ETSI TR 103 728 V1.1.1 (2024-01)

TECHNICAL REPORT

System Reference document (SRdoc);
Transmission characteristics;
Technical characteristics for SRD radiodetermination systems for industry automation in shielded environments (RDI-S) within the frequency range 260 GHz to 1 000 GHz

Reference
DTR/ERM-591

Keywords
radio, SRD, SRdoc

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° w061004871

Important notice

The present document can be downloaded from:
https://www.etsi.org/standards-search

The present document may be made available in electronic versions and/or in print. The content of any electronic and/or print versions of the present document shall not be modified without the prior written authorization of ETSI. In case of any existing or perceived difference in contents between such versions and/or in print, the prevailing version of an ETSI deliverable is the one made publicly available in PDF format at www.etsi.org/deliver.

Users of the present document should be aware that the document may be subject to revision or change of status. Information on the current status of this and other ETSI documents is available at
https://portal.etsi.org/TB/ETSIDeliverableStatus.aspx

If you find errors in the present document, please send your comment to one of the following services:
https://portal.etsi.org/People/CommiteeSupportStaff.aspx

If you find a security vulnerability in the present document, please report it through our
Coordinated Vulnerability Disclosure Program:
https://www.etsi.org/standards/coordinated-vulnerability-disclosure

Notice of disclaimer & limitation of liability

The information provided in the present deliverable is directed solely to professionals who have the appropriate degree of experience to understand and interpret its content in accordance with generally accepted engineering or other professional standard and applicable regulations.
No recommendation as to products and services or vendors is made or should be implied.
No representation or warranty is made that this deliverable is technically accurate or sufficient or conforms to any law and/or governmental rule and/or regulation and further, no representation or warranty is made of merchantability or fitness for any particular purpose or against infringement of intellectual property rights.
In no event shall ETSI be held liable for loss of profits or any other incidental or consequential damages.

Any software contained in this deliverable is provided "AS IS" with no warranties, express or implied, including but not limited to, the warranties of merchantability, fitness for a particular purpose and non-infringement of intellectual property rights and ETSI shall not be held liable in any event for any damages whatsoever (including, without limitation, damages for loss of profits, business interruption, loss of information, or any other pecuniary loss) arising out of or related to the use of or inability to use the software.

Copyright Notification

No part may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm except as authorized by written permission of ETSI.
The content of the PDF version shall not be modified without the written authorization of ETSI.
The copyright and the foregoing restriction extend to reproduction in all media.

© ETSI 2024.
All rights reserved.

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The declarations pertaining to these essential IPRs, if any, are publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (https://ipr.etsi.org/).

Pursuant to the ETSI Directives including the ETSI IPR Policy, no investigation regarding the essentiality of IPRs, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

DECT™, **PLUGTESTS™**, **UMTS™** and the ETSI logo are trademarks of ETSI registered for the benefit of its Members. **3GPP™** and **LTE™** are trademarks of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners. **oneM2M™** logo is a trademark of ETSI registered for the benefit of its Members and of the oneM2M Partners. **GSM**® and the GSM logo are trademarks registered and owned by the GSM Association.

Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

The present document is restricted to RDI-S applications as defined in ECC Report 334 ([i.17], clause 2.4.2) that in turn was based on [i.6]. This restriction is due to the expected very low interference potential to primary radiocommunication services (see ECC Report 334 [i.17]), which is seen as a beneficial condition for the successful development of a solution for these applications within CEPT, taking into account that the ITU Radio Regulations (edition 2020) [i.4] does not yet include allocations to primary and secondary radiocommunication services, which makes compatibility studies with the not yet known radio users challenging. Some information on existing users is provided in the ITU Radio Regulations [i.4] with footnotes 5.564A on land mobile and fixed service allocations, and footnote 5.565 on Radio astronomy service, EESS passive and space research service passive. Footnote 5.564A explicitly states that "The use of the above-mentioned frequency bands by land mobile and fixed service applications does not preclude use by, and does not establish priority over, any other applications of radiocommunication services in the range of 275 - 450 GHz" while 5.565 says "The use of the range 275 - 1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275 - 1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275 - 1 000 GHz frequency range."

Studies on possible new entries for primary and secondary radiocommunication services in the frequency range 231,5 - 1 000 GHz are ongoing at ITU-R level since WRC'19 with Resolutions 663 and 731. A review of these is expected at WRC'23, and the finalization is expected at WRC'27.

The present document will take due care identifying appropriate usage restrictions, frequency ranges and limits by considering the above-described situation.

The use of the RDI-S applications should be based on article 4.4 of the ITU Radio Regulations [i.4], which means that the use is subject to no harmful interference being caused to any Radiocommunication Service, and that no claim may be made for the protection against harmful interference originating from Radiocommunication Services.

1 Scope

The present document describes Radiodetermination systems for industry automation in shielded environments (RDI-S) within the frequency range 260 GHz to 1 000 GHz assignment. The described radiodetermination applications are for the measurement of object properties like e.g. layer thicknesses and the S-parameters.

The present document includes in particular:

- Market information.
- Technical information, including expected sharing and compatibility issues.
- Regulatory issues.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ECC Report 139: "Impact of Level Probing Radars Using Ultra-Wideband Technology on Radiocommunications Services", Rottach-Egern, February 2010.

[i.2] ETSI EN 302 372 (V2.1.1) (12-2016): "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".

[i.3] CITEL Member States: "Preliminary views for WRC-19, Agenda Item 1.15".

[i.4] ITU Radio Regulations 2020.

[i.5] Report Recommendation ITU-R RA.2189-1 (09/2018): "Sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz".

[i.6] ETSI TR 103 498 (V1.1.1) (2019-02): "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Transmission characteristics; Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB); Radiodetermination application within the frequency range 120 GHz to 260 GHz".

[i.7] ECC Report 190 (May 2013): "Compatibility between Short-Range Devices (SRD) and EESS (passive) in the 122 to 122,25 GHz band".

[i.8] "CONSORTIS (Concealed Objects Stand-Off Real-Time Imaging for Security)".

[i.9] Benjamin Winkel, Marta Bautista, Federico Di Vruno, Gyula I. G. Józsa :"pycraf GitHub project".

[i.10] Recommendation ITU-R RA.1513-2 (03/2015): "Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis".

[i.11] Recommendation ITU-R RA.769-2: "Protection criteria used for radio astronomical measurements", (Question ITU-R 145/7).

[i.12] Recommendation ITU-R RS.2017-0 (08/2012): "Performance and interference criteria for satellite passive remote sensing".

[i.13] Report Recommendation ITU-R SM.2450-0 (06/2019): "Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz".

[i.14] Recommendation ITU-R P.676-12 (08/2019): "Attenuation by atmospheric gases and related effects".

[i.15] Recommendation ITU-R P.2108-1 (09/2021): "Prediction of clutter loss".

[i.16] Recommendation ITU-R P.2109-1 (08/2019): "Prediction of building entry loss".

[i.17] ECC Report 334: "UWB radiodetermination applications in the frequency range 116-260 GHz".

[i.18] Recommendation ITU-R F.758-7 (11/2019): "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".

[i.19] Recommendation ITU-R F.699-8 (01/2018): "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz".

[i.20] Recommendation ITU-R F.1094-2: "Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources".

[i.21] Recommendation ITU-R F.1097-1 (05/2000): "Interference mitigation options to enhance compatibility between radar systems and digital radio-relay systems".

[i.22] Recommendation ITU-R F.1245-3 (01/2019): "Mathematical model of average and related radiation patterns for point-to-point fixed wireless system antennas for use in interference assessment in the frequency range from 1 GHz to 86 GHz".

[i.23] Recommendation ITU-R P.525-4 (08/2019): "Calculation of free-space attenuation".

[i.24] CRAF: "Radio Observatories in Europe (being updated)".

[i.25] Report Recommendation ITU-R RS.2431-0 (09/2018): "Technical and operational characteristics of EESS (passive) systems in the frequency range 275-450 GHz".

[i.26] Recommendation ITU-R P.452-16 (07/2015): "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0,1 GHz".

[i.27] ECC/DEC(22)03 (11/2022): "Technical characteristics, exemption from individual licensing and free circulation and use of specific radiodetermination applications in the frequency range 116-260 Hz".

[i.28] ETSI EN 305 550-1: "Short Range Devices (SRD) to be used in the 40 GHz to 260 GHz frequency range Harmonised Standard for access to radio spectrum Part 1: communication devices within 57 GHz to 64 GHz, 122 GHz to 123 GHz or 244 GHz to 246 GHz".

[i.29] ETSI EN 305 550-2: "Short Range Devices (SRD) to be used in the 40 GHz to 260 GHz frequency range Harmonised standard for access to radio spectrum Part 2: Radiodetermination for industrial applications (RDI & RDI-S) equipment operating within 116 GHz to 260 GHz".

[i.30] ETSI EN 305 550-3: "Short Range Devices (SRD) to be used in the 40 GHz to 260 GHz frequency range Harmonised Standard for access to radio spectrum Part 3: Radiodetermination for consumer applications within 57 GHz to 64 GHz, 122 GHz to 130 GHz, 134 GHz to 148,5 GHz or 244 GHz to 246 GHz".

[i.31] ETSI EN 305 550-4: "Short Range Devices (SRD) to be used in the 57 GHz to 64 GHz frequency range Harmonised Standard for access to radio spectrum Part 4: Radiodetermination devices at vehicles within 57 GHz to 64 GHz".

[i.32] ETSI EN 305 550-5: "Short Range Devices (SRD) to be used in the 40 GHz to 260 GHz frequency range Harmonised Standard for access to radio spectrum Part 5: Ultra Short Range Communication Device (USRCD) within 57 GHz to 64 GHz".

[i.33] ETSI EN 305 550-6: "Short Range Devices (SRD) using Ultra Wide Band technology (UWB) operating in the frequency range 40 GHz to 260 GHz; Harmonised standard for access to radio spectrum; Part 6: Tank Level and Level Probing Radar equipment operating in the frequency ranges 116 GHz to 148,5 GHz; 167 GHz to 182 GHz and 231,5 GHz to 250 GHz".

NOTE: This multi-part deliverable is not publicly available at the date of publication and may be unavailable for an extended period of time.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

f_L	lowest frequency of the operating frequency range
f_H	highest frequency of the operating frequency range
t_{meas}	active measurement time segment
T_{meas_cycle}	overall repetitive measurement cycle time (including possible idle time segments)
t_{pulse}	pulse duration in a pulsed system or the duration of an individual frequency step in an SFCW modulation scheme

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

APC	Adaptive Power Control
BEL	Building Entry Loss
BW	Band Width
CEPT	European Conference of Postal and Telecommunications Administrations
DC	Duty Cycle
DMR	Distance Measurement Radar
e.i.r.p.	equivalent isotropically radiated power
ECC	Electronic Communication Committee
EESS	Earth Exploration Satellite Service
EUT	Equipment Under Test
FMCW	Frequency Modulated Continuous Wave
FOV	Field Of View
FS	Fixed Service
FSL	Free Space Loss
FSS	Fixed Satelite Service
G	Gain

GB-PAS	Ground-Based Passive Atmospheric Service
HDPE	High Density Poly-Ethylene
HPBW	Half Power Beam Width
I/N	Interferer to Noise ratio
IC	Integrated Circuit
IFOV	Instantaneous Field Of View
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union - Radiocommunication Sector
LL	pase Locked Loop
LMS	Land Mobile Service
LPR	Level Probing Radar
MCL	Minimum Coupling Loss
MMW	MilliMetre Wave
MS	Mobile Service
MSS	Mobile Satellite-Service
N	receiver Noise power density
NF	Noise Figure
OFR	Operating Frequency Range
PE	Poly-Ethylene
PEEK	PolyEther Ether Ketone
PTFE	PolyTetraFluoroEthylene
PVC	PolyVinyl Chloride
RAS	Radio Astronomy Service
RDI	RadioDetermination systems for Industry automation
RDI-S	RadioDetermination systems for Industry automation in Shielded environments
RLS	Radio Location Service
RNS	Radio Navigation Service
RNSS	Radio Navigation Satellite Service
Rx	Receiver
SAR	Synthetic Aperture Radar
SFCW	Stepped Frequency Continuous Wave
SNR	Signal to Noise Ratio
SRD	Short Range Device
SRS	Space Research Service
TGUWB	Task Group Ultra-Wide Band
TLPR	Tank Level Probing Radar
Tx	Transmitter
USRCD	Ultra Short Range Communication Device
UWB	Ultra-Wide Band
VA	Apparent Power
VCO	Voltage Controlled Oscillator
WRC	World Radio Conference

4 Comments on the System Reference Document

4.1 Statements by ETSI Members

No statements or comments have been issued by ETSI members.

5 Presentation of system and technology

5.1 Use cases for future sensor systems

5.1.1 General

Microwaves travel at the speed of light, and this speed is essentially constant under a variety of different environmental conditions. This makes the use of microwaves a very robust measuring principle, which is preferred when high accuracy is required and environmental conditions, such as temperature, pressure, etc. may vary.

