.2).

8.9 GRAPHICAL ILLUSTRATION OF THE RESULTING COMPATIBILITY SITUATION

Figure 100 shows the graphical representation of the compatibility situation between the investigated UWB-applications:

- Generic indoor surveillance radar;
- Radiodetermination systems for industry automation (RDI);
- Short-range assist and surrounding monitoring for vehicles and autonomous systems;
- Level probing radar (LPR);
- Contour determination and acquisition radar (CDR);
- Tank Level probing radar (TLPR);
- Radiodetermination systems for industry automation in shielded environments (RDI-S).

and the considered victim Radio Services

- Radio Astronomy Service (RAS);
- Fixed Service (FS);
- Earth Exploration Satellite Service (EESS);
- Amateur Service.

obtained in various conducted studies as outlined in sections 8.1 to 8.8. The green marked frequency bands indicate that compatibility can be ensured under the technical conditions in sections 4 to 0 without the implementation of additional mitigation measures.

Frequency bands (GHz)	FN 5.340 protected	Investigated applications						
		Indoor surveillance radar	RDI	Short range assist	LPR	CDR	TLPR	RDI-S
114.25 -116	5.340							
116-122.25								
122.25-123								
123-130								
130-134								
134-141								
141-148.5								
148.5-151.5	5.340							
151.5-155.5								
155.5-158.5								
158.5-164								
164-167	5.340							
167-174.8								
174.8-182								
182-185	5.340							
185-190								
190-191.8	5.340							
191.8-200								
200-209	5.340							
209-226								
226-231.5	5.340							
231.5-235								
235-238								
238-241								
241-250								
250-252	5.340							
252-260								

	Compatibility can be ensured under the conditions summarised in chapter 8 and the technical conditions in chapters 4 to 7 without the implementation of additional mitigation measures.
	Compatibility cannot be ensured under the conditions summarised in chapter 8 and the technical conditions in chapters 4 to 7 without the implementation of additional mitigation measures.

Figure 100: Compatibility situation between the investigated UWB-applications and all considered Radio Services

ANNEX 1: BUILDING ENTRY LOSS (BEL) MODEL EXTENSION

A1.1 INTRODUCTION

For the MCL calculations and SEAMCAT simulations in this report adequate building entry loss (BEL) values in the frequency range from 116 GHz to 260 GHz are needed to estimate the indoor to outdoor attenuation and thus the shielding effects of buildings. This annex contains an implementation of Recommendation ITU-R P.2109-1 [23] BEL model and extends the model from 100 GHz to up to 300 GHz.

In the absence of any study in the frequencies greater than 100 GHz and as there is at this time no other more sophisticated and more accurate approach to calculate the BEL at the higher frequencies it seems to be reasonable to extrapolate the existing ITU-R model from 100 GHz to 300 GHz

A1.2 RECOMMENDATION ITU-R P 2109-1 BEL MODEL EXTENSION

In Recommendation ITU-R P.2109-1 [23], the BEL model gives predictions for two building cases "traditional" and "thermally efficient", but the original model does not converge for frequencies >175 GHz because the σ_2 parameter gets negative for the traditional building parameter set. A slight modification to the model parameters ($z = -1.8$ instead of $z = -2.1$ for the traditional building parameters) helps to extend the model to up to 300 GHz.

A1.3 EXTENDED MODEL VS. ORIGINAL MODEL VERIFICATION

To compare the extended model with the $z = -1.8$ modification in Figure 101 and Figure 102 the resulting BEL for different probabilities at 100 GHz and an elevation angle of 0° and 90° of the original and extended models are plotted against each other. The "efficient" model curve is identical at 100 GHz, because no changes were made to the model. The z parameter adjustment in the "traditiona"l model results in a very small deviation of the model at low probabilities for 0° elevation (see circle marker), other regions of the curve do not change. With the extended model the resulting BEL losses are even more conservative compared to the original model.

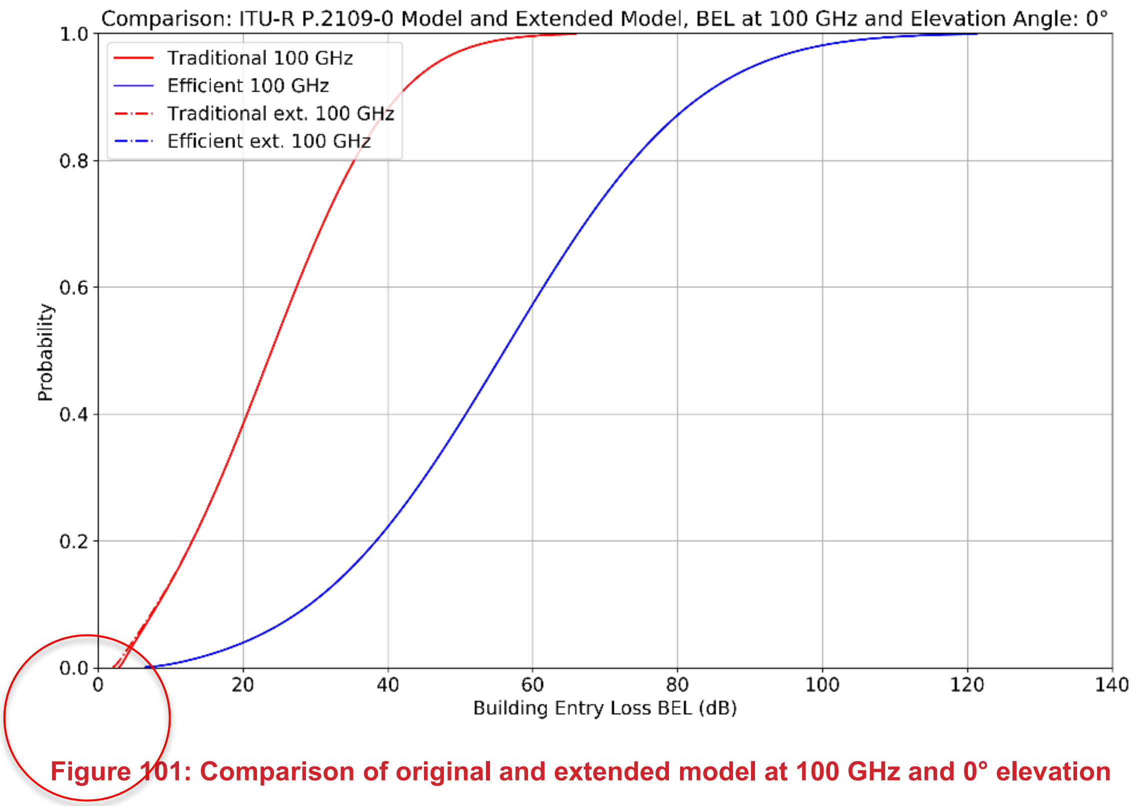


Figure 101: Comparison of original and extended model at 100 GHz and 0° elevation

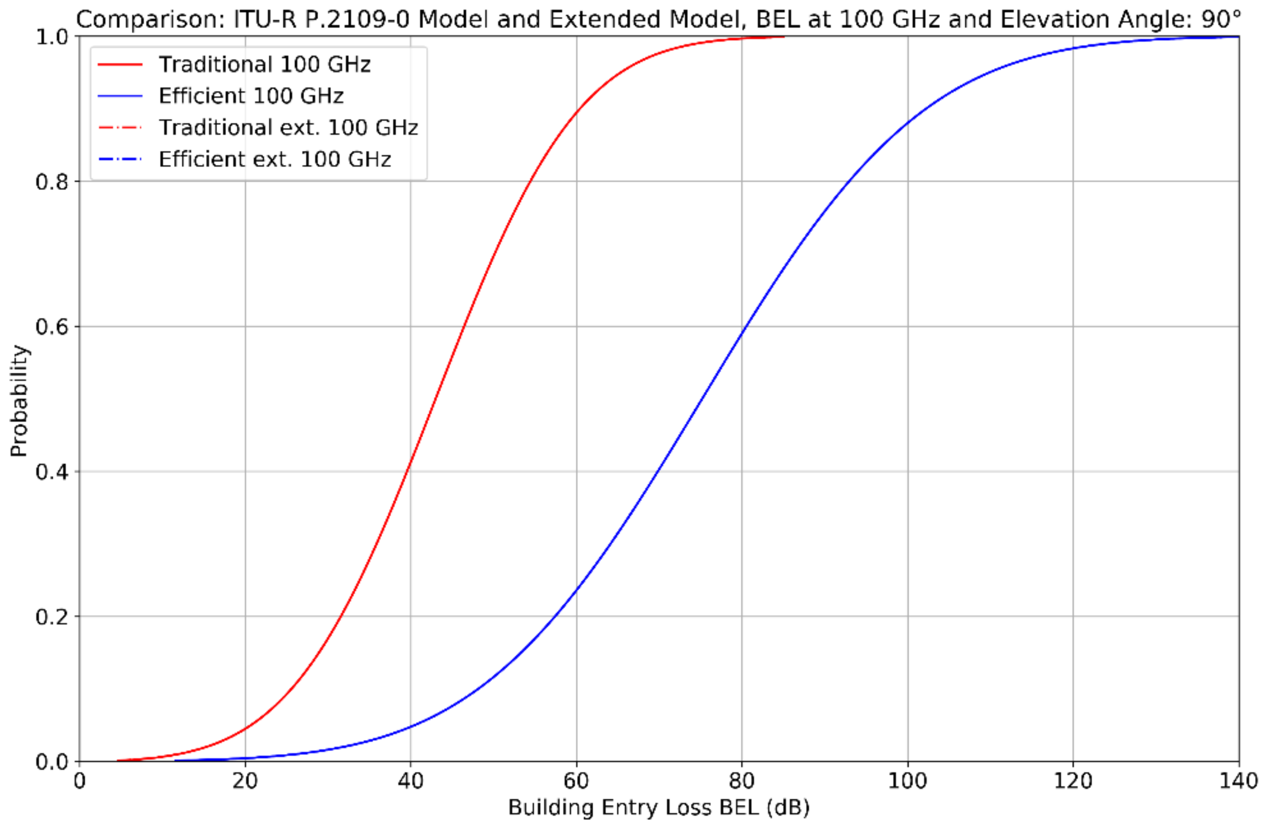


Figure 102: Comparison of original and extended model at 100 GHz and 90° elevation

A1.4 EXTENDED MODEL RESULTS FOR 116 GHZ TO 300 GHZ

In Figure 103 and Figure 104, the BEL at 100 GHz, 116 GHz and 260 GHz for 0° and 90° elevation and different probabilities with the extended model are shown.

Figure 105 and Figure 106 show the BEL in the extended frequency range from 100 GHz to 300 GHz for the probability of P= 0.5 and an elevation of 0° in comparison to the BEL values below 100 GHz.

All in all, the extended model seems to work properly, and the resulting BEL behaves like expected in the higher frequency ranges. The BEL model accuracy is limited even for the lower frequencies below 100 GHz but seems to be feasible to be used as a base for the MCL calculations in this report as there is no more accurate alternative.