Some of the main advantages of microwave technology for all kinds of sensors are therefore:

- high measurement accuracy;
- high repeatability;
- robust measuring performance in a variety of environmental and process conditions;
- high reliability;
- minimum or even no maintenance requirements and wear as a result of no moving parts;
- easy installation;
- non-contact measuring principle, which provides a high independency of ambient conditions or process properties;
- superior long-term stability resulting from self-calibration mechanisms since devices always have stable internal references which are independent of temperature or humidity;
- efficient handling of many devices due to the support of different interfaces;
- the antenna or the radome is usually very robust against contamination with dust, dirt or other adverse environmental influences.

All these factors combined provide a technology that, over time, has proven to bring improvements in environmental protection, human safety, accident prevention and avoidance, as well as more efficient and sustainable use of natural resources and higher-quality of end-products in different manufacturing industries.

With the rise of globally connected devices, a tremendous increase of automation requirements is expected. More and more individualized products will be fabricated in high automated production lines, which contain lots of compact and flexible production units. These production units will contain sensors for both the production processes and for reconfiguration and change. Due to flexible and frequent changes in the process, residuals of prior products and cleaning substances should be detected, for example, with very high accuracy and resolution to maintain product quality and production efficiency.

The sensor systems for industrial automatization need to be small to be easily mounted on or built-in machines. They further should be equipped with small or even already chip-integrated antennas. The high bandwidth is advantageous to get the necessary resolution. The sensors should also be able to measure within short distances with very low transmit power. Short response times, which enable a high measurement rate and constant surveillance of the product in question, is also mandatory for such devices.

The mentioned measurement objectives are either not at all achievable or at most partly achievable with the established and available frequency ranges below and above 260 GHz.

5.1.2 RDI-S systems and applications

5.1.2.1 (Tank) level probing

There are still many measurement tasks which cannot be solved yet with the currently available sensor technology. This is especially the case where very short distances have to be measured, for example, in small vessels and containers, which are widely used in the pharmaceutical, cosmetics and food industries, but generally in shielded environments.

The blocking distance of such sensors should be as small as possible to enable distance measurements up to the edge of the antenna. In addition to that, the size of the whole measurement system should also be very small compared to the size of the tank. This is the case because bypass installations and nozzles will become smaller in small tanks, too. So, narrower beam widths and very compact antenna apertures will become crucial for using the Radar level measurement principle.

The above-mentioned requirements are still a big challenge for the existing (T)LPR sensors in the established frequency bands. With wider frequency bandwidths on higher transmit frequencies the mentioned goals are easier to achieve or can be achieved at all. This, in turn, enables new applications to be measured with microwave technology. Furthermore, the reliability of already existing distance measurement sensors can be improved in a whole slew of applications.

There is already a compact high frequency distance measurement sensor commercially available on the European market. This sensor operates in the 122 GHz to 123 GHz ISM band and features a measuring range from 0,3 m to 10 m. However, the available bandwidth of just 1 GHz in the ISM band is relatively small. Thus, the attainable range resolution and accuracy are actually poor and enable only measurements in standard applications.

Figure 1 shows an example where a TLPR sensor is operated in a very small mixing vessel in a pharmaceutical production process. The deployment of distance measurement radars for level measurement in such small containers is, up to now, very difficult unless impossible.

Measurement conditions:

Measurement range: up to 40 cm

Process temperature: +50…+150 °C

Process pressure: -1…6 bar

Measurement difficulties: changing product density, frequent cleaning cycles, small vessels, short measuring range, measurement through small openings and up to the antenna edge

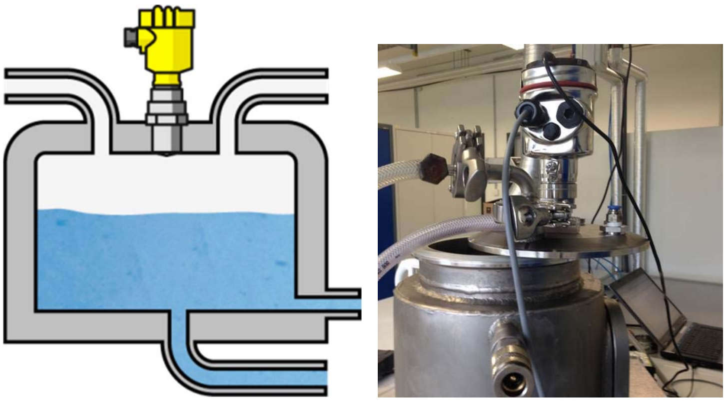


Figure 1: Level measurement in a small pharmaceutical mixing vessel

The intended use of DMR devices at higher transmit frequencies is definitely envisaged in closed containers. There, the benefit of a higher resolution, a smaller antenna or a shorter blocking distance can best be exploited.

- Application environment: industrial areas (indoor and outdoor).
- Aggregation effects: highly unlikely due to a low density of measuring sites, the increased FSL in the higher frequency bands and larger distances between individual sensors.

5.1.2.2 High precision distance measurements for linear rails or pneumatic/hydraulic cylinders

Within a pneumatic or hydraulic cylinder, the use of a Radar sensor for the determination of the piston position offers several advantages. The contactless measurement causes no wear, and the sensor can be included into the cylinder so that no additional mounting support is required in contrast to the outside-mounted sensor. Thus, it can also be used in harsh environmental conditions.

However, the severe multi-path propagation inside the cylinder limits the accuracy of the measurement since all propagation paths have similar lengths, resulting in similar distance information with a strong dispersion effect. Using a higher frequency, e.g. above 260 GHz, allows for a smaller antenna beam width and a focal point on the bottom of the piston. However, for very long cylinders, the multipath problem still exists even with high directive antennas and small beam widths. With sufficient bandwidth, the single paths can be resolved, and the delayed paths can be distinguished from the direct reflection at the bottom of the piston. This results in an improved accuracy of the piston position. The metallic enclosure ensures no harmful radiation leaves the shielded environment:

- Application environment: industrial areas, construction sites (indoor and outdoor).
- Aggregation effects: highly unlikely due to the metallic shielding of the cylinders.

5.1.2.3 Material parameter extraction for production goods

Many of today's goods are produced from raw materials. Rising material costs and increased awareness of the environmental influence of the goods and their production has led to an increased demand for higher production efficiency. This calls for continuous online and offline control and rising automation level of the production process.

RDI-S applications, in the sense of the present document, generally speaking, extract the S-parameters of materials in production. S parameters describe how radiated energy propagates through a multi-port network. Generalizing the network concept, any material composition in the way of the electromagnetic waves can be regarded as such a network. The S-parameters are complex numbers over frequency, as both the magnitude and phase of the incident signal are changed by the network. They can play an important part in improving production monitoring and control, delivering superior performance compared to readily available technologies while significantly reducing the overall total cost of ownership. Application examples for RDI-S systems can also be found in [i.17].

Current applications for RDI-S include (but are not limited to) the online measurement and control of plastic pipe and/or sheet production.

During the fabrication of plastic pipes or sheets in highly efficient facilities (see Figure 2), the thickness and other material properties of the pipes/sheets around the entire perimeter/area have to be determined rapidly during processing. This can be accomplished with high-resolution Radar sensors located after the nozzle of the machine.

The operating principle of thickness measurements of pipes/sheets using Radar is the reflection of the Radar signal at the two surfaces: the first reflection occurs at the outer surface and the second at the inner surface of the pipe. The minimum thickness that can be measured directly correlates with the available bandwidth of the Radar signal. The higher the bandwidth, the better is the resolution that can be obtained for the overall system.

Because one production line for plastic pipes can manufacture a wide range of pipe diameter/wall thickness combinations or a line for sheets of sheet thicknesses or widths and different materials, the Radar sensor used needs to be sufficiently small and adaptable to these tasks.

The small absolute bandwidth available at lower transmit frequencies limits the use of the Radar principle to pipes with high wall thicknesses only. Higher bandwidths, in turn, call for higher centre frequencies.

Wider operating frequency range Radar sensors have several advantages:

- a compact measurement system with the possibility of mounting many Radar sensor heads on the circumference around the pipe;
- a better accuracy of the thickness measurement;
- a smaller beam width to define exactly the local point of the measurement;
- less diffraction effects at the lens due to the large radiating aperture compared to the wavelength;

- a better range resolution so that pipes with small wall/layer thicknesses can be reliably measured.

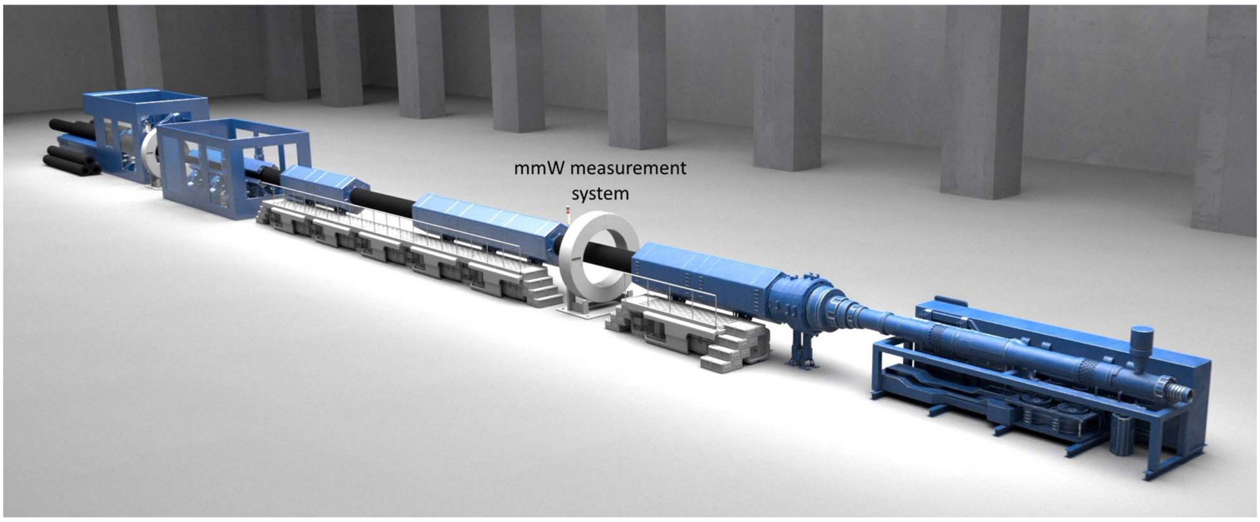


Figure 2: Extruder for plastic pipes with a shielded Radar thickness measurement system

The thickness measurement of plastic or composite parts is a classical short-range application with measurement distances up to 1 metre. This means that only a low-power Tx signal is required. However, for accurate measurements, a high range resolution and, therefore, a large bandwidth is required.

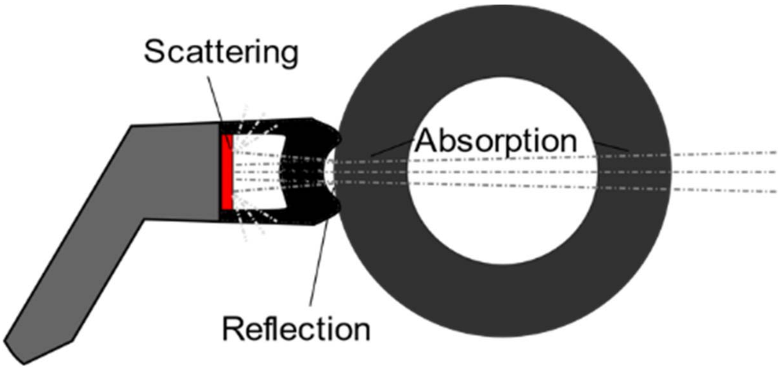


Figure 3: Portable pipe scanner

Figure 3 shows a portable pipe scanner in a 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. In order to measure plastic workpieces down to a thickness of only a millimetre or less, a bandwidth of 100 GHz or higher is required.

With increased bandwidths, new markets where this technology can applied emerge that currently rely on trial-and-error setup or inferior measurement solutions, leading to an overall higher scrap rate and increased start-up time, the latter being in contradiction to the overall manufacturing trend of shorter production lengths for each run.

Pipes and sheets are often made of PolyVinyl Chloride (PVC), PolyPropylene (PP) or PolyEthylene (PE), however other materials are of course possible as well (see Figure 4 and Figure 5). In order to meet the desired requirements for the intended application, pipes or sheets may be 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. Other than being visible, the colour component has no relevant influence on the physical properties of the pipes/sheets. The physical properties are influenced not only by the used materials, but also by the parameters of the production process and the construction of the pipe itself. E.g. there may be separate layers for pressure protection, to add resistance against chemicals and so on.

Figure 4: 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 pipes usually are used for medium transport of fluids or gases, however many other applications in many different industries exist as well (corrosion protection, lifeboat raw material, fish farms, sealings, etc.). With higher bandwidths than possible currently, even smaller hoses or tubes, such as cardiac catheters and dialysis tubes could be measured. These medical products are particularly relying on high precision and accuracy, as the specifications' tolerances are much tighter for these kinds of products compared to larger plastic pipes or sheets. Transceivers with bandwidths up to 200 GHz are already being developed. Measurement systems making use of this technology could be ready for market launch in two to three years.

Plastic sheets on the other hand are e.g. used for insulation, protection, cladding and/or sound insulation and are at the time of this writing almost without an alternative (see Figure 5).

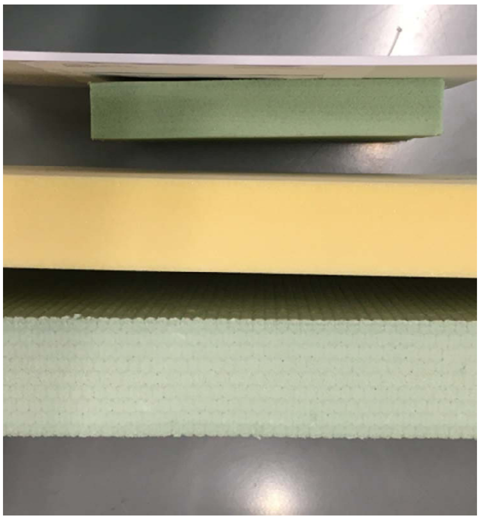


Figure 5: Plastic sheets, foamed and not foamed made from different materials

Higher bandwidths would enable measurements of thin foils or sheet layers - production processes that often today rely on manual or offline referential measurements to get good quality production up and running.

To give further insight into the start-up of a plastic extrusion process, the production of plastic pipes is described in more detail in the following section.

The plastic materials are generally fed as pellets or granules to an extruder, that heats the base material up to 200 °C (depending on the type of plastic used may be even higher) in several heating zones and through the mechanical energy from the feeding screw. Due to the high temperatures, the base material is plasticized 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 the first cooling section (see Figure 6).

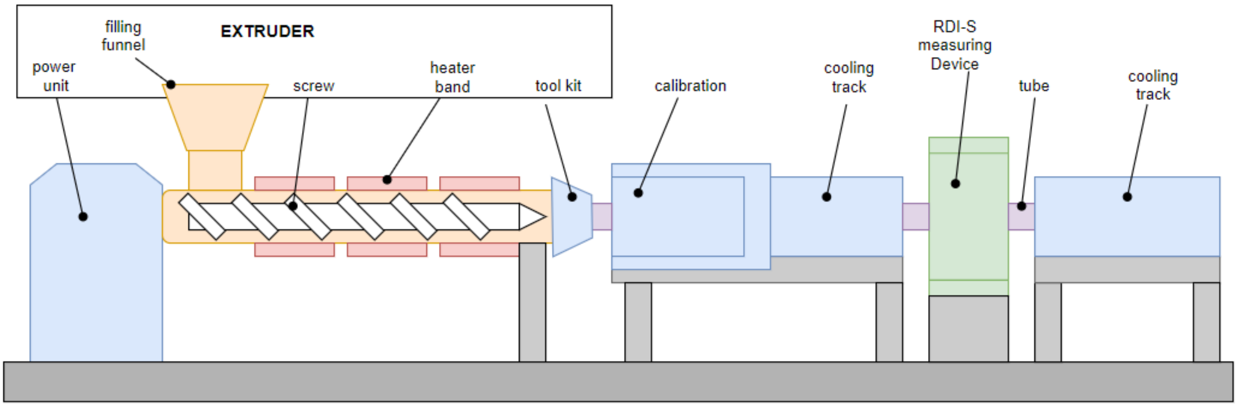


Figure 6: Cross section schematic of the first section of an extrusion line for pipe manufacturing

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 could be done, e.g. using a rotating radar sensor or several radar sensors distributed over the circumference. This would be the soonest 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 metre per minute for large pipes and a 12-metre cooling section, 20 minutes pass before reaching this point. This period may appear long, but considering that several corrections might be needed before specifications are met, it might even take up more than an hour. The overall time until good production quality is reached may take several hours. Typical extrusion lines require additional cooling sections to completely cool down the pipes. It is, therefore, possible that it takes more than an hour for the product to reach the cutting saw, where final dimensions can first be checked with a referential measurement, most of the time by hand. 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, 250 000 euros to 300 000 euros can be saved every year in material value only. Precise online measurement technology enables continuous monitoring of a product's quality as well as closed-loop control. Extrusion lines can be operated by less qualified personnel, or less personnel per line is needed consequently, at the same time, saved energy and time will be added to the overall savings.

Online monitoring of the extrusion process not only allows for layer measurement but also defect detection - crucial particularly in the gas pipe production process where 100 % quality control is mandatory:

- Application environment: production factories (indoor).
- Aggregation effects: may only occur inside a building if numerous sensors are in close proximity.

5.2 Publicly funded projects and available technologies

5.2.1 CONSORTIS project

CONSORTIS project "Concealed Objects Stand-Off Real-Time Imaging for Security" was supported by the European Commission through FP7-SECURITY - Specific Programme "Cooperation: Security" [i.8] from January 2014 to December 2017. Ten companies and research institutes from Finland, Sweden, Germany, the Netherlands and the UK were involved in the development of a demonstrator for stand-off real-time concealed object detection for future implementations of high throughput security screening for European mass-transit markets and infrastructure security.

6 Market information

6.1 Overview

The provision of new frequency bands above 260 GHz for applications like those mentioned in clause 5.1 goes along with the utilization of new semiconductor technologies. Currently, the available frequency regulation is not yet usable for most of the proposed applications. The manufacturers of sensor equipment face, therefore, the current situation where a missing regulation constrains the development of new sensors and the market entry of corresponding applications.

Therefore, an exact market analysis and a prediction of the future are difficult at this particular early time. Finally, the unit price of the Radar IC determines which applications can be covered at reasonable prices and thus the overall market potential. In the present document, some of the use-cases in clause 5.1 were treated in terms of cost and market volume. The overall number of items was back then estimated to reach a quantity of 150 000 to half a million per year depending on the production costs.

A distinct regulation for the mentioned applications in clause 5.1 enables the manufacturers to easily place their innovative products on the European market, which otherwise would be difficult, if not impossible and probably associated with a high risk for the individual company. Therefore, it is expected that the overall market of those applications will rapidly grow after a suitable frequency regulation exists.

6.2 Market Size for Radiodetermination systems for industry automation in shielded environments (RDI-S)

The applications are new and there is a significant market potential, but sales figures are at this early time difficult to predict. Similar sales figures are assumed in comparison to comparable figures from lower frequency ranges.

Table 1: Estimated sales figures and device densities of RDI-S devices in the band 260 GHz to 1 THz

Parameter	Value
Worldwide accumulated number of RDI-S devices in the field 5 years after launch	350 000
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	140 000
European Land Area	10 523 000 km²
Average density of RDI-S devices in Europe	0,0133 devices/km²

The accumulated numbers in Table 1 are based on the estimated market numbers of ECC Report 334 [i.17]. They are made up of the sum of TLPR and RDI-S devices, as both are EUT as described by the present document.

With this, the average density value in Table 1 is calculated for the worst-case scenario that all RDI-S devices use the full frequency range of 260 GHz to 1 000 GHz. With a bandwidth of 100 GHz, e.g. this density value will decrease to 0,00179 devices/km^2.

7 Technical information

7.1 Detailed technical description

7.1.1 Transmitter parameters

Table 2: Typical technical parameters of RDI-S devices for industry automation in shielded environments

Parameter	Value	Notes
Operating Frequency Range (OFR)	260 - 1 000 GHz	
Available modulation bandwidth	740 GHz	
Used modulation bandwidth	50 - 740 GHz	-10 dB bandwidth aligned somewhere in the OFR
Modulation scheme	FMCW or pulse	
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	10 dBm	With 100 % duty cycle and -5 dBm peak carrier power
Conducted mean power spectral density	-37 dBm/MHz	With 50 GHz modulation bandwidth and -5 dBm mean power
Maximum peak e.i.r.p.	55 dBm	
Maximum mean power spectral density (e.i.r.p.)	10 dBm/MHz	Calculated with 47 dBi antenna gain (worst-case)
Minimum unwanted emissions attenuation	10 dB	

The maximum peak power and the maximum mean power spectral density can effectively be measured in the direction of the main radiation of the antenna (main lobe direction) in a radiated test setup. These parameters can also be determined in a conducted test setup provided that the EUT exhibits a suitable antenna connector.

7.1.2 Antenna requirements

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.

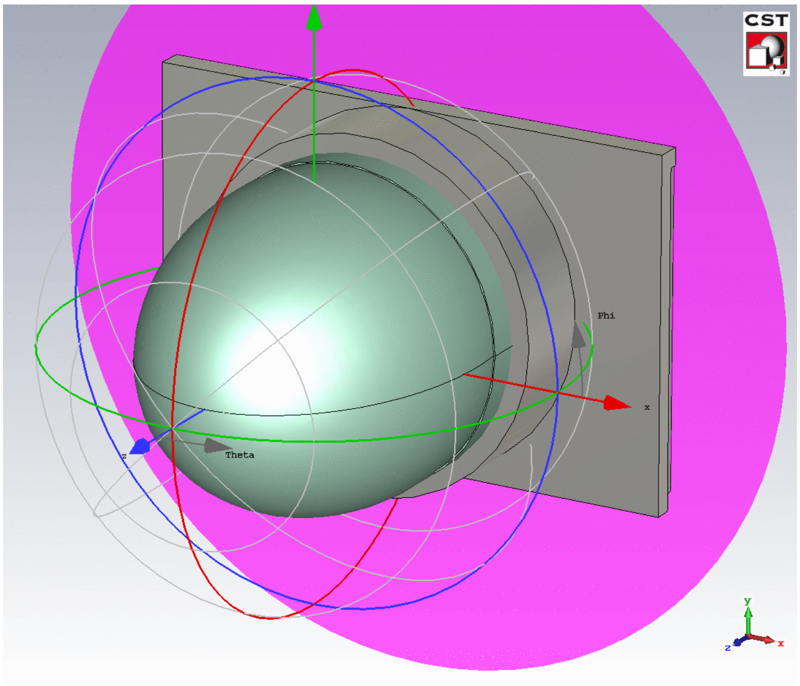


Figure 7: Typical high gain dielectric UWB antenna for RDI-S applications

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.

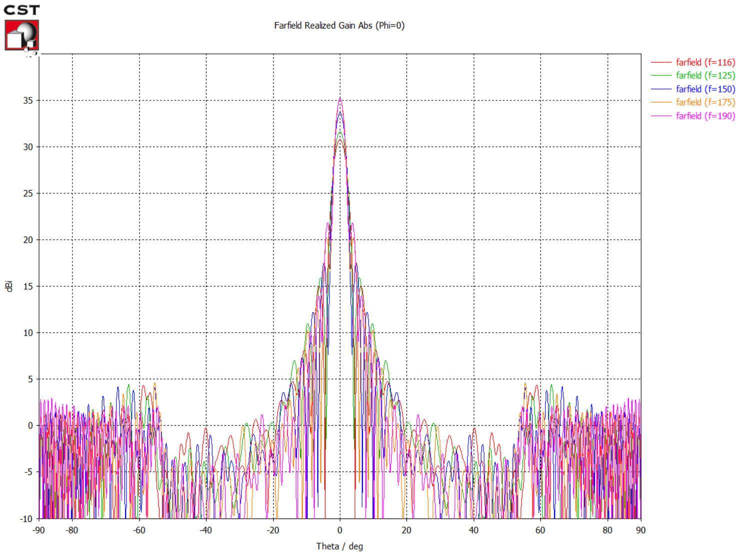


Figure 8: Antenna pattern in Φ=0° plane from 116 GHz to 190 GHz [i.17]

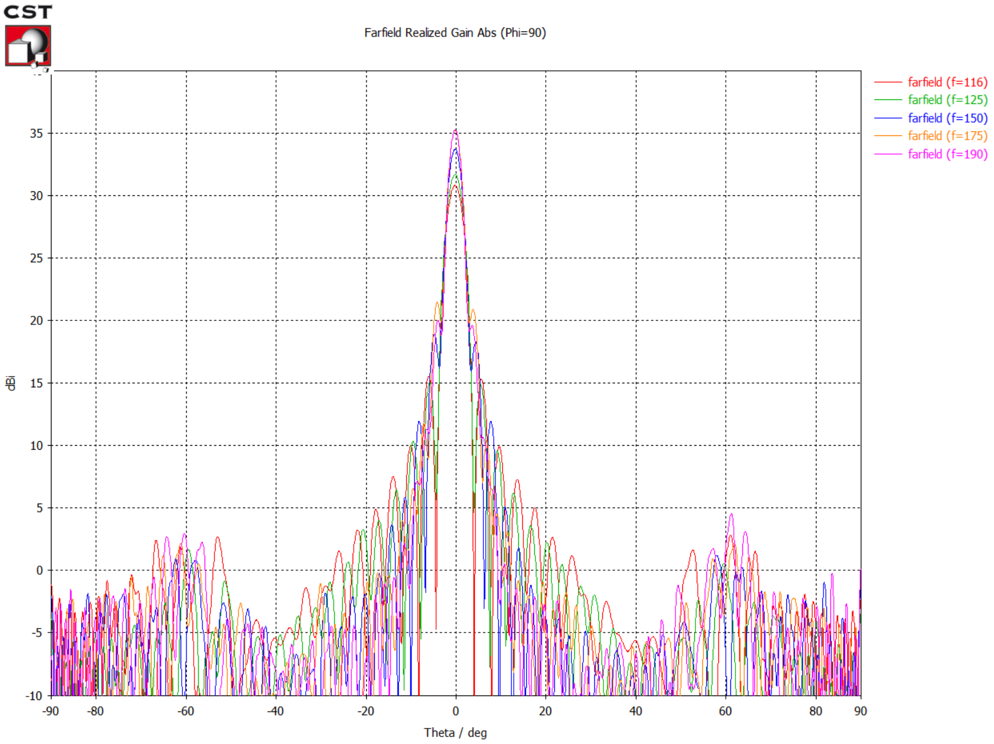


Figure 9: Antenna pattern in Φ=90° plane from 116 GHz to 190 GHz [i.17]

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 are shown. The antenna gain in the main beam direction varies from around 31 dBi to 36 dBi. Antenna patterns and levels should also be representative for frequencies beyond 260 GHz and scale accordingly with higher gain and similar patterns.