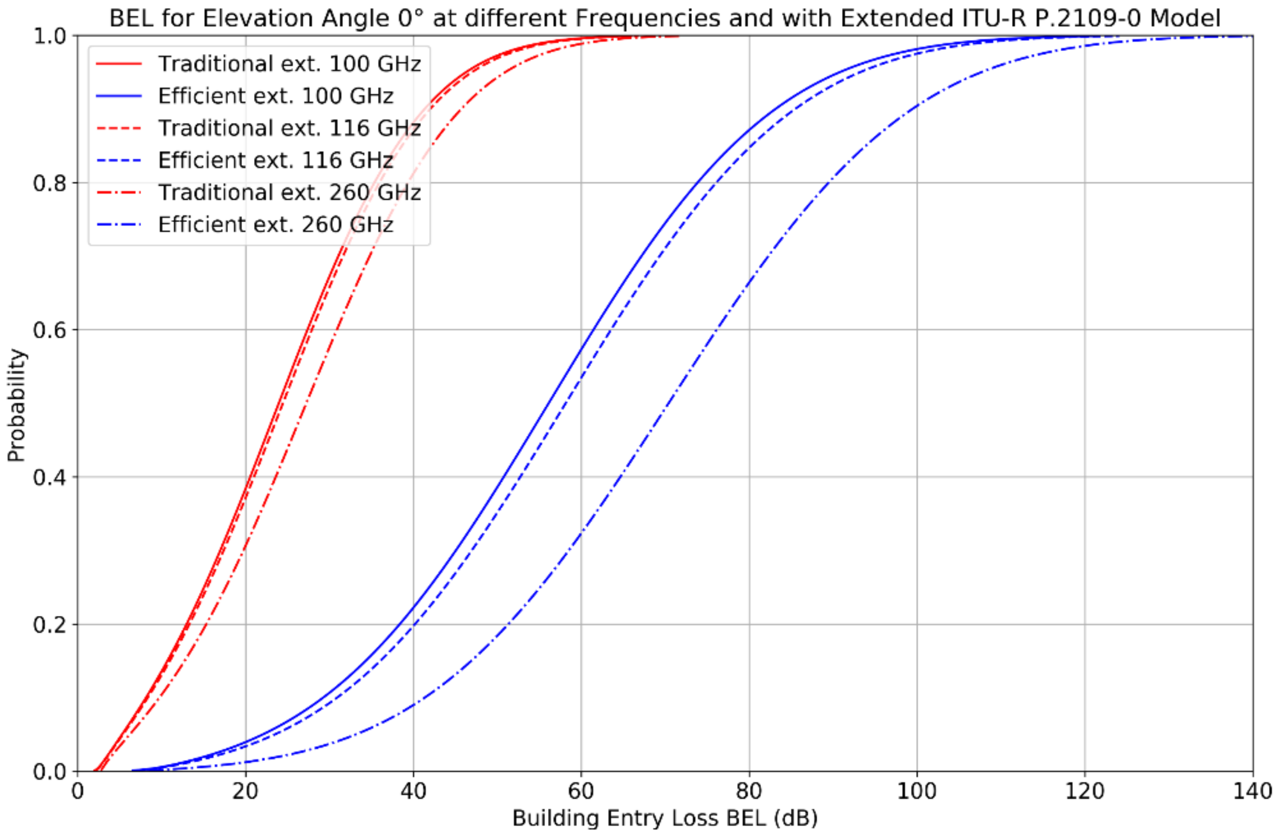


Figure 103: Extended model BEL at 100, 116 and 260 GHz and 0° elevation

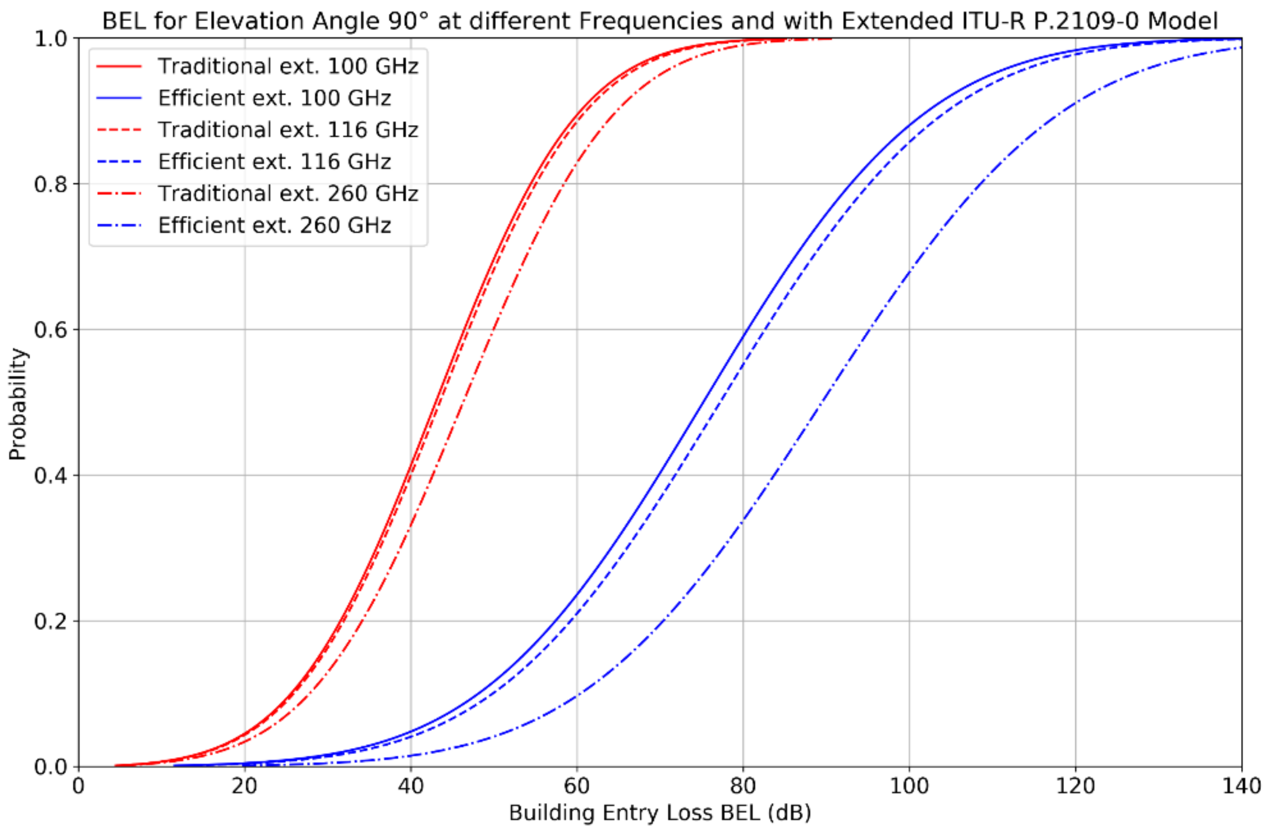


Figure 104: Extended model BEL at 100, 116 and 260 GHz and 90° elevation

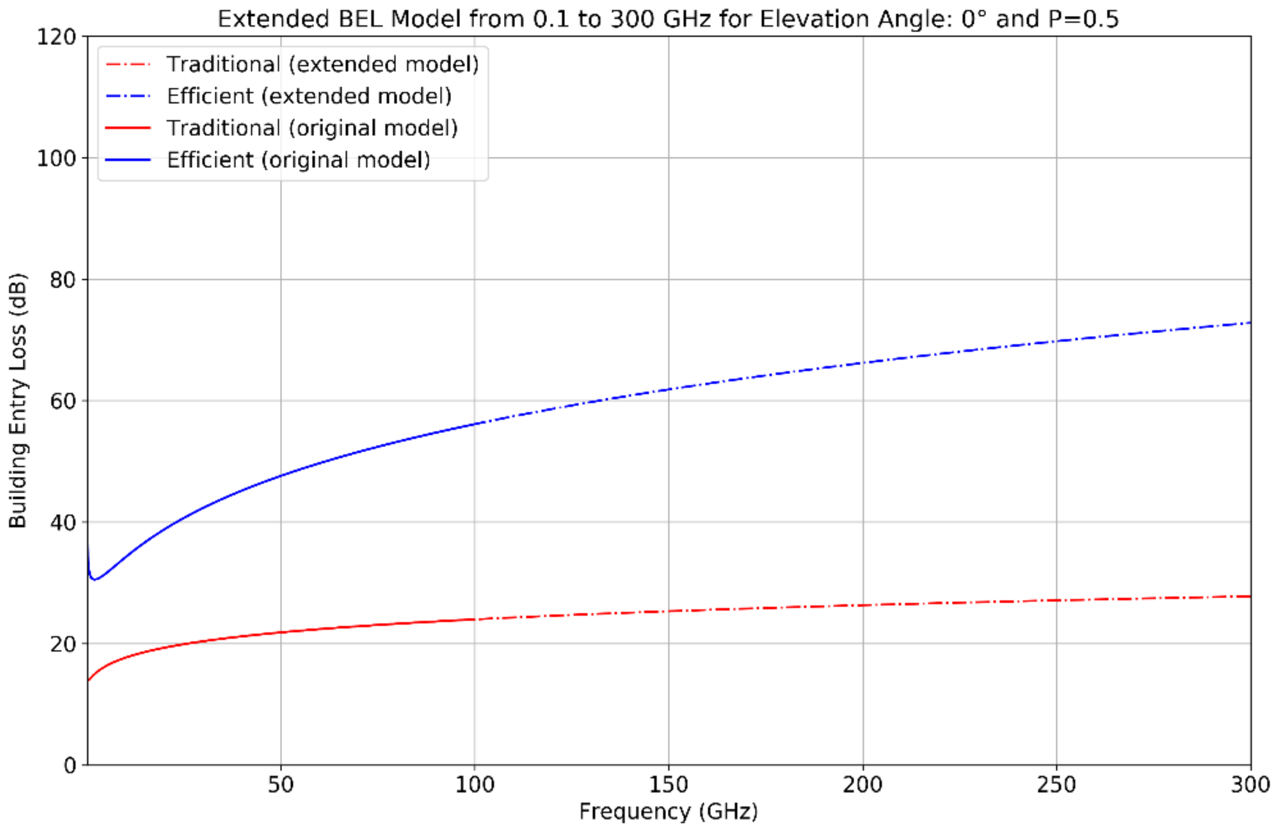


Figure 105: BEL over frequency extrapolated for 100 GHz to 300 GHz and P=0.5

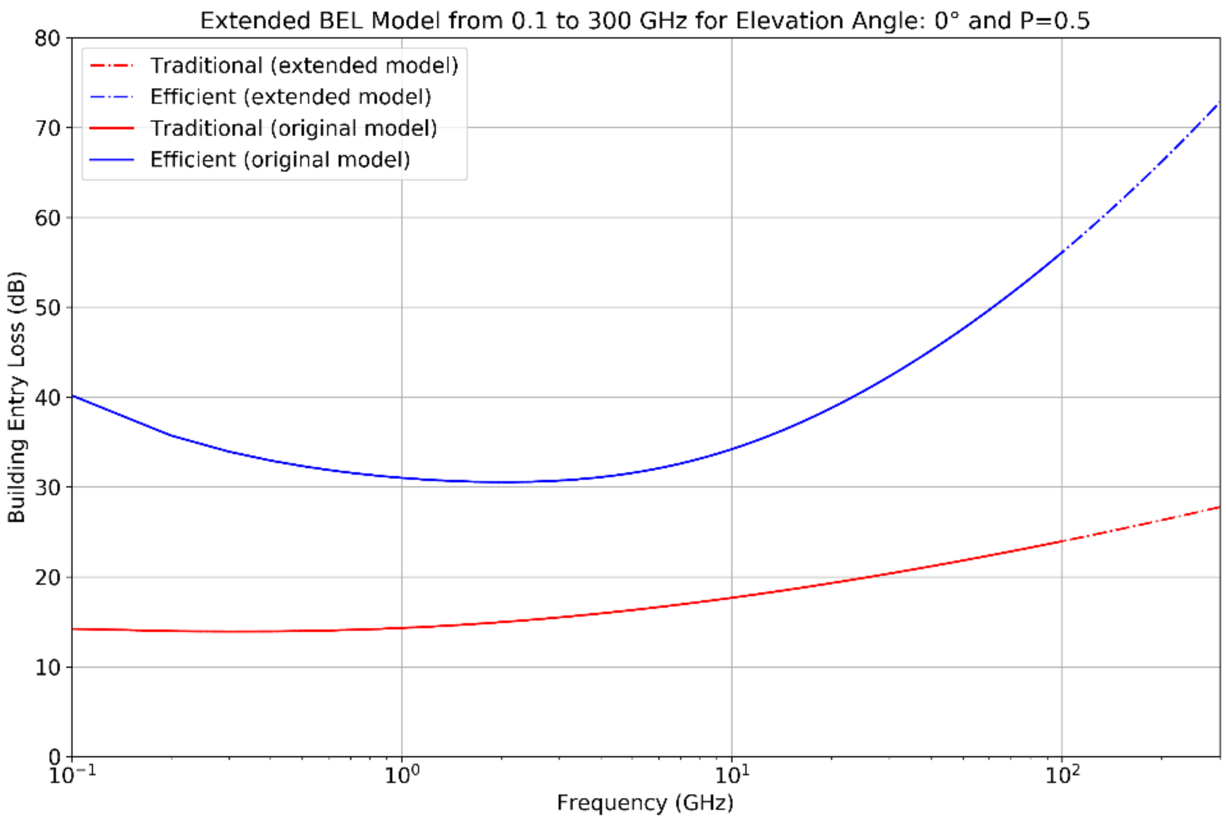


Figure 106: BEL over frequency extrapolated for 100 GHz to 300 GHz and P=0.5 (log x-axis)

ANNEX 2: MATERIAL MEASUREMENTS FOR BUILDING ENTRY LOSS (BEL) MODEL EXTENSION

A2.1 INTRODUCTION

Building entry loss (BEL) values are needed for the studies to examine the impact of radiodetermination sensors for industry automation (type C application) on the radiocommunication services. In this section measurement results of different types of typical building material are provided in order to verify the proposed BEL model frequency range extension (refer to Annex 1).

A2.2 MEASUREMENT SETUP

In order to evaluate the frequency dependent attenuation of the materials a simple measurement setup with a custom programmable radar sensor as signal source and a R&S FSEK30 spectrum analyser was used. This setup allows measurements with a dynamic range of around 60 dB. The dynamic range is limited by the sweep time of the spectrum analyser and the missing frequency synchronisation between the FSEK30 and the radar sensor itself. For a larger dynamic range, a network analyser-based measurement setup might be a better choice, but unfortunately was not available at the time the measurements have been conducted.

The transmitted power is measured in 1 GHz step widths with 56 steps in the frequency range from 120 GHz to 175 GHz to provide smooth measurement curves. The attenuation measurements are calibrated to a reference transmission measurement with no object in direct line of sight between Tx- and Rx-antenna. All measurements are referenced to this scenario. In order to show the achieved maximum dynamic range a reference measurement with full shielding by means of a metal plate is provided.

Table 125: Overview of the used measurement equipment

Type	Model
Transmitter	Custom USB D-Band FMCW radar configured in programmable frequency CW-mode. Connector: WM-1651 (WR-06) waveguide compatible to standard UG387 flange. Frequency range: 120 GHz to 175 GHz
Receiver	Rohde & Schwarz FSEK30 with external Radiometer Physics SAM-170 harmonic mixer
Antenna (Tx & Rx)	MI-WAVE 261D-24/387 standard gain horn with 24 dBi gain

In Table 125, a short overview of the used measurement equipment is given, and Figure 107 shows a photograph of the measurement setup. A custom Python script is used to control the FSEK via SCPI language and program the radar transmitter device to step to the different frequency points and record the received power.

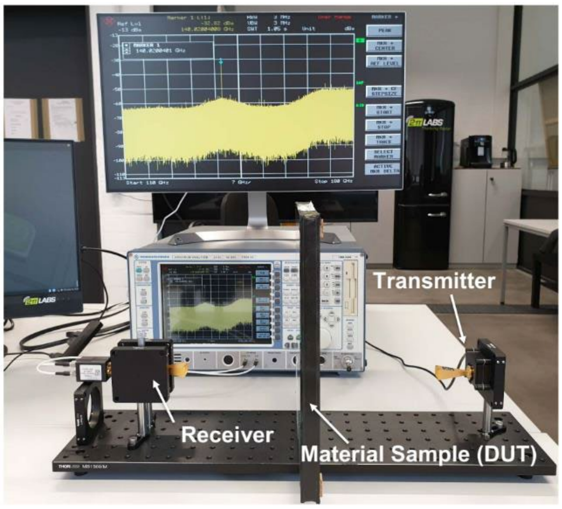


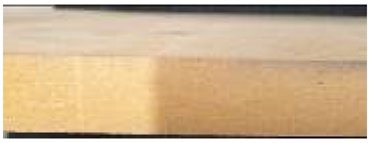
Figure 107: Photograph of the measurement setup with a 300x300 mm glass sample

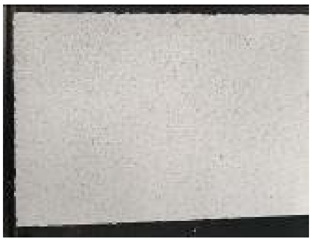
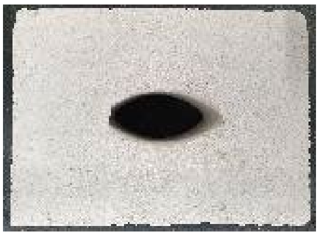
A2.3 BUILDING MATERIALS

In order to verify the proposed BEL model extension with real material measurements a variety of typical building material has been selected. Different wooden material samples have been chosen to have a starting point for the BEL values for wooden houses ("traditional" BEL model). As the windows are the most critical building structures for modern energy efficient buildings (“efficient” BEL model) in terms of signal attenuation, measurements of typical 2-layer and 3-layer window material are provided. In addition, also measurements of typical wall materials for modern standard buildings have been conducted.

In Table 126 all measured materials are listed, a photograph is provided and the measured attenuation at 120 GHz is given. Figure 108 shows the measurement results for the different building materials.

Table 126: Overview of the measured building materials

Material type	Attenuation at 120 GHz	Details	Photograph
Wooden	13 dB	Medium-density fibreboard (MDF) with a thickness of 18 mm	
Wooden	36 dB	Beech-Multiplex board with a thickness of 25 mm (measured in 90° and 45° orientation)	
Window	35 dB	Typical 4 mm float glass window with a thin silver coating (measured in 90° and 45° orientation)	

Material type	Attenuation at 120 GHz	Details	Photograph
Window	38 dB	Typical modern 2-layer standard window glass sample with 4 mm float glass, 16 mm argon filled gap and a second 4 mm float glass with a thin metallic coating (measured in 90° and 45° orientation)	
Window	60 dB	Typical modern 3-layer passive-house window glass sample with 4 mm float glass (coated), 12 mm argon filled gap, 4 mm float glass middle layer, a second 12 mm argon filled gap and a third 4 mm float glass layer (coated).	
Wall	>60 dB	Concrete slab with a thickness of 47 mm	
Wall	>60 dB (Note 1)	Autoclaved aerated concrete (AAC) with a thickness of 75 mm	
Wall	>60 dB (Note 1)	Typical brick with a thickness of 175 mm (measured in the middle at hole-position)	

Note 1: Limited by measurement setup, the actual attenuation is expected to be much higher.

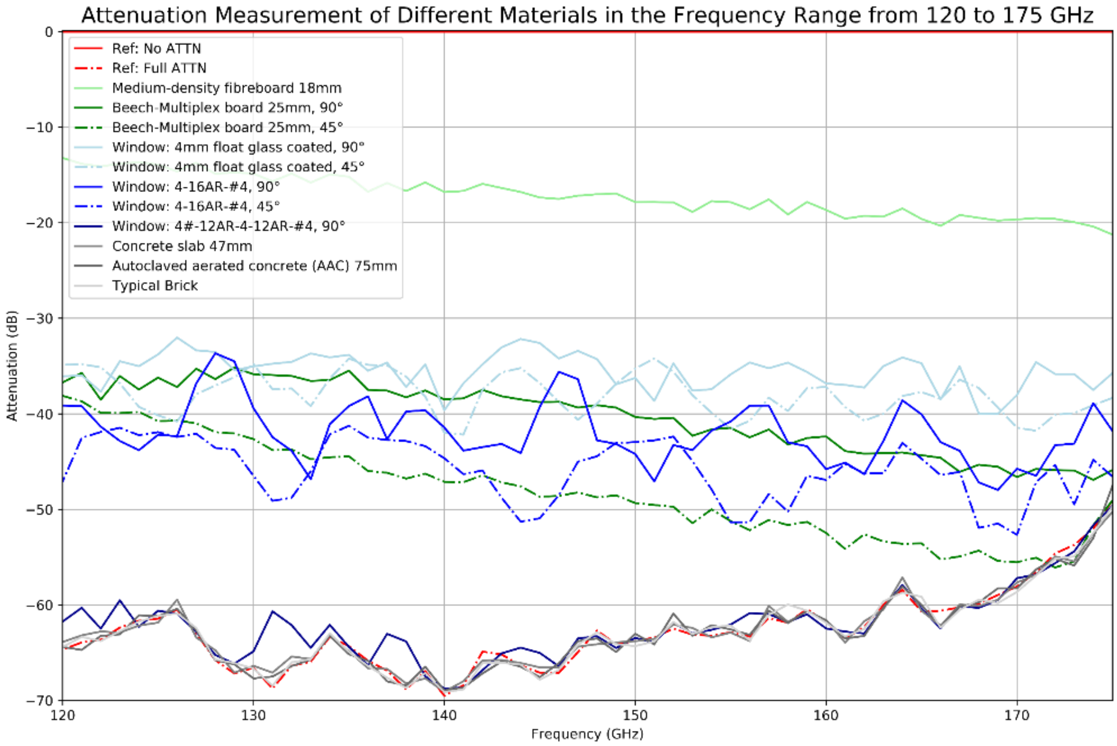


Figure 108: Results of the attenuation measurements of typical building materials

A2.4 CONCLUSION

Even the thin wooden material samples show a considerable attenuation in the evaluated frequency range. Given that also traditional buildings are not constructed with just a single layer of wooden material, but more complex multi-layer material mixes (wooden materials, insulation materials and plasterboard), a significant attenuation can be expected even for those traditional building types. The measured attenuation of just one thin wooden layer (especially the multiplex board) confirms the extended building entry loss model and indicates that the extrapolated model might even be too pessimistic and the real BEL values are much higher.

For thermally efficient buildings, the most critical facade penetrations in terms of signal attenuation are the windows. The measurements show that typical modern standard glass windows exhibit higher attenuation with increasing frequencies. The minimum attenuation of around 33 dB occurs at about 126 GHz for the single-glazed window with thin silver coating.

This aspect in combination with the facts that all measured thin wall material samples offer attenuations of more than 60 dB (limited by the dynamic range of the measurement setup) and that typical buildings have much higher wall thicknesses compared to the measured samples, the typical attenuation values can be expected to be multiples of the measured values. This confirms the suggested BEL frequency range extension and again indicates that the used BEL values might be also for the energy efficient buildings too pessimistic and are very likely even higher in real world scenarios.

With these measurement results in mind and considering a 70% traditional and 30% energy efficient building distribution the use of the very conservative attenuation values in Figure 109 is suggested. It is as a starting point for the MCL calculations for type C industrial automation measurement equipment in shielded environments.

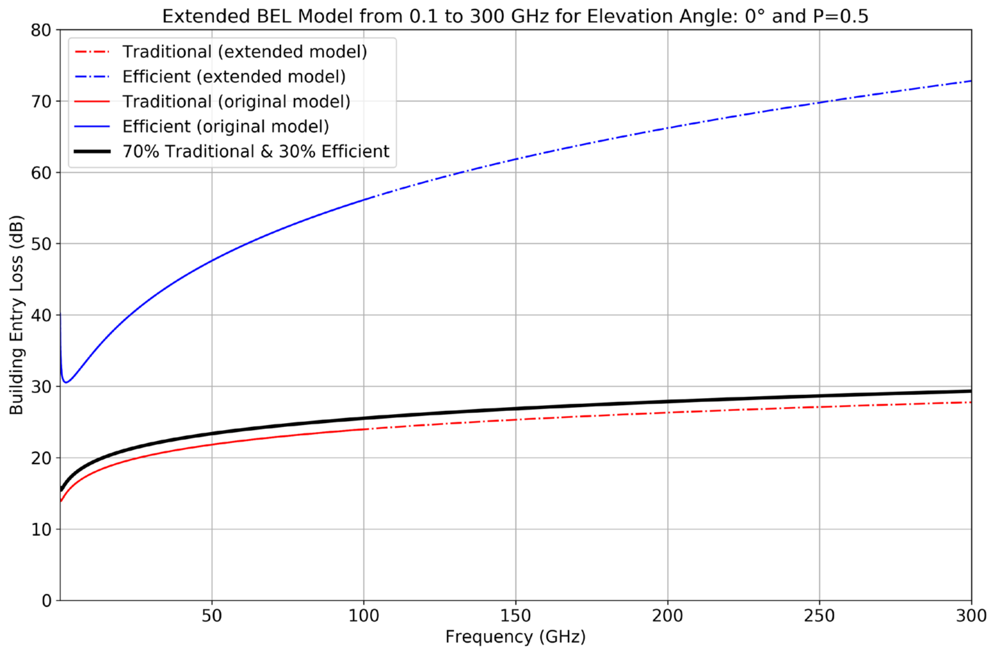


Figure 109: Suggested BEL model extension up to 300 GHz

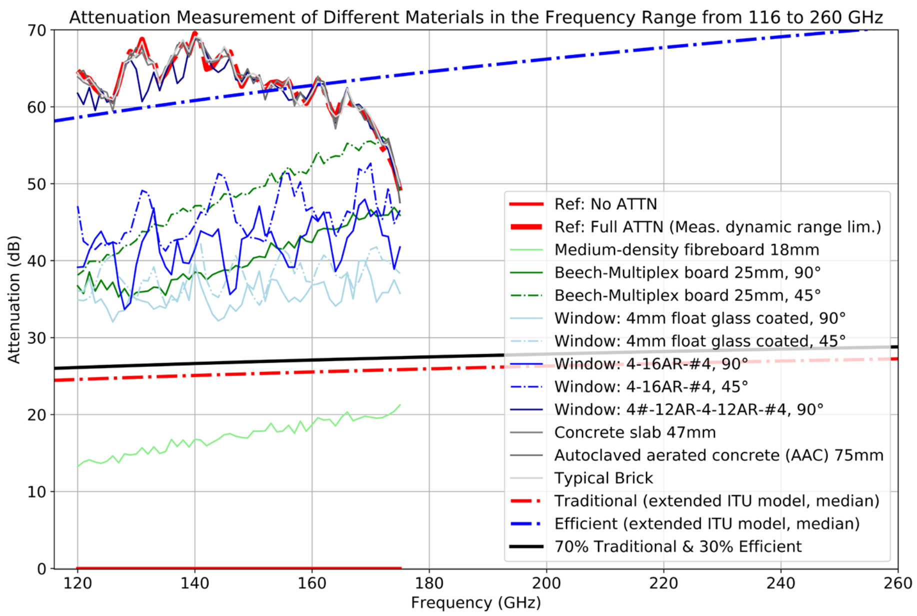


Figure 110: Combined BEL model extension with results of attenuation measurements

ANNEX 3: EXPERIMENTAL EVALUATION OF REFLECTION LOSSES FOR MATERIALS MEASURED BY LEVEL PROBING RADAR (LPR)

A3.1 INTRODUCTION

Following ECC Report 139, annex 2 [4], this report provides practical measurement results and simulations for establishing the levels of scattered emissions generated from the operation of LPR devices at frequencies beyond 116 GHz. The results can be used for interference calculations in compatibility studies in the context of the regulation of new frequency bands for the operation of LPR devices.

A3.2 THEORETICAL CONSIDERATIONS OF REFLECTION LOSSES

The theoretical considerations comprehensively elaborated in ECC Report 139, annex 2 [4] are valid for higher frequencies >116 GHz, as well. So, there is no need for a new derivation of the various contributions to reflection losses. The expected tendencies for higher frequencies, however, shall briefly be discussed according to the classification of reflection losses done in ECC Report 139, annex 2:

- Reflection loss by reflection coefficient;

  The relevant physical property for the reflection coefficient of materials is the relative dielectric constant. The general tendency for the relative dielectric constant is a decrease with frequency referred as dispersion. For many technical materials (plastics, ceramic, glass) and minerals, the decrease from 26 GHz to higher frequencies up to 250 GHz is not significant. In organic materials, however, there are differences due to the dispersion of water. For instance, the theoretical reflection coefficient of water for normal incidence is −2.4 dB at 26 GHz, −4 dB at 80 GHz and below −6 dB at frequencies higher than 250 GHz. In addition, dielectric losses of most materials increase with frequency, so that strong reflections of metal structures are reduced by thin dielectric cover layers;
- Reflection loss from granularity of the reflecting material:

  The migration from specular reflection to diffuse reflection with increasing frequency is pointed out as a clear advantage for the measurement of solids in Annex 2 of [4]. In the same way, this is an advantage with respect to interference, as the additional loss of diffuse reflection will occur more often and for materials with lower granularity. Simulations and measurements performed in this report will give a practical evidence on this effect;
- Reflection loss due to macro shape of reflecting surface:

  Assuming, that the beam angles of new LPR devices at frequencies beyond 116 GHz will be similar than those of their lower frequency counterparts, there is nothing to add to the discussion in Annex A2.2.3 of [4].

A3.3 SIMULATIONS OF THE REFLECTION LOSS OF A ROUGH CONDUCTIVE SURFACE

In [35], various scattering models have been verified by full-wave simulation and measurements with statistically defined artificial surfaces. Based on these results, simulations on reflection losses of rough materials were done with a Gauss-Huygens-model which had been verified by the described procedure. In the simulated setup the reflection losses of rough conductive surfaces defined by their vertical standard deviation (σh) was calculated over frequency for identical incidence and deflection angles ranging from 0° to 60°. The statistically modelled surfaces on which the simulations are based have a size of Lx=100 mm and Ly=100 mm. The periodicity of their Gaussian distributed profiles is described by the autocorrelation widths lx and ly (section II of [35]).

The simulation results summarised in the following diagrams (see Figure 111) provide an estimate, how the reflection losses increase with frequency and decrease with the angle of incidence (see Figure 112 left). Though, the simulations are not directly useable for quantitative estimations for applications of LPR, they however point out, that one can expect a significantly higher reflection loss from granularity at frequencies beyond 116 GHz.

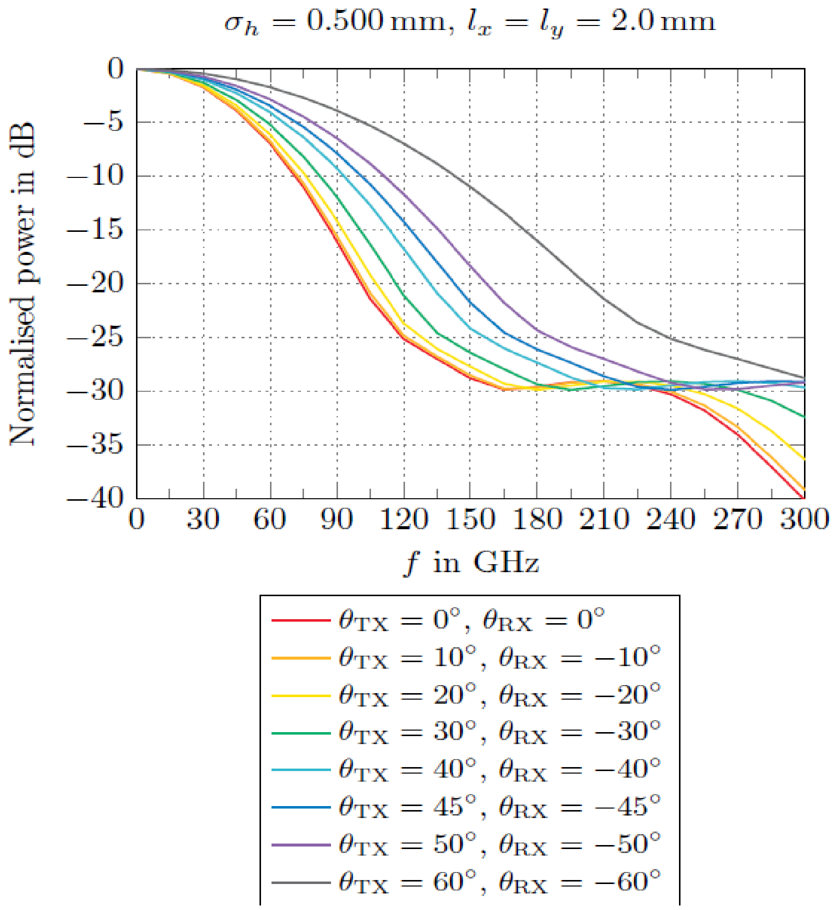
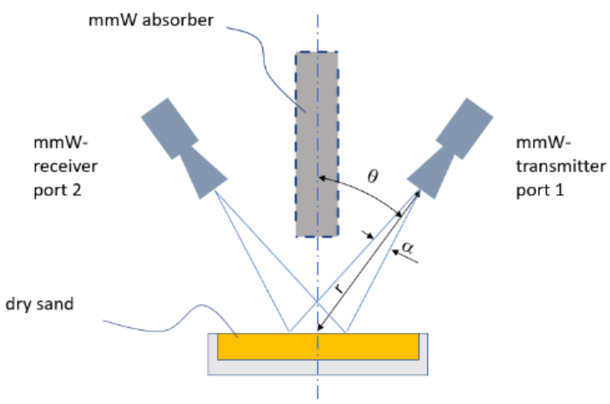


Figure 111: Simulated reflection factor normalised to total reflection (flat metal surface, 0 dB) for a surface roughness with standard deviation of 0.5 mm

A3.4 MEASUREMENTS

Test Setup

The measurements were performed in a similar setup as shown in ECC Report 139, figure A2.2. [4]. For getting more generic results over a wide frequency band, a more idealised setup with a network analyser was used and placed in an absorbing chamber to avoid specular multipath reflections. Figure 112 shows the measurement setup in a schematic and a picture.



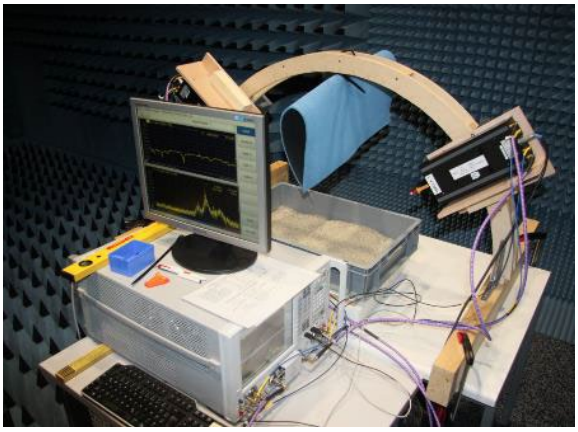


Figure 112: Schematic (left) and picture (right) of the measurement setup.

For the tests, the following test equipment has been used:
- Network analyser: Keysight PNA-X
- WR-5 frequency extender (VDI)
- WR-3 frequency extender (VDI)
- 26 dBi standard gain horn-antennas with approximately 8° beam-width (α).

The distance between the sand surface and the beam-centres of the antennas was 38 cm.

Measurements were performed for the waveguide frequency bands WR-5 from 140 GHz to 220 GHz and WR-3 from 220 GHz to 330 GHz. The polariaation of the setup was chosen parallel to the sand surface under test. The calibration was done in two steps. First the waveguide ports were calibrated using waveguide TRL calibration standards. Second for each angle of incidence (θ) the reflection of a thin flat metal plate placed on the sand's surface was recorded. All measurements are normalised to the respective metal plate reference measurement, so that systematic errors from imperfections in the mechanical setup are compensated out. Measurements were performed for angles of incidence of 20°, 30°, 33°, 40° and 50° in transmission mode using S21. For each angle of incidence five frequency sweeps were averaged and for getting sufficiently high dynamic range the IF-bandwidth of the NWA was chosen to be 1 kHz. Angles below 20° were not possible due to mechanical limits of the setup. From theory and from simulation, it can be deduced, that the worst-case which is lowest reflection loss or highest reflection factor corresponds to highest angle of incidence. Thus, the missing values for angles below 20° are of minor relevance.