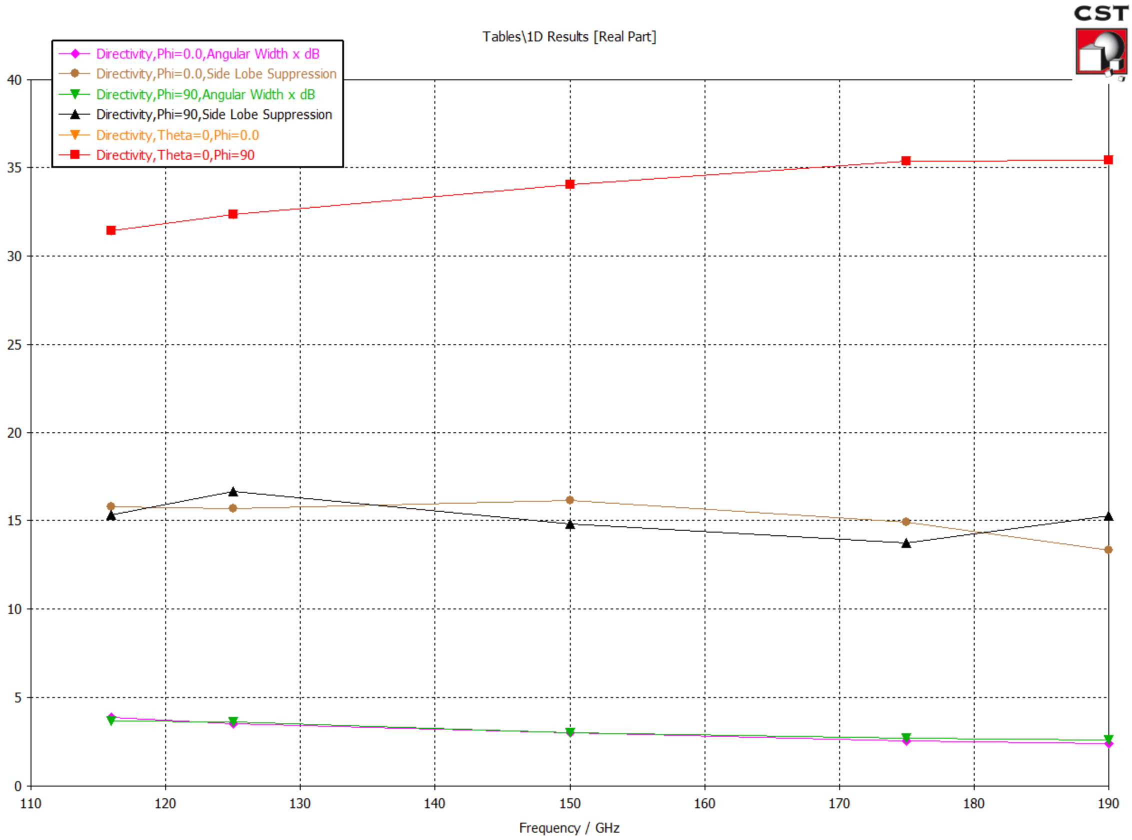


Figure 10: Directivity, HPBW and side lobe suppression for both planes from 116 GHz to 190 GHz taken from ERC Report 334 [i.17]

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 3: 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 beamwidth	between 2,3° and 3,9°	depends on individual antenna type/between open waveguide and high-gain antenna
Antenna gain	typically, 6 dBi to 47 dBi	
Antenna polarization	Linear or circular	

7.1.3 Mitigation techniques

7.1.3.1 General information

The mitigation techniques described below can be applied to all radiodetermination sensors in order to significantly reduce or to entirely avoid interference to other Radiocommunication services and applications in sharing environments. The application of mitigation techniques is mainly aimed at reducing the transmitter emissions within the operating frequency ranges. However, also the transmitter (unwanted) emissions outside the operating frequency ranges or the other emissions and even the receiver spurious emissions can be reduced by mitigation. Adequate mitigation techniques could be developed and determined in compatibility studies and/or simulations.

7.1.3.2 Adaptive power control (APC)

The APC is a mechanism to automatically regulate the transmitter output power depending on the conditions of the corresponding receive signal. That means if the signal power in the total receiver bandwidth is large enough and exceeds a certain SNR ratio which is needed for a reliable measurement, the transmit power can be reduced until the minimum SNR ratio is reached.

This procedure can help to reduce the probability of interference against other radio users sharing the same spectrum. However, there are limitations on the APC mechanism for some applications as described in ECC Report 139 [i.1], clause 3.2, page 20.

The APC feature is difficult and thus costly to implement in single chips or chipsets especially at higher frequencies. Thus, the APC functionality should not be made compulsory but can rather be an optional measure to reduce interference potential.

7.1.3.3 Duty cycle over signal repetition period (DC_T_{rep})

Duty cycle over signal repetition period (DC_T_{rep}) is defined as the ratio of the sum of all active measurement periods T_{on} (bursts, sweeps, scans) to the signal repetition period T_{rep}, i.e.

$$DC_{T_{rep}} = \frac{\sum T_{on}}{T_{rep}} \tag{1}$$

where:

- T_{on} is a measurement period when the transmitter of the EUT is active;
- T_{rep} is the overall measurement cycle of the EUT, including any off-times of the transmitter.

Duty cycle over signal repetition period is also sometimes referred to as "duty cycle resulting from user" in some sources dealing with UWB devices. This duty cycle usually applies to both, FMCW modulation as well as pulse modulation. A duty cycle of e.g. 1 % represents an interference mitigation of 20 dB.

EXAMPLE: A Frequency Modulated Continuous Wave Radar (FMCW) transmits two measurement periods T_{on} = 20 ms within an overall repetition period of T_{rep} = 100 ms.
The equivalent duty cycle over signal repetition period is 2 × 20 ms/100 ms = 40 %.
This is equivalent to a mitigation factor of -3,98 dB.

The duty cycle over signal repetition period (DC_T_{rep}), when implemented in the EUT as an exclusive mitigation technique, which is equivalent to a mean e.i.r.p. spectral density reduction of at least 20 dB.

If the implemented duty cycle over signal repetition period (DC_T_{rep}) mitigation technique does not achieve a reduction of the mean e.i.r.p. spectral density of at least 20 dB, it may be combined with other mitigation techniques as described in clause 7.1.3.

With this mitigation technique, definitions of the regulatory limit (mean power spectral density) and their measurement need to be defined precisely as to avoid double counting of this factor.

7.1.3.4 Duty cycle over measurement period (DC_T_{on})

The duty cycle over the measurement period (DC_T_{on}) is defined as the ratio of the sum of all the pulse durations t_{pulse} to the active measurement period T_{on}, i.e.

$$DC\_T_{on} = \frac{\Sigma\, t_{pulse}}{T_{on}} \qquad (2)$$

where:

- t_{pulse} is the duration of a single transmission during an active measurement period T_{on};
- T_{on} is the measurement period when the transmitter of the EUT is active.

Duty cycle over the measurement period (DC_T_{on}) is also sometimes referred to as "duty cycle resulting from modulation" in some sources dealing with UWB devices. This duty cycle usually applies to both, FMCW modulation as well as pulse modulation. A duty cycle of e.g. 1 % represents an interference mitigation of -20 dB.

EXAMPLE: A frequency-modulated continuous wave Radar (FMCW) transmits altogether ten individual ramps of t_{pulse} = 1 ms duration each within a total measurement period T_{on} = 20 ms.
The equivalent duty cycle over the measurement period is 10 × 1 ms/20 ms = 50 %.
This is equivalent to a mitigation factor of -3 dB.

With this mitigation technique, definitions of the regulatory limit (mean power spectral density) and their measurement need to be defined precisely as to avoid double counting of this factor.

7.1.3.5 Frequency domain mitigation

For the SFCW and FMCW modulation techniques, the instantaneous bandwidth of the transmit signal is at all times close to zero. Due to the fact that for both modulation techniques, FMCW and SFCW, the (narrowband) transmit signal is swept or switched over time, the whole operating frequency range is not at all times fully occupied during the sweep. That means that a potential victim receiver is affected by the transmit signal only in those time periods when the instantaneous transmit signal frequency strikes the victim receiver bandwidth.

EXAMPLE for FMCW modulation (with typical values):

- FMCW modulation:
  - FMCW Radars, which use single frequency ramps or short sequences of frequency ramps, usually apply ramp duration times between 100 µs and 2 ms. If a bandwidth of, for example, 50 GHz is swept within a ramp duration of 2 ms, a 250 MHz victim receiver is only affected within the time period of:

$$\frac{250\,MHz}{50\,GHz} \times 2\,ms = 10\,\mu s$$

  - This results also in a frequency domain mitigation factor of:

$$\frac{10\,\mu s}{2\,ms} = 0{,}5\,\%$$

or -23 dB.

With this mitigation technique, definitions of the regulatory limit (mean power for spectral density) and their measurement need to be defined precisely to avoid double counting of this factor.

7.1.4 Shielding effects

The wall shielding of a tank or a pipe made of metal, concrete or any other comparable attenuating material is an intrinsic mitigation factor for sensor installations in such environments. To ensure a proper shielding, sensor installations should comply with certain installation requirements. Examples for such installation requirements e.g. for Tank Level Probing Radar sensors (TLPR) can be found in ETSI EN 302 372 [i.2], Annex E and in ECC Report 334 [i.17].

Emissions caused, for example, by DMR installations in open-air environments can also be reduced by shielding due to special installation environments. For example, boundary fences of bulk good heaps made of metal or concrete or a floating roof tank inside a cylindrical metallic wall can serve, in this case, as additional shielding.

Another shielding effect is provided by the outer walls and other structures of the industrial building the device is deployed and used in since the victim receiver is always located outdoors. The propagation and shielding losses increase with higher frequencies. This could be considered as a big advantage for the higher frequency ranges with respect to possible harmful victim-receiver interference. The propagation through buildings is almost "line-of-sight" only. In ECC Report 190 [i.7], a shielding-loss value of > 60 dB is used for indoor/outdoor attenuation at 122 GHz.

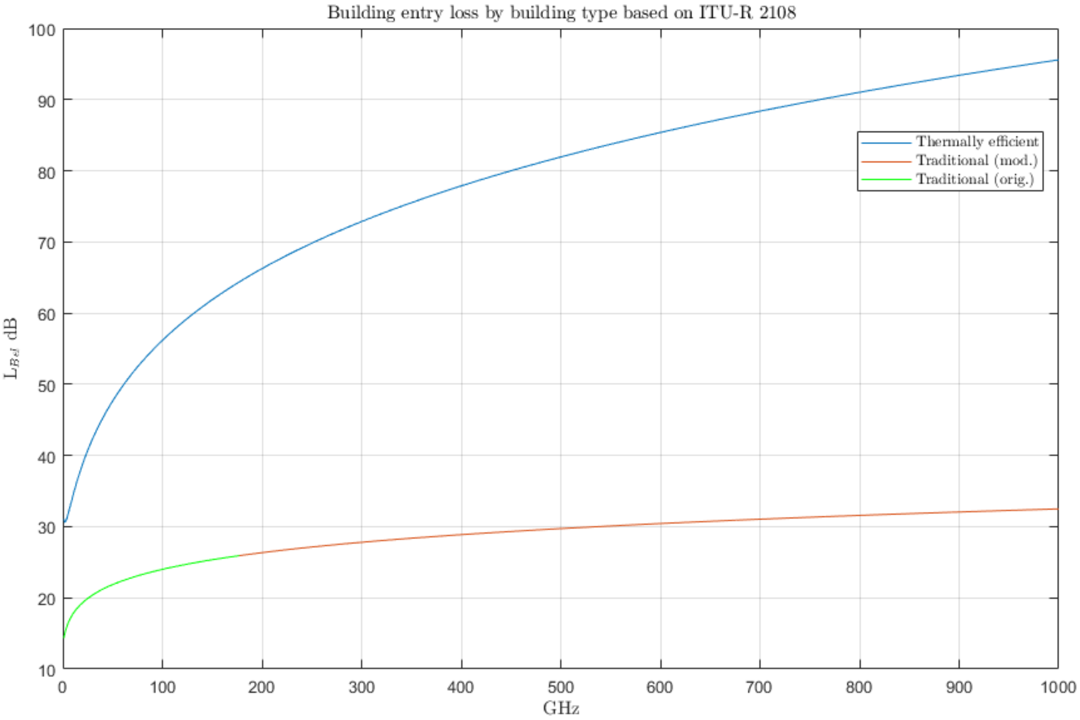


Figure 11: Median building entry loss as per Recommendation ITU-R P.2108-1 [i.15] at median value of the probability distribution

MCL calculations and extension of the ITU building loss model [i.16] for Building Entry Loss (BEL) were introduced by ESA-EUMETSAT at the studies done for the development of ECC Report 334 [i.17]. The original model is based on measurements up to 74 GHz. By changing the parameter *z*, which influences the distribution's standard deviation, the formula can be extended to render valid values up to 1 000 GHz. This could be used as a starting point for the calculation of building shielding losses, as at the time of this writing, there are no building entry loss measurements available in the frequency range from 260 GHz to 1 000 GHz. Figure 11 shows an according diagram where the thermally efficient BEL can be evaluated with the model up to 1 000 GHz (blue line in Figure 11) while the traditional model needs modification of one parameter concerning the model's standard deviation (red line in Figure 11), as the unmodified model only would deliver values up to 175 GHz (green line overlay in Figure 11).