Test Results

For a flat surface of typical, dry sand with maximum 2 mm granularity the measured reflection factors versus frequency are plotted in Figure 113 and Figure 114. The measured reflection loss (Lreflection) for θ=33° takes values from 17 dB to 27 dB with local minima going over 40 dB. Its increase towards higher frequencies is significant in the WR-5 band (140 GHz to 200 GHz) as expected from theory and simulations.

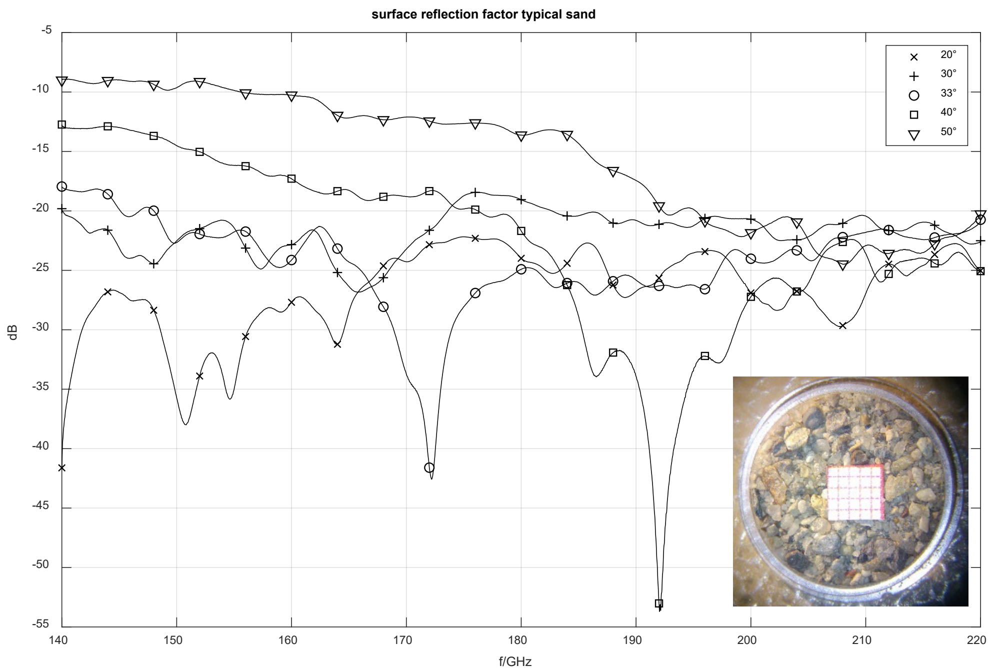


Figure 113: Measured reflection factors of fine sand with up to 2 mm granularity in the WR-5 band (140 GHz to 220 GHz) for incidence/deflection angles from 20° to 50° normalised to a reference measurement of a flat metal surface (total reflection). (The picture in the lower right corner shows the granularity of the sand compared to a 1 mm grid)

For higher frequencies and especially in the WR-3 band (220 GHz to 330 GHz (see Figure 114)), the dependency on the angle of incidence is not visible anymore. This indicates that diffuse reflection dominates specular reflection. The increase of the reflection loss towards higher frequencies is minor significant.

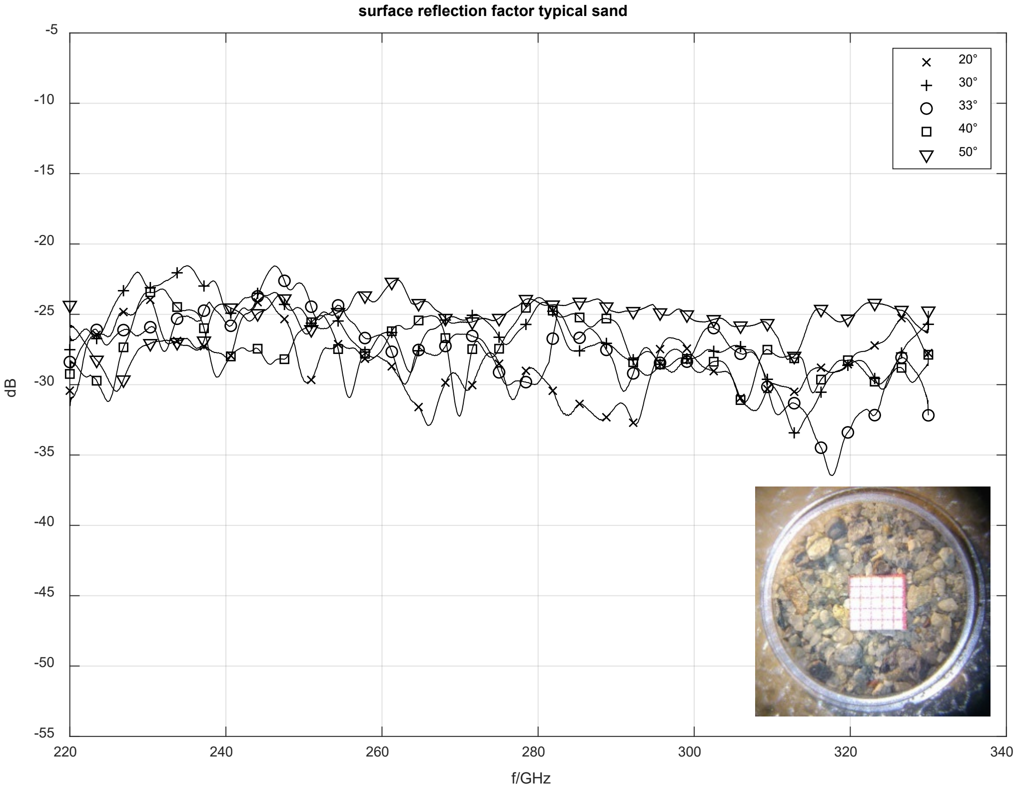


Figure 114: Measured reflection factors of fine sand with up to 2 mm granularity in the WR-3 band (220 GHz to 330 GHz) for incidence/deflection angles from 20° to 50° normalised to a reference measurement of a flat metal surface (total reflection). The picture in the lower right corner shows the granularity of the sand compared to a 1 mm grid

ANNEX 4: ANTENNA CHARACTERISTICS FOR (TANK) LEVEL PROBING RADAR

A4.1 INTRODUCTION

In order to adapt optimally to the situation found in the field, the process industry cannot use off the shelf horn antennas like for example used in measurement labs or test houses. Instead, well-designed antennas are needed to cope with adverse environmental conditions inside the tank like high pressure, chemical corrosiveness, condensate, dust and dirt layers.

Typical materials for antenna fillings having good chemical resistance are PTFE (polytetrafluoroethylene) or PEEK (polyether ether ketone) while at the same time having low losses and suitable dielectric constants of around 2 to 4.

These materials are suitable for industrial applications and have also the ability to be machined (or even to be moulded) enabling the opportunity to be produced in large quantities.

All results are given under far field conditions for both planes φ=0° and φ=90°. Data files of the results are also provided in an annex to this contribution.

A4.2 CALCULATION METHOD

The software tool MICROWAVE STUDIO 2018 was used for conducting the simulations. This software has proven to be well suited in many projects and is highly recommended by researchers as well as by antenna designers in the industry (see [37], [38] and [39]).

For the simulations the following parameters have been used. The dielectric constant was set to 2.1 according to standard values around 2.05 found in literature, and the loss tangent to tan(δ) =2E-4 (see [40], [41], [42], [43] and [44]). The mesh size is defined using at least 18 cells per wavelength, including a standard material-based mesh refinement.

The far field radiation characteristics of the antenna are calculated using the so-called realised gain, which takes into account the impedance mismatch loss. It is defined as follows:

$$G_{\text{realised}}(\theta,\varphi) = 4\,\pi\,\frac{\text{power radiated per unit solid angle}}{\text{stimulated power}}$$

The following frequency bands which are proposed for LPR and TLPR have been studied:

- 116-148.5 GHz;
- 167-182 GHz;
- 231.5-250 GHz.

All results are given under far field conditions for both planes φ=0° and φ=90°, typically corresponding to the E- and H-plane, used as reference planes for linearly polarised devices.

Antenna gain figures are given for the particular center frequencies under investigation.

A4.3 FREQUENCY RANGE 116-148.5 GHZ

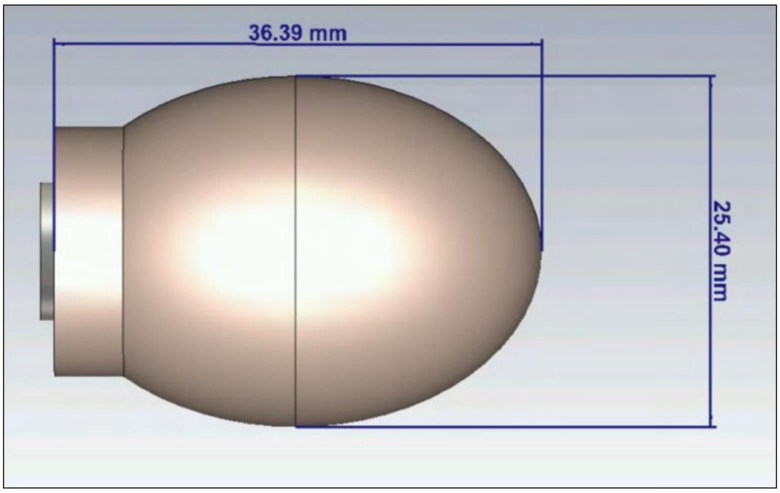


Figure 115: Dimension of the antenna

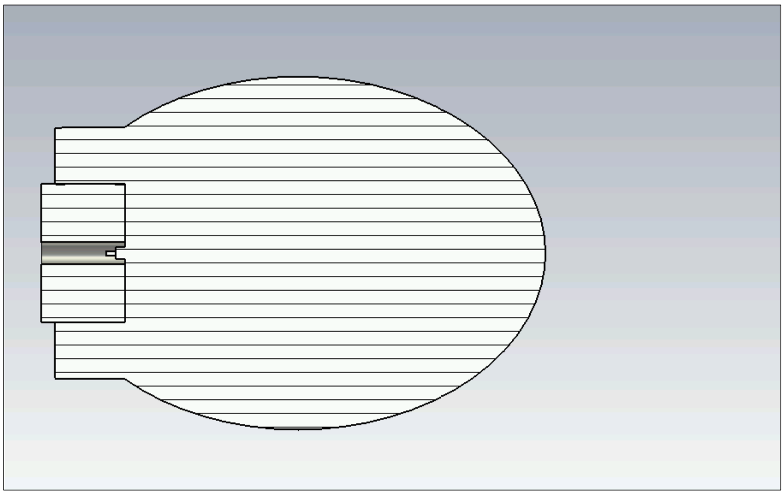


Figure 116: Lens cut view

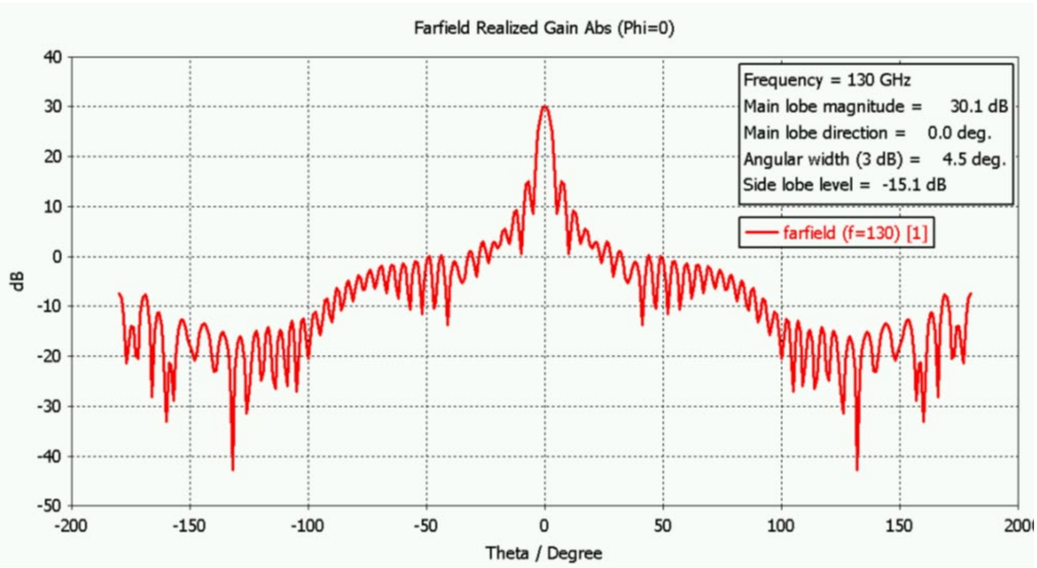


Figure 117: Farfield Gain (φ=0°)

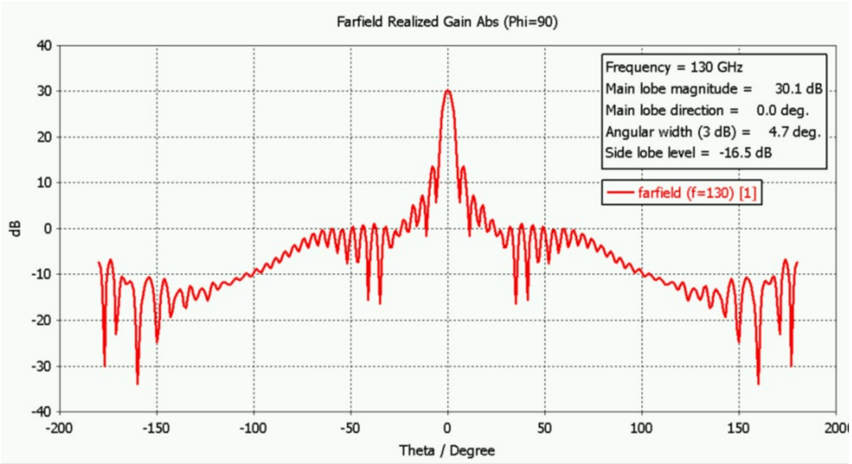


Figure 118: Farfield Gain (φ=90°)

A4.4 FREQUENCY RANGE 167-182 GHZ

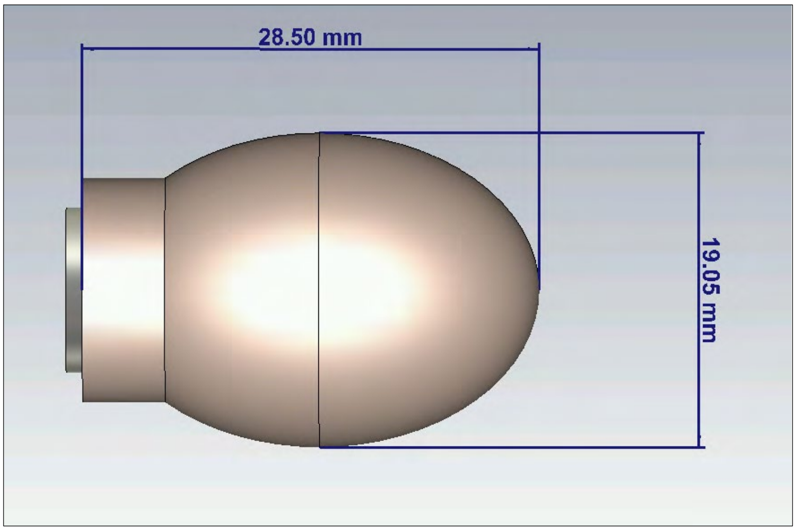


Figure 119: Dimension of the antenna

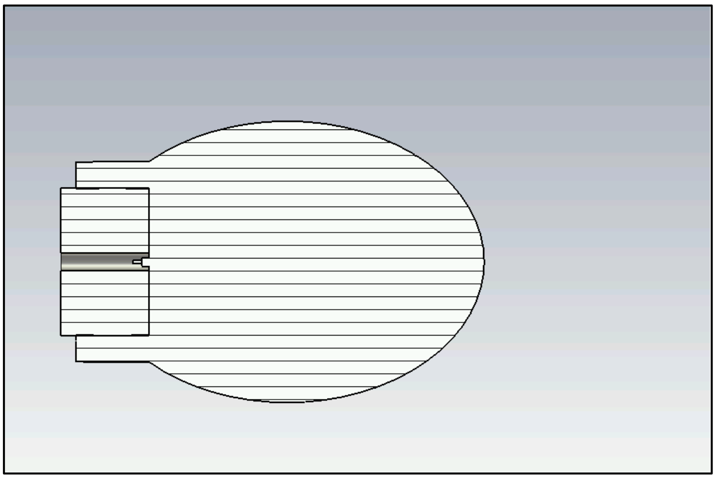


Figure 120: Lens cut view

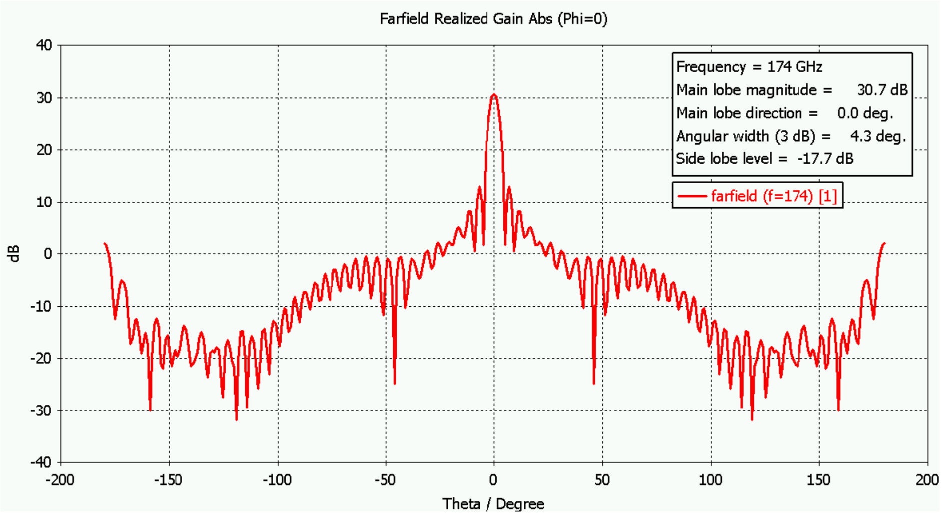


Figure 121: Farfield Gain (φ=0°)

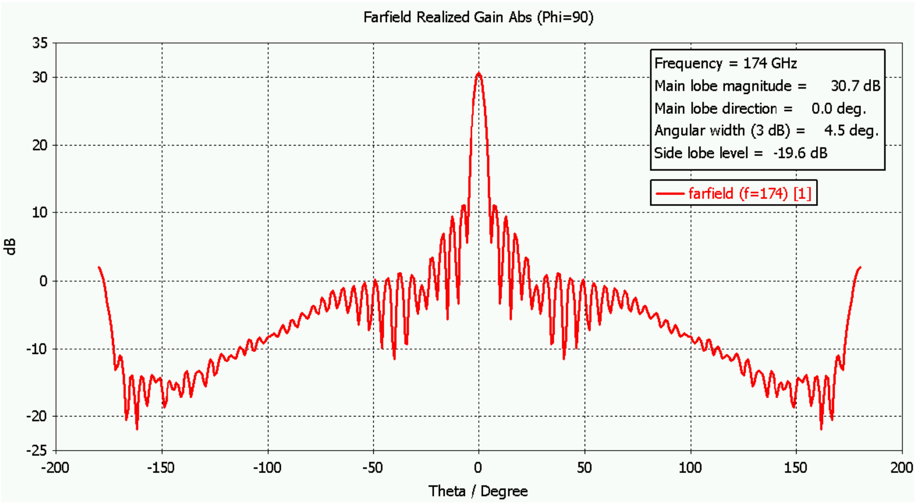


Figure 122: Farfield Gain (φ=90°)

A4.5 FREQUENCY RANGE 231.5-250 GHZ

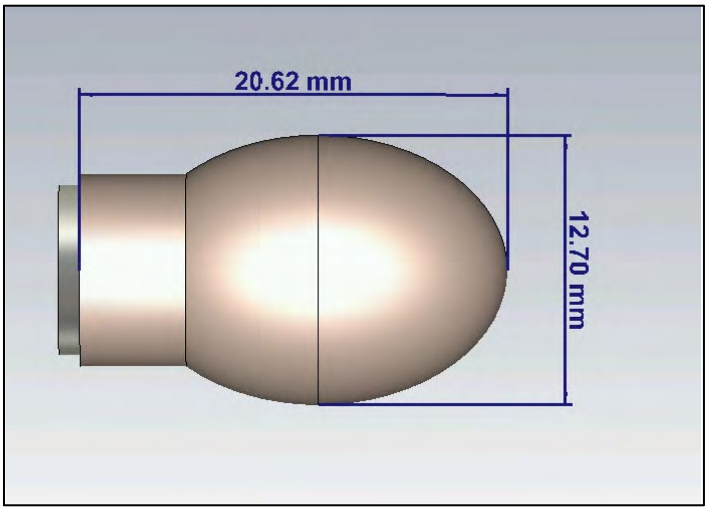


Figure 123: Dimension of the antenna

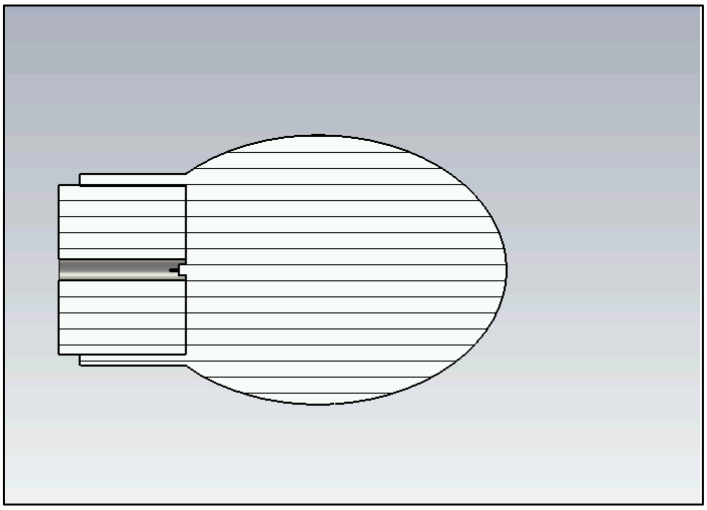


Figure 124: Lens cut view

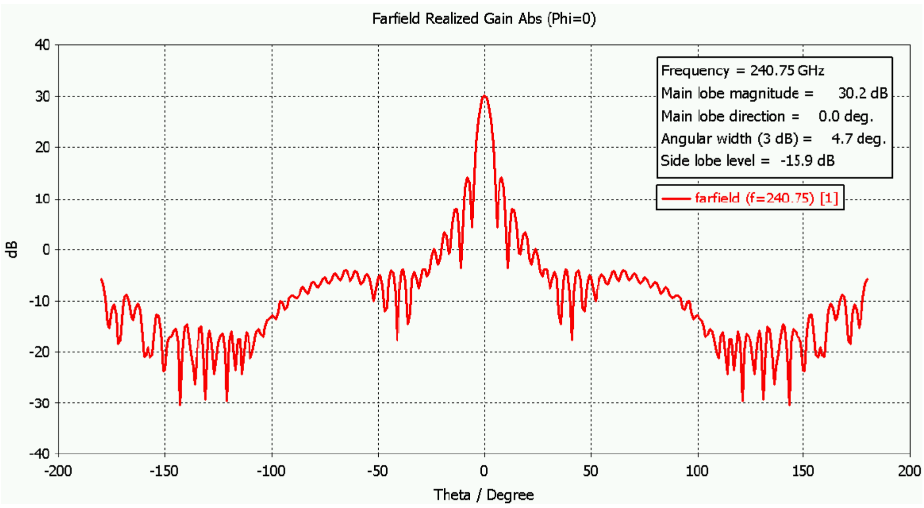


Figure 125: Farfield Gain (φ=0°)

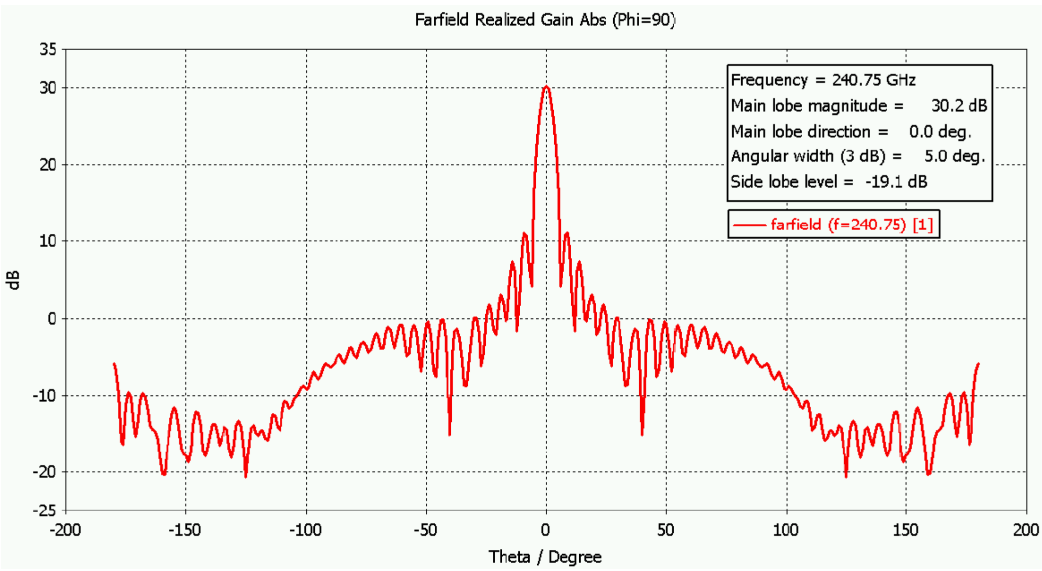


Figure 126: Farfield Gain (φ=90°)

A4.6 RESULTS

Table 127: Antenna characteristics overview 116-148.5 GHz

Frequency	116 GHz		130 GHz		148.5 GHz	
	φ=0°	φ=90°	φ=0°	φ=90°	φ=0°	φ=90°
Typical antenna gain in main beam in dBi	29	29	31	31	32	32
Antenna gain >24° in dBi	4	2	3	1	-1	2
Sidelobe suppression >24° in dB	25	27	28	30	33	30
Antenna gain >60° in dBi	-1	0	-1	0	-3	0
Sidelobe suppression >60° in dB	30	29	32	31	35	30
Half power beamwidth (HPBW) in degrees			4.5	4.7		

Table 128: Antenna characteristcs overview 167-182 GHz

Frequency	167 GHz		174 GHz		182 GHz	
	φ=0°	φ=90°	φ=0°	φ=90°	φ=0°	φ=90°
Typical antenna gain in main beam in dBi	31	31	31	31	32	32
Antenna gain >24° in dBi	2	2	2	1	1	1
Sidelobe suppression >24° in dB	29	29	29	30	31	31
Antenna gain >60° in dBi	0	-1	-1	-1	-2	-1
Sidelobe suppression >60° in dB	31	32	32	32	34	33
Half power beamwidth (HPBW) in degrees			4.3	4.5		

Table 129: Antenna characteristcs overview 231.5-250 GHz

Frequency	231.5 GHz		240.75 GHz		250 GHz	
	φ=0°	φ=90°	φ=0°	φ=90°	φ=0°	φ=90°
Typical antenna gain in main beam in dBi	30	30	31	31	31	31
Antenna gain >24° in dBi	0	2	0	2	-3	2
Sidelobe suppression >24° in dB	30	28	31	29	34	29
Antenna gain >60° in dBi	-3	-1	-4	-1	-5	-1
Sidelobe suppression >60° in dB	33	31	35	32	36	32
Half power beamwidth (HPBW) in degrees			4.7	5.0		

ANNEX 5: CALCULATION OF THE RAS VLBI INTERFERENCE THRESHOLD

Two representative frequencies are used in the following sample calculation: 150 GHz and 224 GHz The values indicated for the power entering receiver and spectral power flux density are directly taken from Recommendation ITU-R RA.769-2, table 1 and table 3 [9]. The values for receiver and antenna noise temperatures are from table 1 of RA.769-2.

For 224 GHz, VLBI thresholds are not provided in Recommendation ITU-R RA.769-2 but data has been combined from Recommendation ITU-R RA.769-2, table 1 (threshold levels of interference detrimental to radio astronomy continuum observations) and the method from Recommendation ITU-R RA.769-2, section 2.3 that indicates that “the tolerable interference level is determined by the requirement that the power level of the interfering signal should be no more than 1% of the receiver noise power to prevent serious errors in the measurement of the amplitude of the cosmic signals.”

The receiver noise power is:

$$P_R = k\,(T_A + T_R)\Delta f \tag{17}$$

So, taking the values of Recommendation ITU-R RA.769-2, table 1 for T_A, T_R and Δf and accounting for a factor of 0.01 (1%) the input power is:

$$P_I = 0.01 \cdot 1.38 \cdot 10^{-23} \frac{W}{K \cdot Hz} \cdot (14 + 30)K \cdot 8 \cdot 10^9\ Hz = 4.8571 \cdot 10^{-14}\ W \tag{18}$$

Expressed in dBW:

$$P_I^{dB} = -133.1\ dBW \tag{19}$$

To compute the spectral power flux density (SPFD), one divides the power by the effective area of an isotropic antenna $c^2/4\pi f^2$ and the bandwidth Δf, or equivalently:

$$\begin{aligned} SPFD = {} & P_I^{dB} + 20 \cdot log f - 158.8\ dB - 10 \cdot log \Delta f \\ = {} & -133.1\ dBW + 20 \cdot \log(150 \cdot 10^9)Hz - 158.5\ dB - 10 \cdot log(8 \cdot 10^9)Hz \\ = {} & -167.1\ dB\left(\frac{W}{m^2 Hz}\right) \end{aligned} \tag{20}$$

The same methodology is used at 224 GHz.

ANNEX 6: INFORMATION ABOUT STATE-OF-THE-ART GLASS WINDOWS IN BUILDINGS AND THEIR DISTRIBUTION IN EUROPE

A6.1 INTRODUCTION AND BACKGROUND

Several EU Directives concerning energy efficiency and energy performance of buildings are in place:

- Directive 2010/31/EU [53] of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings;
- Directive (EU) 2018/844 [54] of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency;
- Directive 2012/27/EU [55] of the European Parliament and of the Council of 25 October 2012 on energy efficiency.

This Annex gives an example what distribution of building window technology can be expected over Europe.

An overview of implemented national law is given in Table 130.