Outside the building or shielded environment, clutter loss has to be taken into account where it applies. Recommendation ITU-R P.2108-1 [i.15] describes different models for clutter loss up to 100 GHz, depending on the interference scenario. Figure 12 to Figure 14 show the extrapolated model results for different interference scenarios of [i.15] up to 1 000 GHz

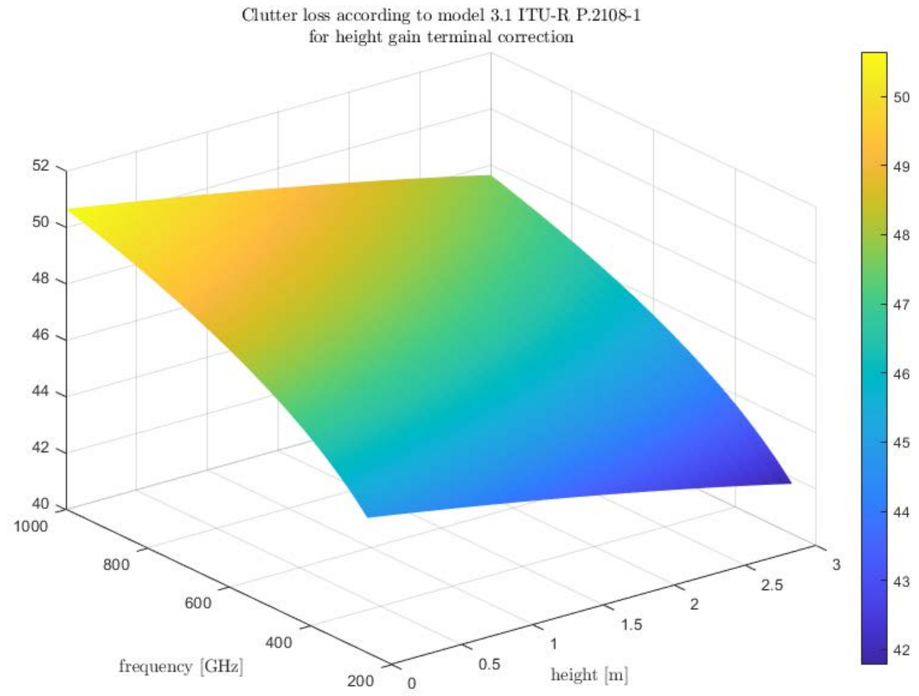


Figure 12: Median clutter loss in dB accounting for height gain terminal correction according to model 3.1 in Recommendation ITU-R P.2108-1 [i.15]

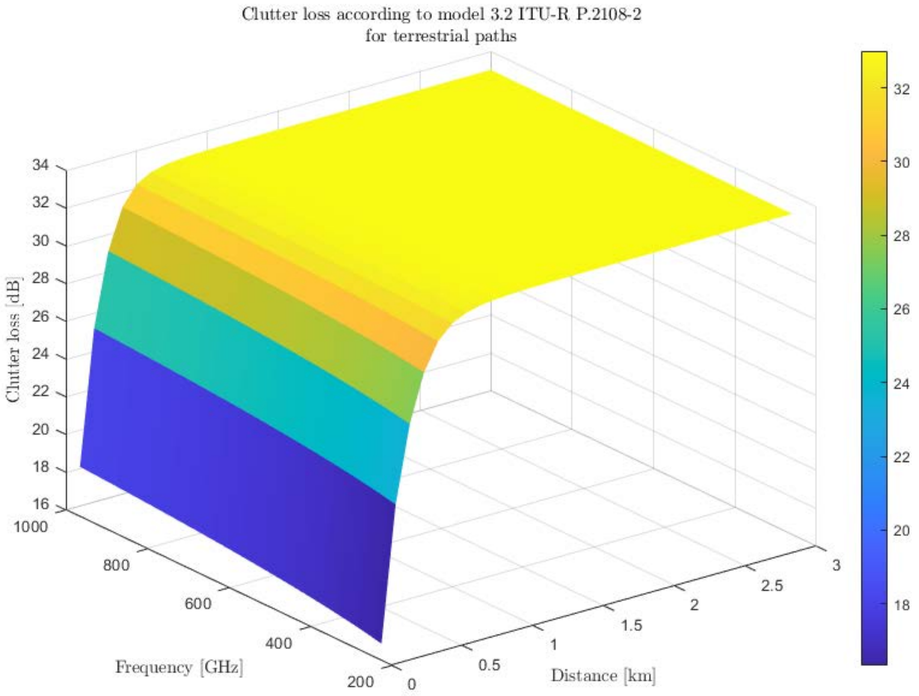


Figure 13: Median clutter loss in dB for terrestrial paths according to model 3.2 in Recommendation ITU-R P.2108-1 [i.15]

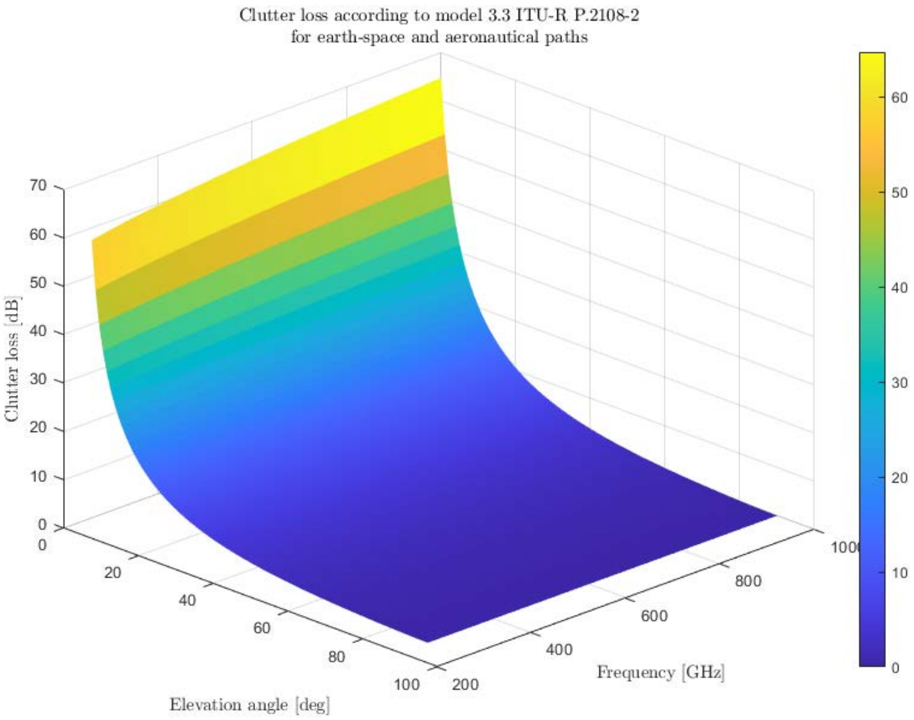


Figure 14: Median clutter loss in dB for earth-space and aeronautical paths according to model 3.3 in Recommendation ITU-R P.2108-1 [i.15]

7.1.5 Atmospheric attenuation

Harmful interference towards services such as Fixed service, Radio Astronomy service and Earth Exploration Satellite service should take the atmospheric attenuation into account as well, especially since the attenuation generally increases with the frequency. This principle has been applied in the radio astronomy sharing study in Report Recommendation ITU-R RA.2189-1 [i.5] and the interference criteria Recommendation ITU-R RS.2017-0 [i.12]. There is an ITU Recommendation in place, Recommendation ITU-R P.676-12 [i.14], that offers a general attenuation model for the attenuation of atmospheric gases and related effects. Figure 15 depicts the corresponding attenuation with respect to the model in [i.14] for winter mid-latitudes at different height levels for the IRAM 30 m radio telescope situated in the Sierra Nevada in Spain. Note that using the winter scenario leads to a decrease in attenuation and thus can be seen as a worst-case example for the atmospheric attenuation at this site.

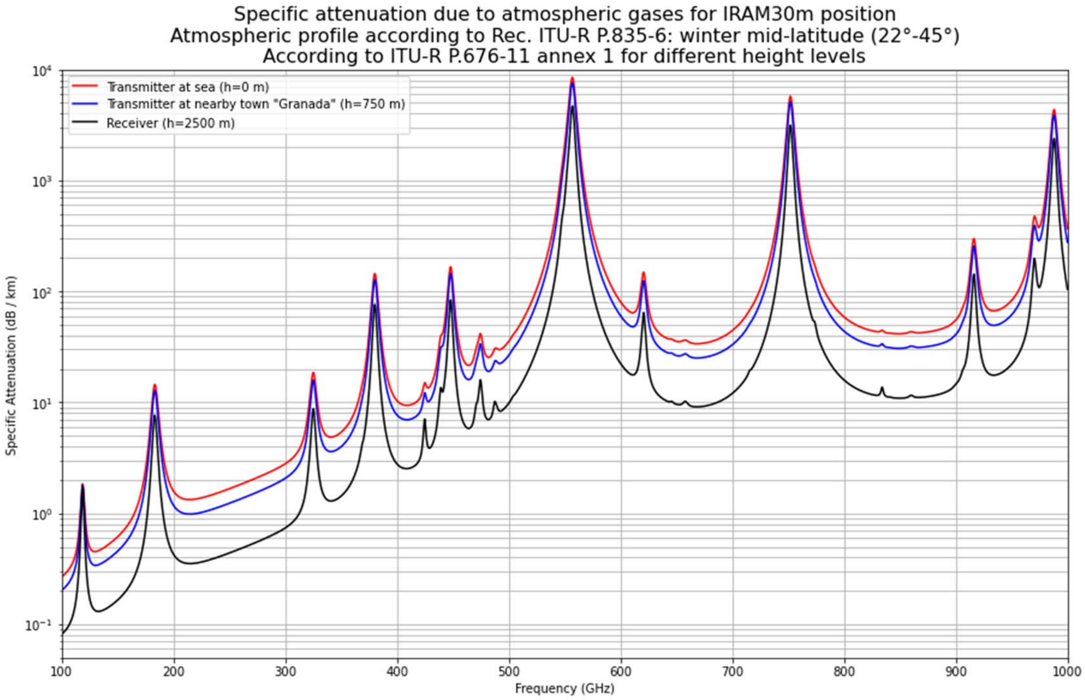


Figure 15: Atmospheric attenuation for winter conditions according to Recommendation ITU-R P.676-12 [i.14]

7.2 Status of technical parameters

7.2.1 Current ITU and European Common Allocations

According to the ITU Radio Regulations 2020 [i.7], the following allocations to radiocommunication services in the respective frequency range of 260 GHz to 1 THz are listed.

Table 4: From ITU Radio Regulations 2020 [i.7], Allocation to services 248 - 3 000 GHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
(…)		
252 - 265 GHz	FIXED MOBILE MOBILE-SATELLITE (Earth-to-space) RADIO ASTRONOMY RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.149 5.554	
265 - 275 GHz	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY 5.149 5.563A	
275 - 3 000 GHz	(Not allocated) 5.564A 5.565	

Footnotes:

5.149 In making assignments to stations of other services to which the bands:

13 360 - 13 410 kHz,
25 550 - 25 670 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,
1 330 - 1 400 MHz,
1 610,6 - 1 613,8 MHz,
1 660 - 1 670 MHz,
1 718,8 - 1 722,2 MHz,
2 655 - 2 690 MHz,
3 260 - 3 267 MHz,
3 332 - 3 339 MHz,
3 345,8 - 3 352,5 MHz,
4 825 - 4 835 MHz,
4 950 - 4 990 MHz,
4 990 - 5 000 MHz,
6 650 - 6 675,2 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)

5.554 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)

5.563A 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)

5.564A

For the operation of Fixed and Land Mobile service applications in frequency bands in the range 275 - 450 GHz:

- The frequency bands 275 - 296 GHz, 306 - 313 GHz, 318 - 333 GHz and 356 - 450 GHz are identified for use by administrations for the implementation of Land Mobile and Fixed Service applications, where no specific conditions are necessary to protect Earth Exploration-Satellite service (passive) applications.

- The frequency bands 296 - 306 GHz, 313 - 318 GHz and 333 - 356 GHz may only be used by Fixed and Land Mobile service applications when specific conditions to ensure the protection of Earth Exploration-Satellite service (passive) applications are determined in accordance with Resolution 731 (Rev.WRC-19).

In those portions of the frequency range 275 - 450 GHz where Radio Astronomy applications are used, specific conditions (e.g. minimum separation distances and/or avoidance angles) may be necessary to ensure protection of radio astronomy sites from land mobile and/or fixed service applications, on a case-by-case basis in accordance with Resolution 731 (Rev.WRC-19).