Table 130: List of national Regulations

Member state	Institute	National Regulation
Austria	Ecofys Germany GmbH	OIB-Richtlinie 6 Energieeinsparung und Wärmeschutz
Belgium-Brussels	Brussels Energy Agency	-
Belgium - Flanders	Flemish Energy Agency	Energy law (Energiebesluit) of November 19, 2010, Annex VII
Belgium - Wallonia	EE buildings department	Réglementation PEB du 01/01/2017 au 31/12/2020
Bulgaria	Sofia Energy Agency - SOFENA	Ministry of Regional Development -Ordinance 7 of the Energy Efficiency of Buildings
Croatia	Ministry of Construction and Physical Planning	Technical regulation on rational energy consumption and thermal protection in buildings (OG 128/2015)
Cyprus	Ministry of Energy, Commerce, Industry and Tourism	Ministerial Order for Minimum Energy Performance Requirements 2013 (ΚΔΠ 244/2013, ΚΔΠ 432/2013, ΚΔΠ 119/2016)
Czech Republic	Building Engineering-Consultants Prague	CSN 730540-2
Denmark	Danish Ministry of Climate, Energy and Buildings, Danish Energy Agency	Executive Order on the Publication
Estonia	Tallinn University of Technology	Concerted Action 2014 / Minimum energy performance requirements
Finland	Ministry of the Environment	4/13 Ministry of the Environment degree on improving the energy performance of buildings undergoing renovation or alternation

Member state	Institute	National Regulation
France	ADEME/DTVD/SB	Arrêté du 3 Mai 2007 relatif aux caractéristiques thermiques et à la performance énergétique des bâtiments existants Arrêté du 13 Juin 2008 relatif à la performance énergétique des bâtiments existants de surface supérieure à 1000 m2 lorsqu’ils font l’objet de travaux de rénovation importants
Germany	Ecofys Germany GmbH	Energieeinsparverordnung zur Zweiten Verordnung zur Änderung der Energieeinsparverordnung vom 18. November 2013 (BGBl. I S.3951) (Energieeinsparverordnung 2014)
Greece	Laboratory of Building Construction and Building Physics Civil Engineering Department, Aristotle University of Thessaloniki	Ministerial Decision 5825/30-03-2010 FEK B΄ 407
Hungary	Building Energetics Affiliation of the Hungarian Chamber of Engineers	7/2006. (V. 24.) TNM the definition of the energy characteristics of buildings, Annex 1 & Annex 5
Ireland	Sustainable Energy Authority	Building Regulations 2011: Technical Guidance Document L-Conservation of Fuel and Energy-Dwellings Section 2.1.2.4-Table 5
Italy	Politecnico di Milano	National Ministerial Decrees (D.M. 26/06/2015)
Latvia	Ministry of Economics Latvia	Construction Law & Regulations Regarding Latvian Construction Standard LBN 002-01 Thermotechnics of Building Envelopes
Lithuania	Ministry for Environment of the Republic of Lithuania	STR 2.05.01:2013 "Design of Energy Performance of Buildings"
Luxembourg	Ministry of Economy	Règlement grand-ducal concernant la performance énergétique des bâtiments d’habitation-Annexe p.15 & p.34
Malta	Malta Intelligent Energy Management Agency	Doc F-Technical Guidance Conservation of Fuel and Natural Resources Part A energy performance of : Minimum requirements on the buildings – Malta, 2015
Netherlands	National Enterprising Netherlands Sustainable Construction and Services, Team Housing	Bouwbesluit 2015, Richtlijn energieprestatie gebouwen
Poland	National Energy Conservation Agency	“Regulation on the technical conditions that should be met by buildings and their location” issued by the Minister of Infrastructure of 12 April 2002 (updated in 2008 and 2015)
Portugal	University of Minho, Department of Civil Engineering	Decree-law nº 28/2016; Ordinance nº 319/2016; Ordinance nº 379A/2015; Ordinance nº15793-k/2013.
Romania	Ministry of Regional Development and Public Administration, Technical Directorate	Code for thermal calculation of building elements: C 107-2005 with further amendments in 2010, 2012 and 2016, Methodology for calculating energy performance of buildings: Mc 001-2006 with further amendments in 2010 and 2013

Member state	Institute	National Regulation
Slovak Republic	Building Testing and Research Institute Bratislava	STN 73 0540-2; STN 73 0540-3
Slovenia	Building and Civil Engineering Institute ZRMK	Building code PURES 2010 and TSG-1-004:2010 URE (Technical guideline for construction: TSG-1-004:2010 Efficient use of energy)
Spain	Hochschule Luzern, Technik & Architektur Zentrum für Integrale Gebäudetechnik ZIG	Código Técnico de la Edificación (CTE). Documento Básico de Ahorro de Energía (DB-HE), 2013
Sweden	Boverket-National Board of Housing, Building and Planning	BBR Swedish Building code, section 9:92
UK – England	Department for Communities and Local Government	Building Regulations 2010 (SI 2010/2214), Building (Approved Inspectors etc.) Regulations 2010* (SI 2010/2214 and 2010/2215) Energy Performance of Buildings (England and Wales) Regulations (SI 2012/3118) incl. amendments from 2013
UK – Wales	Welsh Government	See UK-England Amendments compared to England: - Building (Amendment) (Wales) Regulations 2014 SI 2014/110 (W. 10); - Building (Amendment) (Wales) Regulations 2014 SI 2013/747 (W. 89).
UK – Northern Ireland	Department of Finance and Personnel Northern Ireland	Own building regulation: Building Regulations (Northern Ireland) 2012 (SR 2012 No. 192) Building (Prescribed Fees) Regulations (Northern Ireland) 1997 (SR 1997 No. 482); Energy Performance of Buildings (Certificates and Inspections) Regulations (Northern Ireland) 2008 (SR 2008 No. 170). Incl. amendments from 2014
UK – Scotland	Local Government and Communities Directorate (Scotland)	Own building regulation: Building (Scotland) Regulations 2004 and Energy Performance of Buildings (Scotland) Regulations 2008 Incl. amendments from 2013

A6.2 DISTRIBUTION OF WINDOW TECHNOLOGIES

As an alternative to comprehensive studies of the above-mentioned directives, this section gives a view on existing window technologies by considering a market analysis [51] for the total window stock in Germany, conducted by the German Window and Façade Association together with the German Federal Flat Glass Association.

NOTE: The study was compiled/revised by Univ.-Prof. Dr.-Ing. Gerd Hauser, Technical University of Munich and Dr. Rolf-Michael Lüking in cooperation with the Window and Façade Association (Verband Fenster + Fassade, VFF) and the Federal Flat Glass Association (Bundesverband Flachglas, BF).

Table 131 shows the different glass types in relation to the known categories ”traditional” and “thermally efficient”:

- Traditional: High transmission types, included in the 70%-amount of the 70%/30% distribution;
- Thermally efficient: Low transmission types, included in the 30%-amount of the 70%/30% distribution.

Table 131: Categories of glass types

Glass Types	U-value W/(m2K)	traditional	thermally efficient
Single-pane glass	5.8	x	
Double-glazed windows	2.8	x	
Insulation glass 4/12/4 (uncoated)	2.8	x	
2-pane insulation glass 1st generation	1.4		x
2-pane insulation glass 2nd generation	1.2		x
2-pane insulation glass 3rd generation	1.1		x
3-pane insulation glass	< 0.8		x

Table 132 to Table 134 give an extract from annex 1 of [51]. The tables start with the year 1971 and end 2016. Columns having dots should indicate that changes here are not of interest. A new column starts if a new type of glass was put on the market.

For the first time in 1994, the market size of thermally efficient glass windows is above 34%. It is worth to mention that from 1994 until today this number hasn’t dropped anymore below 34%.

This evaluation indicates that the 70% traditional and 30% thermally efficient distribution at least in Germany would be applicable from 1994 onwards for all newly installed windows.

Since 2003 solely 100% thermally efficient windows have been sold and installed in Germany.

Table 132: Market Share of Glass Types (1971 to 1990)

Glass Types	1971	…	1979	1980	…	1990
Single-pane glass	30%	…	0%			
Double-glazed windows	70%	…	5%			
Insulation glass 4/12/4 (uncoated)			95%	100%	…	90%
2-pane insulation glass 1st generation						10%
2-pane insulation glass 2nd generation						
2-pane insulation glass 3rd generation						
3-pane insulation glass						

Table 133: Market Share of Glass Types (1994 to 2003)

Glass Types	…	1994	…	1999	…	2003
Single-pane glass						
Double-glazed windows						
Insulation glass 4/12/4 (uncoated)	…	66%	…	9%	…	
2-pane insulation glass 1st generation	…	34%	…	45%	…	
2-pane insulation glass 2nd generation				46%	…	100%
2-pane insulation glass 3rd generation						
3-pane insulation glass						

Table 134: Market Share of Glass Types (2004 to 2016)

Glass Types	2004	2005	….	2008	…	2016
Single-pane glass						
Double-glazed windows						
Insulation glass 4/12/4 (uncoated)						
2-pane insulation glass 1st generation						
2-pane insulation glass 2nd generation	90%	75%	…			
2-pane insulation glass 3rd generation	10%	20%	…	85%	…	41%
3-pane insulation glass		5%	…	15%	…	59%

A6.3 TREATMENT OF BUILDING ENTRY LOSS IN OTHER ECC REPORTS

Table 135 shows a summary of building entry loss values at different centre frequencies used in other ECC Reports.

Table 135: Building entry loss values used in other ECC Reports

Deliverable	Centre frequency	Building entry loss value	Notes
ECC Report 302 [70]	6.175 GHz	17 dB for traditional building 32 dB for thermally efficient building	Model according to ITU-R P.2109 [23] with 30% thermally efficient and 70% traditional buildings
ECC Report 190 [21]	122 GHz	>60 dB	between SRDs and EESS
ECC Report 064 [17]	10 GHz	17 dB	Building attenuation for space applications

A6.4 CONCLUSIONS

Three European Directives pursuing the goals of energy efficiency and in particular energy efficient buildings have been identified.

A market study of used window technologies in Germany has been analysed.

As from 1994 the 70%/30% distribution has been fulfilled for newly installed windows.

From 2003 onwards solely 100% energy efficient window technology has been used for newly installed windows.

All European member states have regulations in place reflecting these goals, in particular for refurbishment purposes (see Table 130).

The use of the 70%/30% distribution is therefore well justified as the assumptions behind this rule could be fully confirmed by investigation of a market study conducted by the institutes cited in [51].

As a compromise it has been used the 70%/30% distribution BEL value (like also used in ECC Report 302 [70]) for devices where the orientation and beam direction cannot be controlled. For devices with a clear installation requirement like “main beam not pointing towards windows” it is used the lump sum value of at least 50 dB BEL as a reasonable value that is well backed even for multilayer wooden materials by the material measurements in this Report.

ANNEX 7: CAR GLASS MATERIAL ATTENUATION MEASUREMENTS FOR 120 TO 175 GHZ

A7.1 INTRODUCTION AND BACKGROUND

In this section, measurement results for the attenuation of an example selection of different car glass window types are provided to support the shielding loss that is used in the conducted MCL calculations. The testing of the provided variety of example window types helped to get a better understanding on the possible achievable shielding level of in-vehicle to outside scenarios. Due to the fact that a vehicle body mainly consists of metal the windows are considered the weakest point in terms of RF shielding in the frequency range above 116 GHz. Vehicles are environments that are fully controlled by the manufacturer, so a high shielding level can be guaranteed by designing the vehicle with specific window types.

A7.2 MEASUREMENT SETUP

To measure the frequency dependent attenuation of the car glass window materials a simple measurement setup with a custom programmable radar sensor as signal source and a R&S FSEK30 spectrum analyser was used. This setup allows measurements with a dynamic range of around 60 dB. The dynamic range is limited by the sweep time of the spectrum analyser and the missing frequency synchronisation between the FSEK30 and the radar. For a larger dynamic range without increasing the measurement time too much by selecting very narrow RWB/VBW filter bandwidths a network analyser-based measurement setup might be a better choice, but unfortunately was not available for the measurements. The transmitted power is measured in 1 GHz step width with 56 steps in the frequency range from 120 to 175 GHz to provide smooth measurement curves.

The attenuation measurements are calibrated to a reference transmission measurement with no object in the beam. All measurements are referenced to this measurement. To show the achieved maximum dynamic range a reference measurement with full shielding (metal plate) is provided.

Table 136: List of the used measurement equipment

Type	Model
Transmitter	Custom USB D-Band FMCW radar configured in programmable frequency CW-mode. Connector: ▪ WM-1651 (WR-06) waveguide compatible to standard UG387 flange. Frequency range: ▪ 120-175 GHz
Receiver	Rohde & Schwarz FSEK30 with external Radiometer Physics SAM-170 harmonic mixer
Antenna (Tx & Rx)	MI-WAVE 261D-24/387 standard gain horn with 24 dBi gain

In Table 136, a short overview of the used measurement equipment is given, and Figure 127 shows a photograph of the measurement setup. A custom Python script is used to control the FSEK via SCPI language and program the radar transmitter device to step to the different frequency points and record the received power.

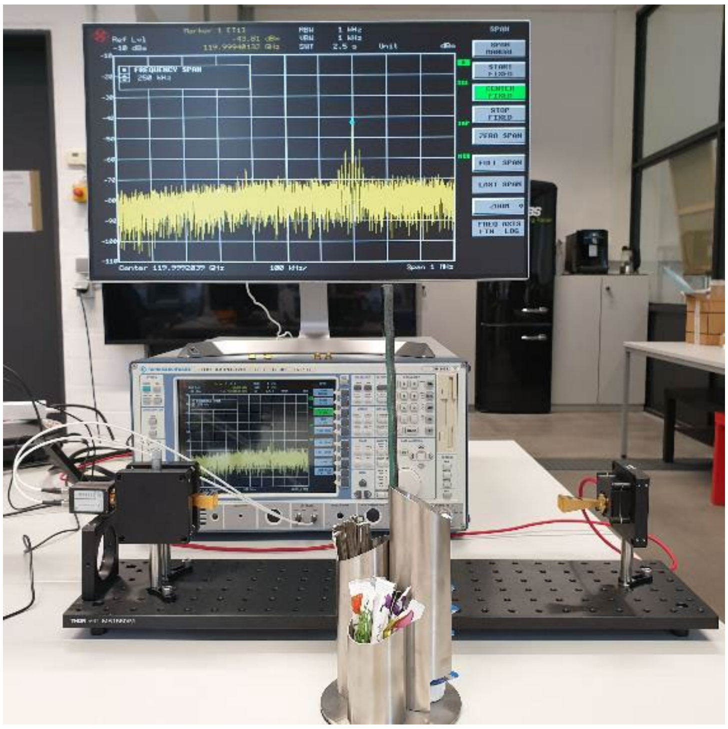


Figure 127: Photograph of the measurement setup with a 300x300 mm car glass sample in 90° angle

A7.3 MATERIAL SAMPLES AND MEASUREMENTS

To provide a good overview of the shielding capabilities of available standard car glass window material types a variety of example test samples were measured. Windows with embedded heating wires were measured in both polarisations (H/V) and some measurements were also repeated with an angle of 45° instead of 90°.

Figure 128: Photograph of the measurement position for car glass samples with camera mounting points and sun shielding

Unfortunately, some window samples are equipped with mounting structures for camera assistant systems like shown in Figure 128. Those DUTs were measured at a point where the signal attenuation is assumed to be caused mainly by the window glass. This might influence the measurement accuracy. But the effect is assumed to be insignificant, because the results show that the measurements are still well in line with other window types of the same category.

Figure 129 shows the measurement results. The red dashed line indicates the dynamic range limit of the measurement setup. Except one outlier in the blue “JLR560 IRR HUD1” curve at 122 GHz which may result from a malfunction of the peak detect mode (spectrum analyser detected the noise floor instead of the signal peak) all acquired measurement data seems plausible.