The use of the above-mentioned frequency bands by Land Mobile and Fixed Service applications does not preclude use by, and does not establish priority over, any other applications of radiocommunication services in the range of 275 - 450 GHz. (WRC-19).

5.565 The following frequency bands in the range 275 - 1 000 GHz are identified for use by administrations for passive service applications:

- Radio Astronomy service: 275 - 323 GHz, 327 - 371 GHz, 388 - 424 GHz, 426 - 442 GHz, 453 - 510 GHz, 623 - 711 GHz, 795 - 909 GHz and 926 - 945 GHz;
- Earth Exploration-Satellite service (passive) and Space Research service (passive): 275 - 286 GHz, 296 - 306 GHz, 313 - 356 GHz, 361 - 365 GHz, 369 - 392 GHz, 397 - 399 GHz, 409 - 411 GHz, 416 - 434 GHz, 439 - 467 GHz, 477 - 502 GHz, 523 - 527 GHz, 538 - 581 GHz, 611 - 630 GHz, 634 - 654 GHz, 657 - 692 GHz, 713 - 718 GHz, 729 - 733 GHz, 750 - 754 GHz, 771 - 776 GHz, 823 - 846 GHz, 850 - 854 GHz, 857 - 862 GHz, 866 - 882 GHz, 905 - 928 GHz, 951 - 956 GHz, 968 - 973 GHz and 985 - 990 GHz.

The use of the range 275 - 1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275 - 1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275 - 1 000 GHz frequency range. All frequencies in the range 1 000 - 3 000 GHz may be used by both active and passive services. (WRC-12)

7.2.2 Sharing and compatibility studies already available

The ECC Reports 139 and 190, mentioned in ECC Report 334 [i.17], could be used as a reference, albeit addressing a much lower frequency band than envisaged in the present document.

In ECC Report 139 [i.1] the impact of Level Probing Radars (LPR) using Ultra Wide Band technology in all currently available frequency bands for LPR (see clause A.1) on radiocommunication services has been investigated. The studies in the frequency ranges around 24 GHz and 80 GHz with the Fixed Service, EESS passive and the Radio Astronomy service could easily be used as reference for the higher frequency ranges requested in the present document.

ECC Report 190 [i.7] (Compatibility between SRD and EESS (passive) in the 122 - 122,25 GHz band) analysed the impact of SRDs on EESS (passive). It could be useful as a reference for potential studies against EESS (passive) in the bands 260 - 1 000 GHz.

In the ITU Radio Regulations 2020 [i.4], resolution 663 invites administrations to participate in studies regarding RLS and Wave Imaging applications in the frequency ranges 231,5 GHz to 275 GHz and 275 GHz to 700 GHz in time for WRC-27. Related studies have not been publicized so far.

In the ITU Radio Regulations 2020 [i.4], resolution 731 invites the ITU Radiocommunication Sector to carry out sharing and compatibility studies, namely "…to conduct studies to determine the specific conditions to be applied to the Land-Mobile and Fixed-Service applications to ensure the protection of EESS (passive) applications in the frequency bands 296 - 306 GHz, 313 - 318 GHz and 333 - 356 GHz; (…) to study means of avoiding adjacent-band interference from Space Service (downlinks) into Radio Astronomy frequency bands above 71 GHz". Also, related studies have not been publicized so far.

Additionally, there are some recommendations available from the ITU regarding the topics sharing and interference for Radio Astronomy and Remote Sensing systems.

Report Recommendation ITU-R RA.2189-1 [i.5] examines sharing between the Radio Astronomy service and active services in the frequency range 275 - 3 000 GHz.

Recommendation ITU-R RA.1513-2 [i.10] provides the result of the studies on the levels of data loss to Radio Astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the Radio Astronomy service on a primary basis.

Recommendation ITU-R RA.769-2 [i.11] deals with protection criteria used for Radio Astronomical measurements.

Recommendation ITU-R RS.2017-0 [i.12] examines performance and interference criteria for passive Satellite Remote Sensing.

Recommendation ITU-R F.758-7 [i.18] considers the criteria and parameters for sharing of Fixed Service with other radiocommunication services up to 86 GHz.

Recommendation ITU-R F.699-8 [i.19] contains reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz which can be used for sharing studies.

Recommendation ITU-R F.1094-2 [i.20] examines the maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources is derived.

Recommendation ITU-R F.1097-1 [i.21] covers options for mitigation that can help to make sharing between Fixed service and other applications possible.

Recommendation ITU-R F.1245-3 [i.22] contains mathematical models of average and related radiation patterns for point-to-point fixed wireless system antennas for use in interference assessment in the frequency range from 1 GHz to 86 GHz that can be used as a reference.

Report Recommendation ITU-R SM.2450-0 [i.13] contains sharing and compatibility studies between Land-Mobile, Fixed and Passive service applications in the frequency range 275 - 450 GHz.

These recommendations and reports can be a useful source to evaluate the overall compatibility.

The following well-known formula can be used to calculate the received power at the victim receiver:

$$P_R = P_T + G_T + G_R - PL - A - S \tag{1}$$

where:

P_R: the power at the output port of the receive antenna.

P_T: the power at the input port of the transmit antenna.

G_T: the gain of the transmit antenna in the direction of the receive antenna.

G_R: the gain of the receive antenna in the direction of the transmit antenna.

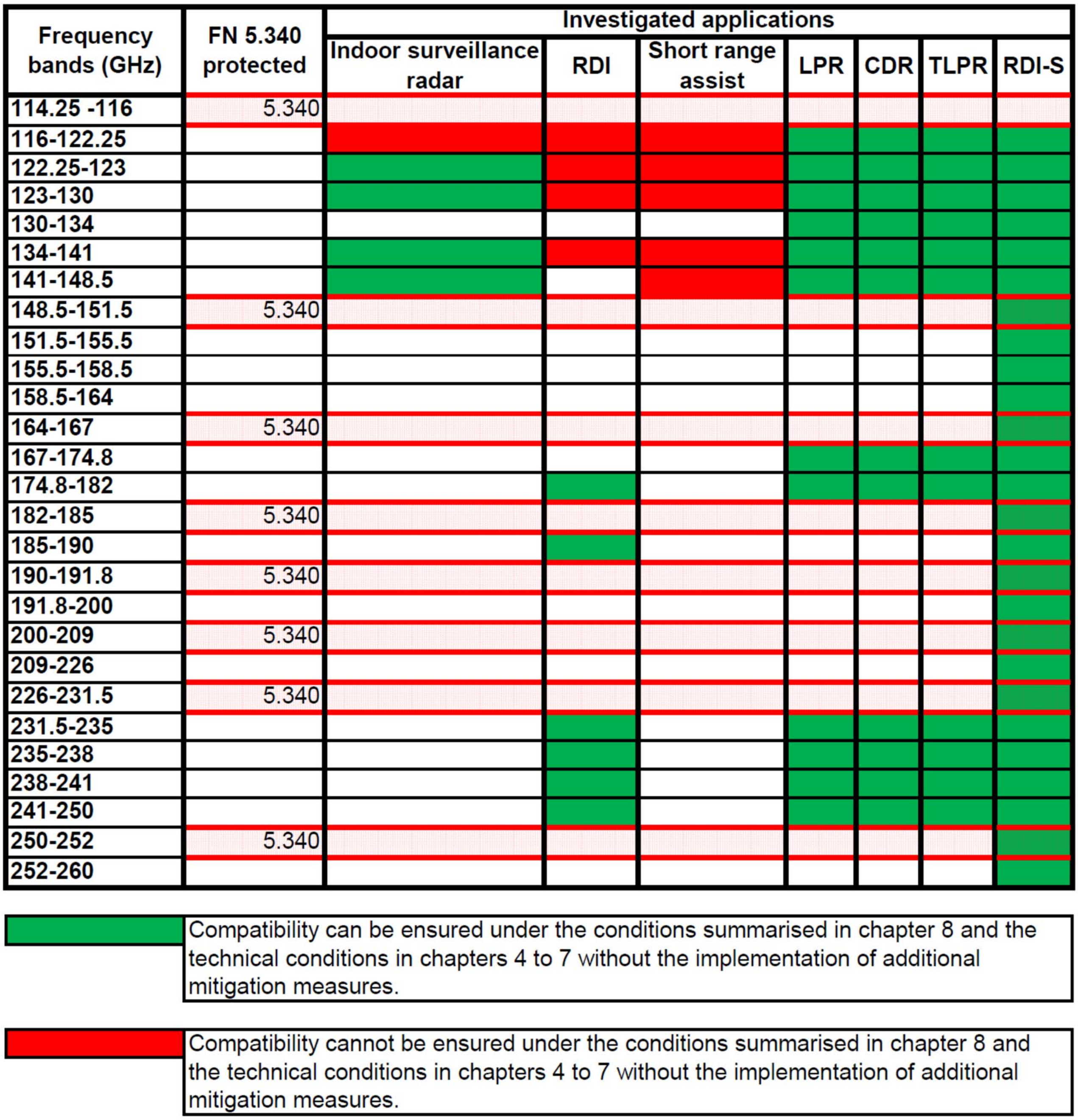
PL: the path loss between transmit and receive antennas due to geometric spreading and terrain blockage.

A: the additional loss factor due to atmospheric absorption.

S: application dependent shielding/losses or mitigation.

All terms are expressed in logarithmic units.

ECC Report 334 [i.17] has (amongst others) studied the interference scenarios and potential of RDI-S applications toward victim receivers of FS, EESS, RAS in the frequency range 116 - 260 MHz in detail. This can be used as a reference, since the interference scenarios as well as the characteristics of RDI-S systems remain the same. The general outcome of this ECC Report is summarized in the following Figure 16.



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 16: Compatibility situation between the investigated UWB-applications and all considered radiocommunication services in ECC Report 334 [i.17]

Figure 17 shows in addition some detailed results of studies with RDI-S from ECC Report 334 [i.17]. From this it can be seen that compatibility with RDI-S can be achieved with all concerned radiocommunication services in the band 116 - 260 GHz.

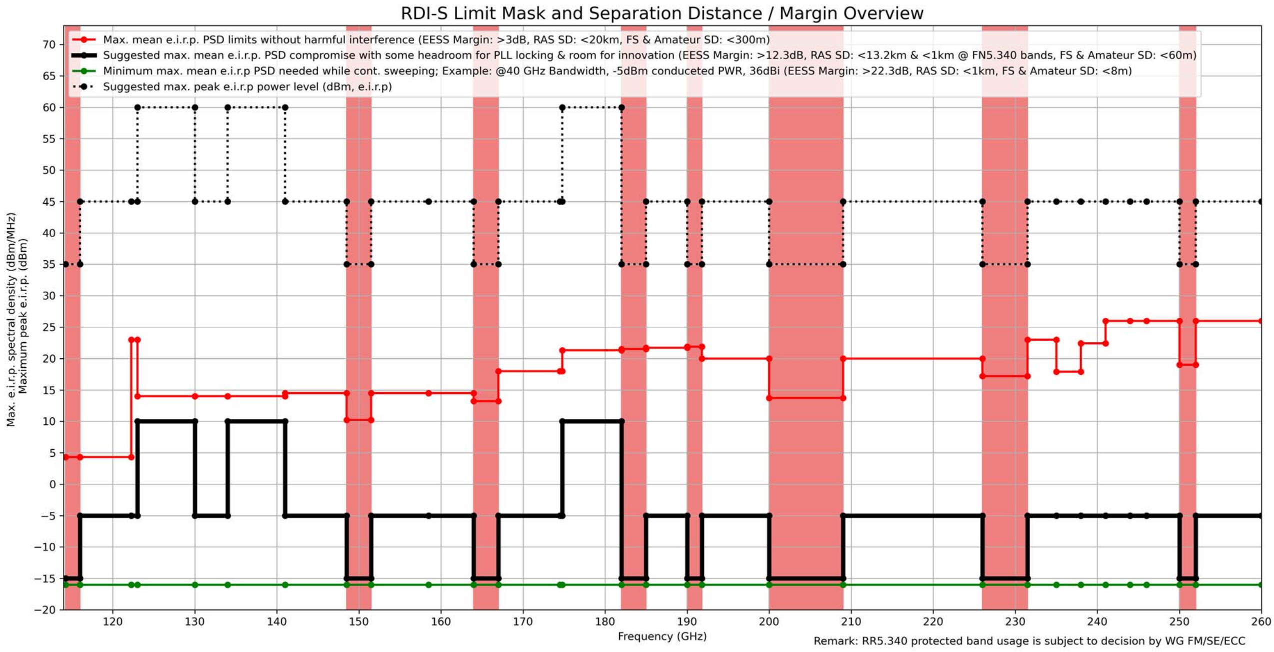


Figure 17: RDI-S limit masks from ECC report 334 [i.17] for reference

7.2.3 Sharing and compatibility issues still to be considered

The request in the present document is for a continuous frequency band in the frequency range 260 - 1 000 GHz as indicated in clause 8 below. Therefore, the compatibility situation depends on the selected frequency range. Below is a summary of all radiocommunication services and the frequency bands affected.

The following radiocommunication services need to be considered according to clause 7.2.1.