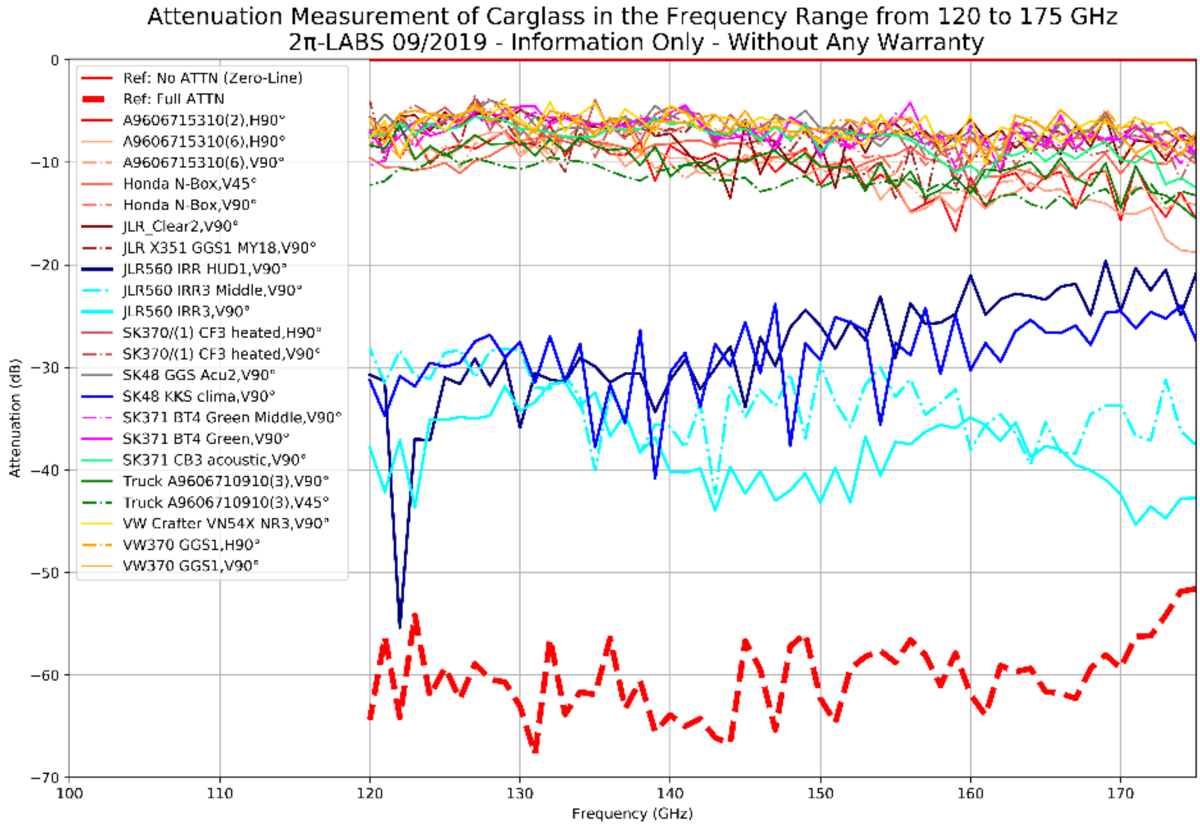


Figure 129: Attenuation measurement results of typical car glass materials

A7.4 CONCLUSIONS

There are mainly two different groups of material types that can be identified:

1 “Standard” glass types with at least around 5 dB to up to 19 dB attenuation in the measured frequency range. The difference here between the samples seems to be caused mainly by different thicknesses and foils between the window layers.

2 “Metallized” glass types that provide a much higher shielding starting at around 20 dB. “IRR” abbreviation in the sample name may stand for “infrared rejection” and “clima” also indicated a special metal coating similar to energy efficient glass for building windows. It is interesting that for some coatings the losses seem to be lower at higher frequencies.

ANNEX 8: DERIVATION OF APPORTIONMENT FACTORS FOR EESS (PASSIVE)

A8.1 INTRODUCTION

The European Common Allocations Table [3] (see Table 34) shows that in the range from 116 GHz to 260 GHz EESS (passive) bands are adjacent to between 4 and 7 different Radiocommunication Services. Some bands are also shared with other Radiocommunication Services which may have specified power limits e.g. footnote 5.562C [3]. This could represent between 5 and 8 possible sources of interference. If all services are being used in the same area operating with an equivalent aggregate power level at the same time, based on an equal apportionment between services an apportionment margin of 7 to 9 dB could be applied to the protection criteria. The new applications considered in this Report are in addition to existing applications and an additional factor may be applied.

A8.2 APPORTIONMENT INDUCED BY ALLOCATIONS TO RADIO SERVICES

The allocated Radiocommunication Services are summarised in Table 137, assuming that all Services share the protection criteria with equal apportionment. The geometry of each Services systems has not been considered.

Table 137: Band-by-band apportionment factors in the frequency range 114.25-260 GHz induced by allocations to Radio Services

Frequency band (GHz)	Potential interfering Radio Service	Other sources	Total number of sources	Effective number of sources (without those potentially not operating at the same place)	Resulting apportionment factor
114.25-116	FS (below/above) MS (below/above) ISS (in-band/above)		6	4 (MS and FS unlikely to coexist)	6 dB
116-122.25	FS (below/above) MS (below/above) ISS (in-band/above)	EHF systems	7	5 (MS and FS unlikely to coexist)	7 dB
148.5-151.5	FS (below/above) MS (below/above) Radiolocation (below/above)		6	4 (MS and FS unlikely to coexist)	6 dB
164-167	FS (below/above) MS (below/above) FSS (below/above) MSS (below) ISS (above)		8	5 (MS and FS unlikely to coexist) (MSS and FSS unlikely to coexist)	7 dB
174.8-182	FS (below/above) MS (below/above) ISS (below/in-band/above)	EHF systems	11	7 (MS, Radionavigation and FS unlikely to coexist)	8.5 dB

Frequency band (GHz)	Potential interfering Radio Service	Other sources	Total number of sources	Effective number of sources (without those potentially not operating at the same place)	Resulting apportionment factor
	MSS (above) Radionavigation (above) Radionavigation-Satellite (above)			(MSS and Radionavigation-Satellite unlikely to coexist)	
182-185	FS (below/above) MS (below/above) ISS (below/in-band/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)		10	6 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	7.8 dB
185-190	FS (below/above) MS (below/above) ISS (below/in-band/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)	EHF systems	11	7 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	8.5 dB
190-191.8	FS (below/above) MS (below/above) ISS (below/in-band/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)		10	6 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	7.8 dB
200-209	FS (below/above) MS (below/above) FSS (above) ISS (below) MSS (below) Radionavigation (below) Radionavigation-Satellite (below)		9	5 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	7 dB
226-231.5	FS (below/above) MS (below/above)		7	4	6 dB

Frequency band (GHz)	Potential interfering Radio Service	Other sources	Total number of sources	Effective number of sources (without those potentially not operating at the same place)	Resulting apportionment factor
	FSS (below/above) Radiolocation (above)			(MS, Radiolocation and FS unlikely to coexist)	
235-238	FS (below/above) MS (below/above) FSS (below/in-band/above) Radiolocation (below) Radionavigation (above) Radionavigation-Satellite (above)		10	5 (MS, Radiolocation and FS unlikely to coexist) (FSS and Radionavigation-Satellite unlikely to coexist)	7 dB
239-248	New frequency range according to resolution 662 WRC-19. Not yet assessed.				
250-252	FS (above) MS (above) Amateur and Amateur-Satellite (below) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)		7	4 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	6 dB

The “resulting apportionment factor” in Table 137 above is derived under the following assumptions:

- All Radio services are expected to transmit in the IFOV of the satellite;
- All produced interference signals are present in the victim receiver bandwidth and add up constructively, at equal level.

In order to generate the final apportionment factor for all SRD-applications which are a subject of this Report, the following assumptions have been made:

- All applications in the respective frequency band are expected to transmit in the IFOV of the satellite;
- All produced interference signals are present in the victim receiver bandwidth and add up constructively, at equal level.

A second approach applied the assumptions to only give a 0.5 weight to interferers located in adjacent bands to EESS (passive) allocations outside 5.340 protected bands and to not consider the ISS service in the bands 114.25 to 122.25 GHz and 174.8 to 191.8 GHz as a potential source of interference. In addition to that EHF systems are considered as generic and hence cover both, FS and MS. This alternative approach would lead to the situation shown in Table 138.

Table 138: Alternative band-by-band apportionment approach in the frequency range 114.25-260 GHz induced by allocations to Radio Services

Frequency band (GHz)	Potential interfering Radio Service	Total number of sources	Reassessment of the total number of sources taking account of either no operation in same geographic location or OOB from adjacent user as a fraction of in-band emissions	Resulting apportionment factor using even distribution
114.25-116	FS (below/above) MS (below/above) ISS (above)	5	2 (MS and FS unlikely to coexist)	3 dB
116-122.25	FS (in-band/above) MS (in band/above) ISS (above)	5	2 (MS and FS unlikely to coexist)	3 dB
148.5-151.5	FS (below/above) MS (below/above) Radiolocation (below/above)	6	2 (MS and FS unlikely to coexist)	3 dB
164-167	FS (below/above) MS (below/above) FSS (below/above) MSS (below) ISS (above)	8	3 (MSS and FSS unlikely to coexist) (MS and FS unlikely to coexist)	5 dB
174.8-182	FS (in-band/below/above) MS (in-band/below/above) ISS (below/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)	11	4 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	6 dB
182-185	FS (below/above) MS (below/above) ISS (below/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)	9	3 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	4.8 dB
185-190	FS (in-band/below/above) MS (in-band/below/above) ISS (below/above) MSS (above) Radionavigation (above)	11	4 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	6 dB

Frequency band (GHz)	Potential interfering Radio Service	Total number of sources	Reassessment of the total number of sources taking account of either no operation in same geographic location or OOB from adjacent user as a fraction of in-band emissions	Resulting apportionment factor using even distribution
	Radionavigation-Satellite (above)			
190-191.8	FS (below/above) MS (below/above) ISS (below/above) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)	9	3 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	4.8 dB
200-209	FS (below/above) MS (below/above) FSS (above) ISS (below) MSS (below) Radionavigation (below) Radionavigation-Satellite (below)	9	2 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	3 dB
226-231.5	FS (below/above) MS (below/above) FSS (below/above) Radiolocation (above)	7	2 (MS, Radiolocation and FS unlikely to coexist)	3 dB
235-238	FS (below/above) MS (below/above) FSS (below/in-band/above) Radiolocation (below) Radionavigation (above) Radionavigation-Satellite (above)	10	3 (MS, Radiolocation and FS unlikely to coexist) (FSS and Radionavigation-Satellite unlikely to coexist)	5 dB
250-252	FS (above) MS (above) Amateur and Amateur-Satellite (below) MSS (above) Radionavigation (above) Radionavigation-Satellite (above)	7	2 (MS, Radionavigation and FS unlikely to coexist) (MSS and Radionavigation-Satellite unlikely to coexist)	3 dB

Other alternative approaches could be used that either discount adjacent band use further and result in lower apportionment values or that are based on further analysis of the possible EESS (passive) interference situation due to usage in the adjacent bands by Fixed Service under existing ECC harmonisation deliverables (e.g. relevant FS unwanted emission levels in ECC Recommendation (18)01 [22] and ECC Recommendation (18)02) [46], which may result in more conservative results and hence to higher values of apportionment factor than those given in Table 137.

A8.3 APPORTIONMENT INDUCED BY OTHER UWB-APPLICATIONS

The situation concerning the applications is shown in Table 139 assuming again that all applications would equally share the additionally apportioned margin.

Table 139: Band-by-band apportionment factors in the frequency range 114.25-260 GHz induced by UWB-applications

Affected EESS allocation (GHz)	Potential UWB-applications in the EESS allocation	No. of outdoor UWB-applications	Resulting apportionment from outdoor UWB-applications
114.25 -116	-	0	-
116–122.25	RDI, Short-range assist (car), Generic Indoor surveillance radar, LPR, CDR, RDI-S, TLPR	4	6 dB
148.5–151.5	RDI-S	0	-
164–167	RDI-S	0	-
174.8–182	RDI, LPR, CDR, RDI-S, TLPR	3	4.8 dB
182–185	RDI-S	0	-
185–190	RDI, RDI-S	1	0 dB
190–191.8	RDI-S	0	-
200–209	RDI-S	0	-
226–231.5	RDI-S	0	-
235–238	RDI, LPR, CDR, RDI-S, TLPR	3	4.8 dB
239–248	RDI, LPR, CDR, RDI-S, TLPR	New frequency range according to resolution 662 WRC-19. Not yet assessed.	
250–252	RDI-S	0	-

A8.4 CONCLUSIONS

Based on the methodology described in this annex, a single value of 12 dB apportionment factor, applied to each radiodetermination application individually (see section 2.2), has been used in this Report based on equal apportionment between regular Radio Services and further apportionment between the UWB radiodetermination applications under study. This 12 dB value has also been used in bands protected by RR No. 5.340 where the calculated margin is lower due to emissions being prohibited in those bands.

Table 140: Combined band-by-band apportionment factors in the frequency range 114.25-260 GHz and overall apportionment solution

Affected EESS allocation (GHz)	Article RR 5.340 protected	Combined apportionment factor reflecting the two approaches in Table 137 and Table 138 and the factors from UWB applications in Table 139 (Note 1)	Overall apportionment factor
114.25–116	●	6 dB (Table 137) 3 dB (Table 138)	12 dB
116–122.25		13 dB (Table 137) 9 dB (Table 138)	12 dB
148.5–151.5	●	6 dB (Table 137) 3 dB (Table 138)	12 dB
164–167	●	7 dB (Table 137) 5 dB (Table 138)	12 dB
174.8–182		13.3 dB (Table 137) 10.8 dB (Table 138)	12 dB
182–185	●	7.8 dB (Table 137) 4.8 dB (Table 138)	12 dB
185–190		8.5 dB (Table 137) 6 dB (Table 138)	12 dB
190–191.8	●	7.8 dB (Table 137) 4.8 dB (Table 138)	12 dB
200–209	●	7 dB (Table 137) 3 dB (Table 138)	12 dB
226–231.5	●	6 dB (Table 137) 3 dB (Table 138)	12 dB
235–238		11.8 dB (Table 137) 9.8 dB (Table 138)	12 dB
239–248		New frequency range according to resolution 662 WRC-19. Not assessed	12 dB
250–252	●	6 dB (Table 137) 3 dB (Table 138)	12 dB
Note 1: The combined apportionment comprises the apportionment factors induced by the Radio Services identified either in Table 137 or in the alternative approach shown in Table 138 and the apportionment factor induced by the UWB-applications (Table 139) considered in this Report.			

Considering the alternative approaches described in section A8.2 above, this value of 12 dB may therefore overestimate or underestimate the actually needed apportionment but is lower than the 13 to 20 dB values previously used for UWB in Report ITU-R SM.2057 [69].

On the other hand, other studies considering other terrestrial users in ECC, ITU or in National regulatory situations have allowed a higher level of interference when looking at the overall EESS (passive) interference budget that is available and this would leave less headroom for these additional UWB sources.

Finally, an agreement was reached between all involved UWB and EESS (passive) stakeholders to use an overall lump-sum apportionment factor of 12 dB in this Report as a reasonable compromise, in particular when considering that it is lower than the 13 to 20 dB values previously used for UWB in Report ITU-R SM.2057.

ANNEX 9: ESTIMATING THE NUMBER OF INTERFERERS IN THE FOOTPRINT OF EESS (PASSIVE) SATELLITES FOR PROFESSIONAL INDUSTRIAL APPLICATIONS

A9.1 EXISTING MARKET ESTIMATION FOR DIFFERENT APPLICATIONS

For the different radiodetermination applications covered by this Report an individual absolute number of devices has been estimated in a market analysis. For tank level probing radar (TLPR) for example it is estimated that there is a worldwide market potential for 300000 sensors within the next five years until a market saturation takes effect. 40% of the devices are expected to be sold in Europe and are moreover split into the three investigated bands for TLPR (see section 2.2.7.5).

It can be assumed that the individual devices of each industrial sensor application will not be uniformly distributed over the European land area. In the last three rows in Table 29, this average device density has been calculated for TLPR for every considered frequency band. These values must be further improved before they can be used in the aggregate studies.

For generic devices and devices which are marketed to residential consumers it can be expected that the highest density of devices can be found in big metropolitan areas where the density of the population is maximal. One application which belongs to this category is for example generic indoor surveillance radar (section 2.2.1). However, the same might also apply to sensors used for cars, as the car density can also be expected maximal in densely populated areas. The only one car application covered by this Report is short-range assist for vehicles (section 2.2.3).

In ECC Report 190 [21] for generic SRDs the Paris area was considered as an appropriate worst-case scenario where a very high population density correlates directly with a high density of these generic devices under consideration. Table 5 in ECC Report 190 illustrates the evaluated deployment densities.

This Report, however, also covers sensors which are solely destined for industrial use, i.e. in industrial areas. The few applications which fall under this category are:

- Level probing radar (LPR) and tank level probing radar (TLPR);
- Contour detection radar (CDR);
- Radiodetermination systems for industry automation (RDI);
- Radiodetermination systems for industry automation in shielded environments (RDI-S).

The densities of such sensors do not correlate with the population density or the density of private households per square kilometre. However, it can be assumed that these sensors are uniformly distributed over industrial areas as they are deployed in many different industries (please compare the description of the individual application scenarios in section 2.2).