Earth exploration services (passive) and space research services (passive):

Most allocations are according to the following footnotes of the ITU Radio Regulations [i.4]:

Footnote 5.149:

In making assignments to stations of other services to which the bands: (…) 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).

Also, in the ITU Radio Regulations [i.4], footnote 5.565 lists the following frequency bands for (non-exclusive) use by EESS:

275 - 286 GHz, 296 - 306 GHz, 313 - 356 GHz, 361 - 365 GHz, 369 - 392 GHz, 397 - 399 GHz, 409 - 411 GHz, 416 - 434 GHz, 439 - 467 GHz, 477 - 502 GHz, 523 - 527 GHz, 538 - 581 GHz, 611 - 630 GHz, 634 - 654 GHz, 657 - 692 GHz, 713 - 718 GHz, 729 - 733 GHz, 750 - 754 GHz, 771 - 776 GHz, 823 - 846 GHz, 850 - 854 GHz, 857 - 862 GHz, 866 - 882 GHz, 905 - 928 GHz, 951 - 956 GHz, 968 - 973 GHz and 985 - 990 GHz.

Note that footnote 5.565 does not preclude use of the mentioned bands by active services provided the passive services are protected from harmful interference.

Radio astronomy services (passive):

According to [i.4], footnote 5.565, some frequency bands are identified for use with RAS.

In the allocation part, this is band 265 - 275 GHz, where RAS is allocated as a primary service.

Additionally, footnote 5.565 identifies the following bands for use by the administrations:

275 - 323 GHz, 327 - 371 GHz, 388 - 424 GHz, 426 - 442 GHz, 453 - 510 GHz, 623 - 711 GHz, 795 - 909 GHz and 926 - 945 GHz.

Again, footnote 5.565 does not preclude the use of the mentioned bands by active services provided the passive services are protected from harmful interference.

Fixed service and Mobile service:

ITU Radio Regulations [i.4] list (non-exclusive) use of the following bands from 252 - 275 GHz for fixed and mobile services. Footnote 5.564A states:

For the operation of fixed and land mobile service applications in frequency bands in the range 275 - 450 GHz:

The frequency bands 275 - 296 GHz, 306 - 313 GHz, 318 - 333 GHz and 356 - 450 GHz are identified for use by administrations for the implementation of land mobile and fixed service applications, where no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications.

The frequency bands 296 - 306 GHz, 313 - 318 GHz and 333 - 356 GHz may only be used by fixed and land mobile service applications when specific conditions to ensure the protection of Earth exploration-satellite service (passive) applications are determined in accordance with Resolution 731 (Rev.WRC-19).

In those portions of the frequency range 275 - 450 GHz where radio astronomy applications are used, specific conditions (e.g. minimum separation distances and/or avoidance angles) may be necessary to ensure protection of radio astronomy sites from land mobile and/or fixed service applications, on a case-by-case basis in accordance with Resolution 731 (Rev.WRC-19).

The use of the above-mentioned frequency bands by land mobile and fixed service applications does not preclude use by, and does not establish priority over, any other applications of radiocommunication services in the range of 275 - 450 GHz. (WRC-19)

Mobile-Satellite (Earth-to-space) service:

252 - 265 GHz band is allocated to Mobile-Satellite services on a primary basis [i.4].

Radionavigation / Radionavigation-Satellite service:

252 - 265 GHz band is allocated to Radionavigation services on a primary basis [i.4].

Fixed-Satellite service (Earth-to-space):

265 - 275 GHz band is allocated to Fixed-Satellite services (Earth-to-space) on a primary basis [i.4].

The frequency range above 275 GHz, the RR [i.4] does not have any allocation to any radiocommunication services yet. Studies on possible new entries for primary and secondary radiocommunication services in the frequency range 231,5 - 1 000 GHz are ongoing at ITU-R level since WRC'19 with Resolutions 663 and 731. A review of these is expected at WRC'23 and the finalization is expected at WRC'27. Further information is provided in Annex A.

Although the allocations in the ITU Radio Regulations 2020 [i.4] are not finalized yet above 275 GHz, a projection from the band 116 - 260 GHz could be done, since all Radiocommunication services are existing there. The studies from ECC Report 334 [i.17] are therefore an important source to forecast the compatibility situation in the band 260 - 1 000 GHz. These results can't be directly projected to the band above 260 GHz, but the following facts will facilitate the sharing above 260 GHz compared to the lower band:

- the victim receivers' sensitivity thresholds increase with frequency (see orange curve in Figure 18 for EESS passive and RAS);
- increasing attenuation (path loss, material attenuation, atmospheric attenuation) over frequency.

With the knowledge of the victim receiver's interference thresholds (exemplary shown for RA and EESS in Figure 18), a limit mask could be generated as in Figure 17.

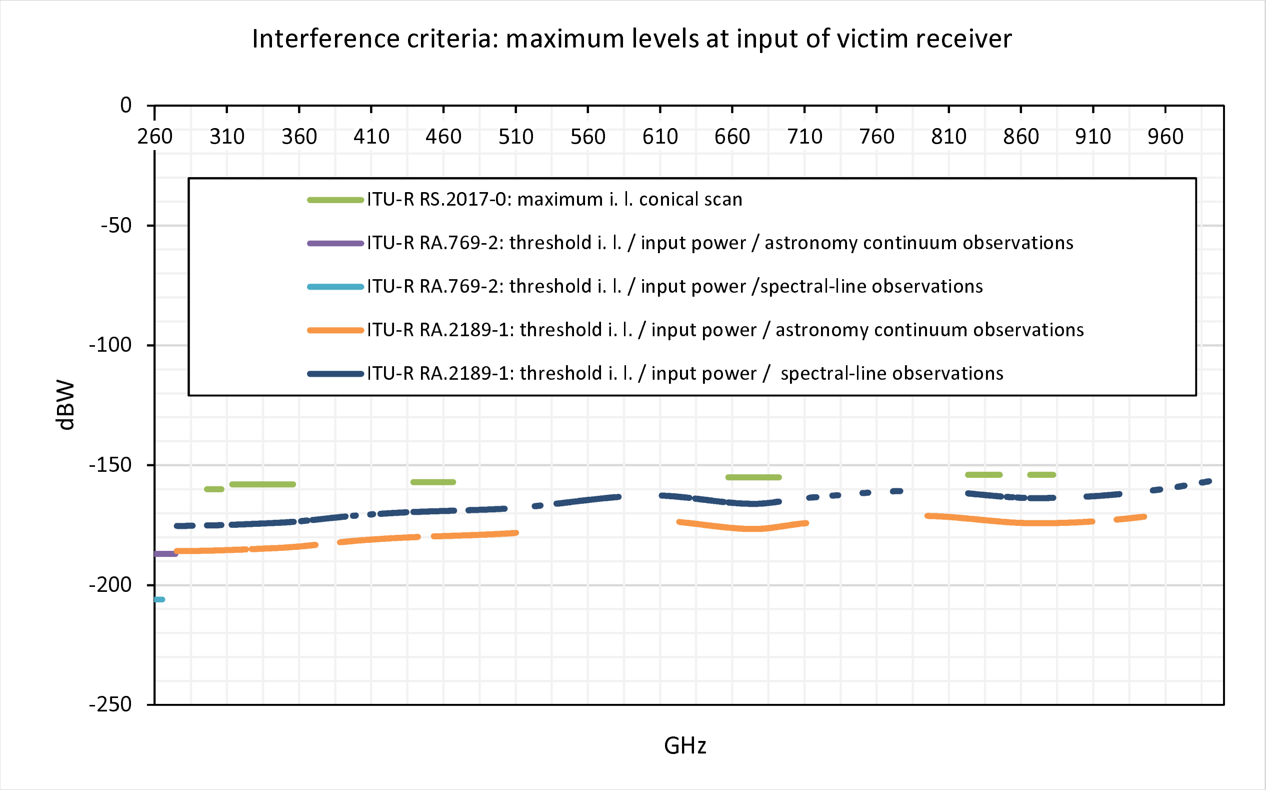


Figure 18: Harmful interference thresholds for satellite passive remote sensing and radio astronomy according to Recommendation ITU-R RS.2017-0 [i.12] and Report Recommendation ITU-R RA.2189-1 [i.5] in the frequency range from 260 GHz to 1 000 GHz

7.3 Information on relevant standards

Table 5: Information on relevant standards

Application	Frequency Ranges [GHz]	ETSI Standard	Status	Responsible ETSI TC ERM
mmW communication	40 - 260 GHz	Draft ETSI EN 305 550-1 [i.28]	drafting	TGUWB
mmW RDI & RDI-S	40 - 260 GHz	Draft ETSI EN 305 550-2 [i.29]	drafting	TGUWB
mmW consumer radiodetermination	40 - 260 GHz	Draft ETSI EN 305 550-3 [i.30]	drafting	TGUWB
60 GHz mmW VA	40 - 260 GHz	Draft ETSI EN 305 550-4 [i.31]	drafting	TGUWB
USRCD mmW communication	40 - 260 GHz	Draft ETSI EN 305 550-5 [i.32]	early draft	TGUWB
mmW LPR & TLPR	40 - 260 GHz	Draft ETSI EN 305 550-6 [i.33]	drafting	TGUWB

8 Radio spectrum request and justification

8.1 Radio Spectrum Request

Frequency usage conditions similar to those for RDI-S in Annex A2.6 of ECC/DEC(22)03 [i.27] are requested for the band 260 - 1 000 GHz. Only SRD radiodetermination systems for industry automation in shielded environments (RDI-S) are in the scope of the present document. Field of application for RDI-S systems, generally speaking, is the extraction of materials' S parameters. The installation of the RDI-S systems in this scope is indoor or inside shielded environments only. The installation is to be carried out in a way that avoids a direct line of sight of the main beam towards windows. Generally, main beam line of sight should not be towards weak points of the shielding. The RDI-S systems are intended for professional use only and not to be marketed to private end users. Accordingly, installation and maintenance are to be carried out by professionally trained personnel only. For slow-ramping FMCW (< 2,5 GHz/ms), notching of sensitive bands may be used (-10 dB). Generally, the required minimum operating bandwidth of RDI-S devices should be at least 50 GHz or 20 % of the start frequency (the start frequency is defined as the lowermost frequency of the band used by the application, so for a start frequency of 500 GHz a minimum operating bandwidth of 100 GHz is required). With a bandwidth less than this, the advantages of the new bands are questionable. Higher operating frequency ranges are envisaged with the availability of corresponding transceivers. Transceivers with larger bandwidths are currently being developed, making way for new areas of application to current devices that are already available in lower operating frequency ranges. The maximum operating bandwidth is the full range from 260 GHz to 1 000 GHz. An initial evaluation of sharing with FS, EESS and RAS can be found in clause 8.3.

Table 6 contains proposed limits for RDI-S applications (a limit mask similar to that in Table 10 of ECC/DEC(22)03 [i.27] is expected as an outcome of compatibility studies).

Table 6: Proposed maximum limits for RDI-S applications from 260 - 1 000 GHz

Parameter	Value	Notes
Maximum peak e.i.r.p.	56 dBm e.i.r.p.	In the direction of the main radiation
Maximum mean e.i.r.p. power spectral density	10 dBm/MHz e.i.r.p.	In the direction of the main radiation

8.2 Justification

The performance of RDI-S radars in terms of thickness measurements is proportional to the operational frequency range used (resolution ~1/BW). Larger operating frequency ranges equal higher resolution, allowing for larger savings in the production of goods or the applicability of this technology to a wider range of production goods.

A more detailed elaboration of why the use of RDI-S with the parameters supplied in the present document is justified can be found in Annex B. With respect to a continuous operating frequency range, it is noted, that notching out frequency bands is technically possible for 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. See also clause B.4.

The request is to allow the use of RDI-S only on a non-interference, non-protection basis, which means that any primary or secondary radio service has priority and any harmful interference should be avoided. Some preliminary studies on the impact of RDI-S on radiocommunication services are offered in clause 8.3.

ITU Radio Regulations 2020 [i.4] does not contain allocations beyond 275 GHz. There are no frequency bands where emissions are prohibited as there are in the frequency range addressed by ECC Report 334 [i.17] via footnote 5.340 of [i.4].

Some frequency bands in the operating frequency range addressed in the present document are "identified for use" by FS, EESS or RAS in the footnotes 5.564A and 5.565. However, this identification "does not preclude use of this range by, and does not establish priority over, any other applications of radiocommunication services in the range of 275 - 450 GHz" (footnote 5.564A explaining the use of LMS and FS) or "does not preclude use of this range by active services" (footnote 5.565 detailing the use of RAS and EESS in the range of 275 - 1 000 GHz). Both footnotes remind of the necessity of protection of the passive services from active services in the according frequency bands, though.

8.3 Compatibility with radiocommunication services

8.3.1 General

With the RDI-S system parameters defined in clause 8.1 and the justification pointed out in clause 8.2, the RDI-S applications described in the present document should be allowed to make use of the full spectrum from 260 GHz to 1 000 GHz, provided that harmful interference of victim receivers is safely avoided. Typical RDI-S applications are listed in clause 5.1 of the present document. According to their intended use, mitigation techniques, as described in clause 7.1.3 may need to be applied to ensure that threshold levels of interference at victim receivers are safely avoided.

For RDI-S devices, 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.