The number of devices in the footprint of the satellite is therefore rather maximal in large industrial areas. Since not much information is available concerning large industrial areas in Europe, the following approach is proposed in order to derive representative device densities of such industrial devices for aggregate interference studies against EESS (passive).

A9.2 PROCEDURE FOR ESTIMATING THE NUMBER OF INDUSTRIAL INTERFERERS IN THE FOOTPRINTS OF EESS (PASSIVE) SATELLITES

1. For European countries the fraction of the land cover used for industrial purposes in relation to the total area of the respective country could be identified for selected countries (see below).

2. In France for example 5% of the total area is of artificial nature. These artificial areas further divide into “housing, services, recreation” (79%), “industrial, commercial” (13%), “transport networks, infrastructures” (4%), “mines, quarries, waste dumpsites” (3%) and “construction” (1%). The four latter categories indicate areas where SRDs for industrial use, like TLPR, can be expected. This yields an overall area which is equivalent to a percentage of 1.05% of the total area of France which is used for such industrial purposes.

3 In the five largest economies in the EU, these percentages range between 1.05% (France) and 1.82% Germany.

Table 141: Fractions of industrial land cover on total area

County	Percentage of industrial land cover to total area	Relation of total area to industrial land cover
Germany	1.82%	1/(1.82%) = 55.0
United Kingdom	1.48%	1/(1.48%) = 67.6
France	1.05%	1/(1.05%) = 95.2
Italy	1.25%	1/(1.25%) = 80.0
Spain	1.23%	1/(1.23%) = 81.3

4 For the aggregate studies against EESS victims it is assumed that all industrial SRDs are aggregated in industrial areas and that the footprint of the satellite is targeting only such industrial areas no matter how large this footprint of the satellite is. It should be noted that for relatively small satellite footprints in the range of up to 50 km² this assumption might be quite reasonable. However, it should also be emphasized that for larger footprints (up to 2000 km²) this assumption might overestimate the absolute number of SRDs in the footprint of the satellite as there are no industrial areas in Europe with that enormous size.

5 In order to project the country-specific industrial land cover fraction to whole Europe, a relation of 75 is proposed which lies roughly in the middle between the values of Germany (55) and France (95.2). This proposal implicitly assumes that 1.33% of the total European land area is covered by industry.

6 In order to estimate the relevant device densities for the aggregate studies, the uniform device density over the total European area must be consequently weighted (multiplied) with this factor of 75.

7 In order to increase the confidence of the outlined device density estimation a further range approach up to the factor of 2 x 75 = 150 (see item 6 before) shall be checked for the worst cases.

Example: For TLPR in the band 116 to 148.5 GHz the average device density in Europe with uniform distribution is calculated to be 0.0057 devices/km² (see Table 29). Provided the fact that TLPR devices are only deployed in industrial areas this value has to be weighted with the introduced factors of 75 and 150. This yields an assumed device density in industrial areas (and thus also as assumed in the footprint of the EESS satellite) of 0.428 devices/km² up to 0.855 devices/km².

For the nadir scanner N1 in the band 148.5 to 151.5 GHz for example the IFOV at the outer position is 759 km² (see technical details of EESS Sensor N1 in the Report). Consequently, the absolute number of TLPR devices in the footprint of the EESS satellite would be between 0.428 devices/km² x 759 km² = 325 devices and 0.855 devices/km² x 759 km² = 649 devices.

ANNEX 10: RDI-S LIMIT MASKS

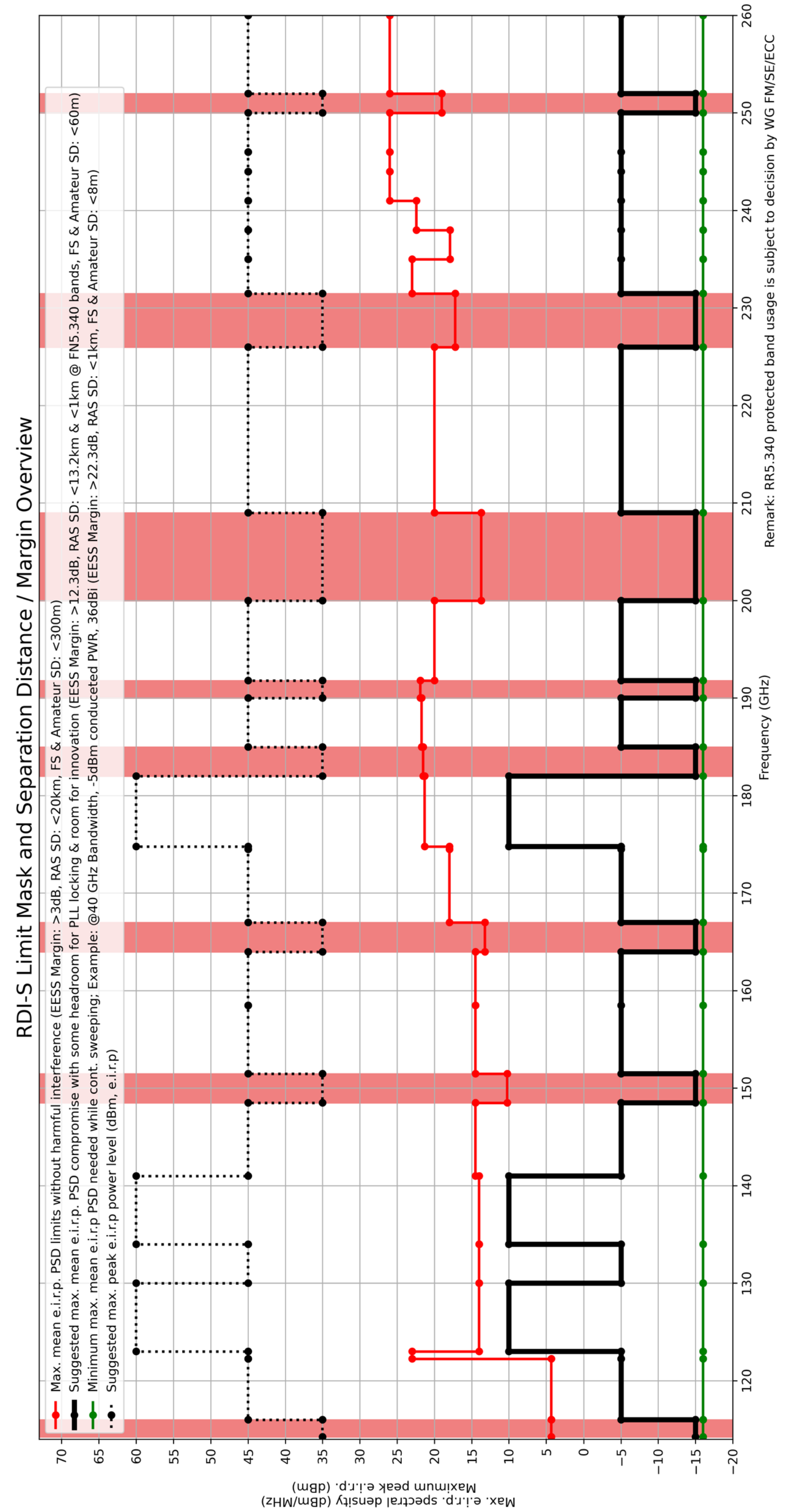


Figure 130: RDI-S limit masks (the suggested maximum mean e.i.r.p. density and the maximum peak e.i.r.p. limits shown in Table 9 are illustrated in the solid black and dashed black lines, respectively)

ANNEX 11: ATMOSPHERIC MODEL USED TO CALCULATE ABSORPTION BY GASES

As part of the calibration of a RAS station, the precipitable water vapour content of the atmosphere is monitored. Figure 131 shows the distribution of the precipitable water vapour content for the years 2007/2008 which is representative of typical weather conditions at the NOEMA site. One can see that in wintertime (dark blue curve), the precipitable water vapour is lower than 1 mm in 25% of the time and lower than 2 mm in 50% of the time (top panel).

Fig. 9: Top: PdB quartiles of precipitable water vapor (dotted lines) during observation for the scheduling year 2007/2008. Curves show the cumulative distributions for winter conditions (dark blue) and the whole year (light blue). Bottom: corresponding distributive distributions. The precipitable water vapor distributions were derived from astronomical observations in the 3 frequency bands (100 GHz, 150 GHz and 230 GHz). They testify to mean columns of 2mm and 4mm water vapor, respectively for the 25% and 50% quartiles. The columns are lower by a factor 2-3 in winter conditions (November to March, dark blue histogram). Overall observing time accounts for 76% of total time in the scheduling year 2007-2008 (the 24% time-out is due to precipitation, wind, maintenance and configuration changes).

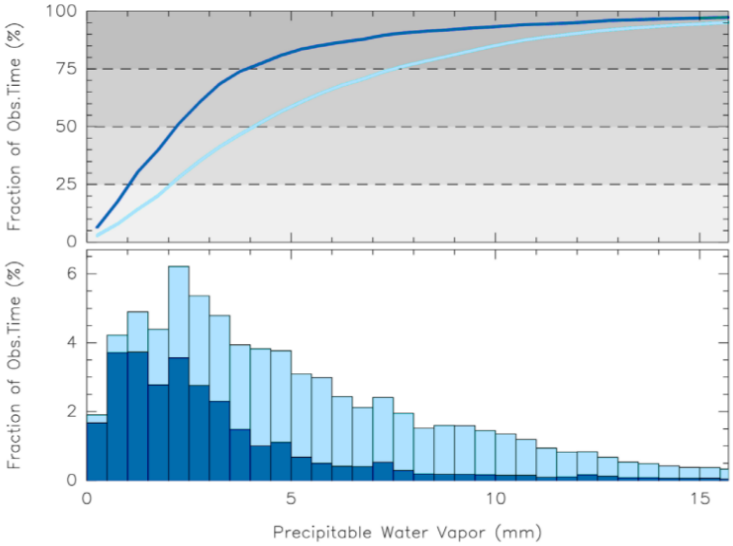


Figure 131: Distribution of water vapour at the NOEMA site

In Figure 132, the integrated vertical water vapor content of the mid-latitude atmosphere reference model (in red) and of the high-latitude reference model from Recommendation ITU-R P.835-6 [29] as a function of the altitude is shown. At the NOEMA altitude (2560 m, shown as a vertical dashed line), the precipitable water vapour is 2.55 mm for the mid-latitude winter and 1.45 mm for the high-latitude winter. So, the high-latitude winter is not even accounting for the 25% best observing conditions in winter, where the propagation is favoured by lower atmospheric gas absorption and hence interferences more likely to occur.

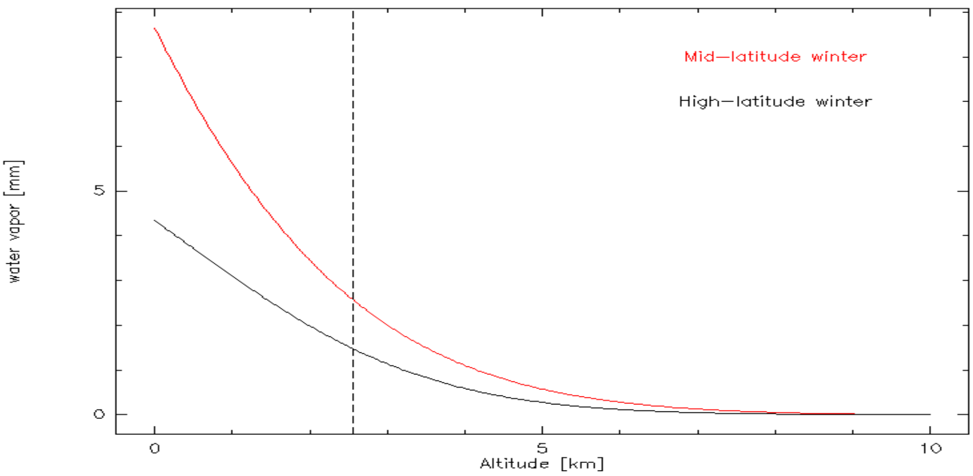


Figure 132: Vertically integrated reference models from ITU-R P.835-6

The situation of the IRAM 30 m telescope is a bit different. Here the precipitable water vapor is lower than 3 mm for 25% of the time.

So, given the observed water vapor distributions for the 30 m and NOEMA telescopes, it is reasonable to use the mid-latitude winter for the 30 m and the high-latitude winter for NOEMA. It is a fact, however, that in some conditions that occur typically in 10% of the wintertime for NOEMA, the water vapor content is much lower than that of the high-latitude winter (<0.75 mm). This means that the use of the mid-latitude winter for the 30 m and high-latitude winter for NOEMA does not constitute a worst-case scenario and that in the best winter observing conditions (which is the most precious observatory time), the atmospheric gas absorption will be lower than considered in this Report.

ANNEX 12: LIST OF REFERENCES

[1] ETSI TR 103 498: "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Transmission characteristics; Radiodetermination applications within the frequency range 120 GHz to 260 GHz"

[2] ECO Frequency Information System, available online at: https://efis.cept.org/

[3] ERC Report 025: "The European Table of Frequency Allocations and Applications in the frequency range 8.3 kHz to 3000 GHz (ECA Table)", approved June 1994 and latest amended October 2021

[4] ECC Report 139: "Impact of Level Probing Radars using Ultra-WideBand technology on radiocommunications services", approved February 2010

[5] ETSI EN 302 729: "Short Range Devices (SRD); Level probing Radar (LPR) equipment operating in the frequency ranges 6 GHz to 8.5 GHz, 24.05 GHz to 26.5 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU"

[6] Hua Wang, Fei Wang, Huy Thong Nguyen, Sensen Li, Tzu-Yuan Huang, Amr S. Ahmed, Michael Edward Duffy Smith, Naga Sasikanth Mannem, and Jeongseok Lee, "Power Amplifiers Performance Survey 2000-Present" [Online]. Available: https://gems.ece.gatech.edu/PA_survey.html

[7] ETSI EN 302 372 V2.1.1 (2016-10): "Short Range Devices (SRD); Tank Level Probing Radar (TLPR) equipment operating in the frequency ranges 4.5 GHz to 7 GHz, 8.5 GHz to 10.6 GHz, 24.05 GHz to 27 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU"

[8] "Handbook on Radio Astronomy", Third Edition of 2013, ITU Radiocommunication Bureau

[9] Recommendation ITU-R RA.769-2: "Protection criteria used for radio astronomical measurements"

[10] Recommendation ITU-R F.758-7: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference"

[11] Report ITU-R F.2416-0: "Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz"

[12] Recommendation ITU-R RS.2017-0: "Performance and interference criteria for satellite passive remote sensing"

[13] Recommendation ITU-R RS.1861: "Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz"

[14] Recommendation ITU-R RS.515-5: "Frequency bands and bandwidths used for satellite passive remote sensing"

[15] Report ITU-R F.2323-0: "Fixed service use and future trends"

[16] ITU Radiocommunication Bureau: "Handbook on Amateur and amateur-satellite services", Edition of 2014,

[17] ECC Report 64: "The protection requirements of Radiocommunications systems below 10.6 GHz from generic UWB applications", approved February 2005

[18] ECC Report 282: "Point-to-point Radio Links in the Frequency Ranges 92−114.25 GHz and 130−174.8 GHz", approved September 2018

[19] Report ITU-R F.2107-2: "Characteristics and applications of fixed wireless systems operating in frequency ranges between 57 GHz and 134 GHz"

[20] Recommendation ITU-R M.1044-2: "Frequency sharing criteria in the amateur and amateur-satellite service"

[21] ECC Report 190: "Compatibility between Short-Range Devices (SRD) and EESS (passive) in the 122 to 122.25 GHz band", approved May 2013

[22] ECC Recommendation (18)01: "Radio frequency channel/block arrangements for "Fixed Service systems operating in the bands 130−148.5 GHz, 151.5−164 GHz and 167−174.8 GHz", approved April 2018

[23] Recommendation ITU-R P.2109-1: "Prediction of building entry loss"

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