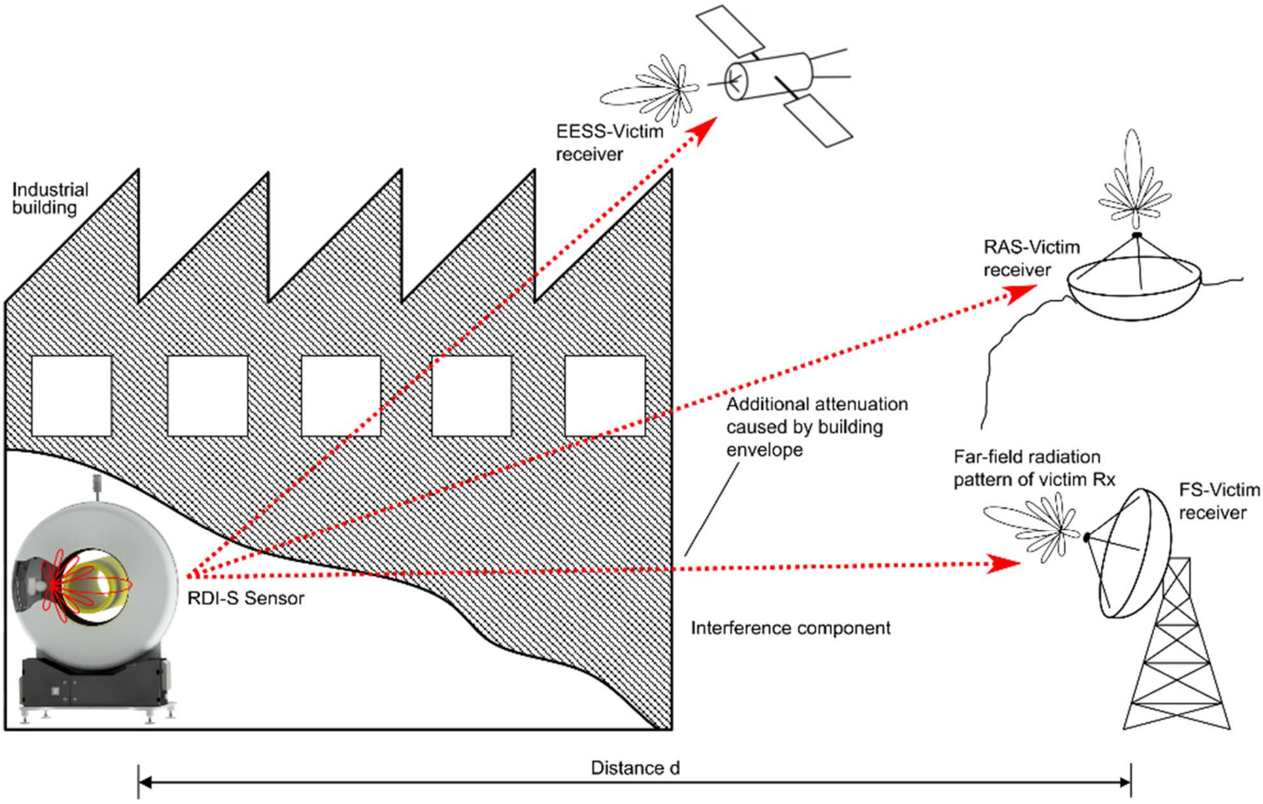


Figure 19: Interference scenario for RDI-S sensors

To evaluate the interference scenarios for RDI-S devices, the Building Entry Loss (BEL) has to be included to account for the building shielding effects. Figure 19 shows a typical interference scenario of RDI-S devices towards terrestrial and space-based victim services.

In Recommendation ITU-R P.2109-1 [i.16], a BEL model is described and building material measurements are provided to support the suggested BEL values. This model has been extrapolated and used in ECC Report 334 [i.17] for aggregate studies. The same model is used in [i.13] that studies sharing between land-mobile, fixed and passive services in the frequency range 275 - 450 GHz.

Taking into account the increased attenuation for higher frequencies and for easy alignment with ECC Report 334 [i.17], a simplified building entry lump sum loss of 60 dB could be used (higher attenuation due to higher centre frequencies with larger operating frequency ranges). This has been done before, e.g. in ECC Report 190 [i.7].

8.3.2 Fixed service (FS) links

For Fixed Service links, interference scenarios, as depicted in Figure 20 and Figure 21, can be used. These typical situations can occur in urban 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. 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).

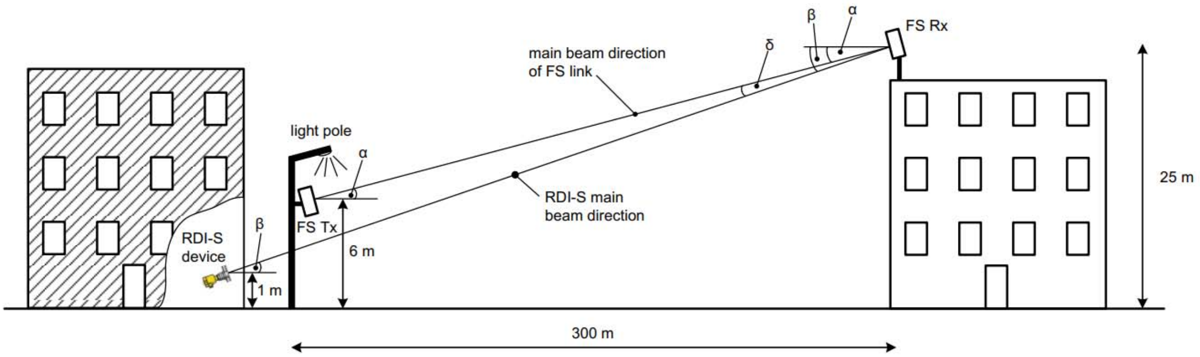


Figure 20: RDI-S scenario 1: Light pole connected to a building by means of an FS link - FS Rx on building

In the first scenario (see Figure 20) 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 should be 1 m. 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.

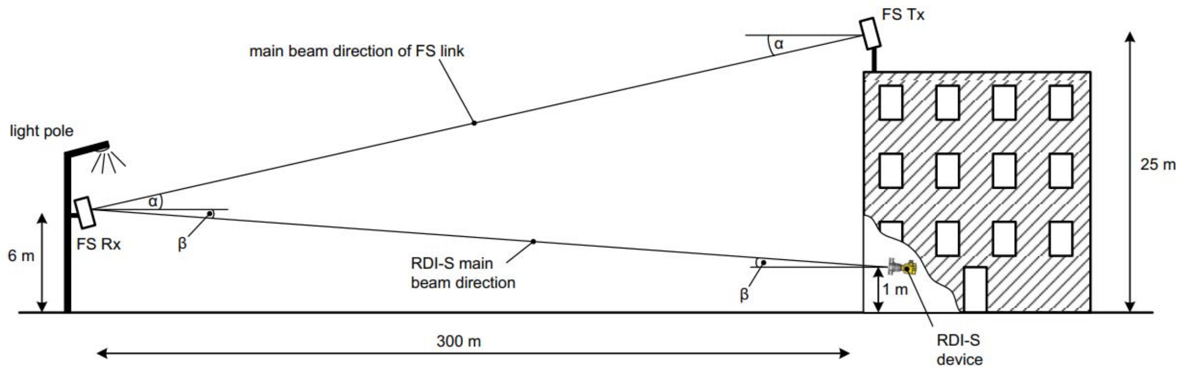


Figure 21: RDI-S scenario 2: Streetlamp post connected to a building by means of an FS link - FS Rx on building

In the second scenario (see Figure 21) 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.

Figure 22 shows the exemplary free space attenuation at a distance of one meter respectively two meters for the operating frequency range from 260 GHz to 1 000 GHz. The increase with frequency is easily visible.

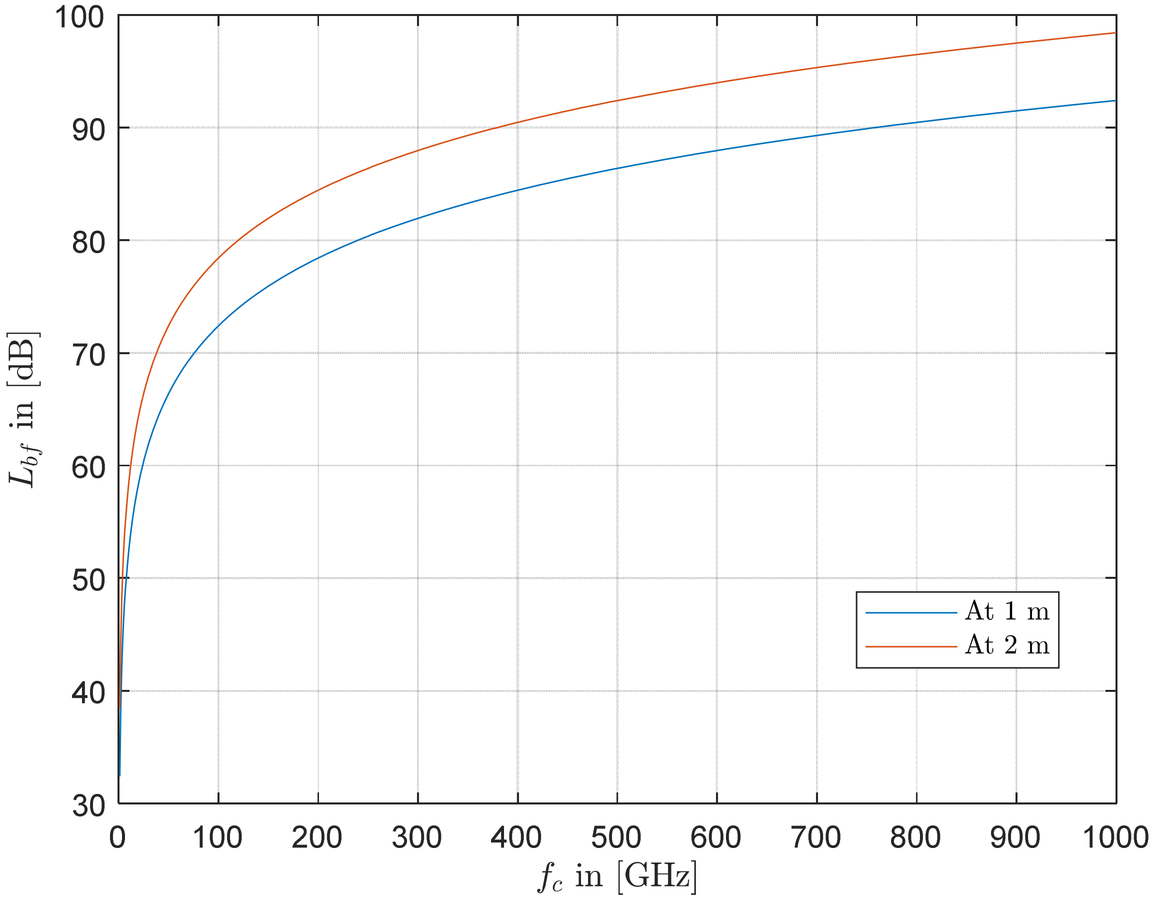


Figure 22: Free-space basic transmission loss L_{bf} between isotropic antennas for short distances from the interferer (Recommendation ITU-R P.525-4 [i.23], eq. (3))

To give an idea about the very low interference potential of RDI-S systems towards FS victim receivers, an exemplary MCL calculation for scenario 2 is carried out, which results in the highest separation distance for both scenarios and can thus be seen as a worst-case example. Not considering clutter loss, atmospheric attenuation and so on, the minimum separation distance using the free space loss model and BEL calculates to:

$$d = 10^{\frac{MCL-32.4-20\log f-BEL}{20}}$$

with:

- f/GHz as the centre frequency of the system (285,5 GHz in this case);
- MCL/dB as the minimum coupling loss = MCL= peak e.i.r.p + Antenna gain FS dBi - Interference threshold FS Imax;
- BEL = building entry loss dB.

The minimum separation distance calculation of an RDI-S system to protect FS using values from ECC Report 334 [i.17] is shown in Table 7. The BEL of 60 dB is taken from ECC Report 334 [i.17] (Annex 2), which is the minimum result of measurements at thin wall material samples below 260 GHz. The separation distance stays under these assumptions below four meters in the most susceptible band from 275 - 296 GHz.

Table 7: Exemplary calculation of minimum separation distance for compatibility of RDI-S with FS interference scenario according to Figure 20, values taken from [i.17]

Parameter	Value
Frequency f [GHz]	285,5
Maximum mean e.i.r.p. spectral density. [dBm/MHz]	10
Gain FS [dBi]	18
NF FS [dB]	16
N [dBm/MHz]	-98
I/N [dB]	-20
Imax [dBm/MHz]	-118
BEL [dB]	60
MCL [dB]	91,5
Minimum separation distance [m]	3,4

8.3.3 Earth exploration satellite services (EESS)

Figure 20 shows the interference scenario of RDI-S systems against victim satellite receivers. Table 8 shows the frequency bands identified for use by EESS in [i.4], footnote 5.565.

Table 8: Frequency bands for EESS in the ITU Radio Regulations 2020 [i.4], footnote 5.565

Frequency band
275 - 286 GHz
296 - 306 GHz
313 - 356 GHz
361 - 365 GHz
369 - 392 GHz
397 - 399 GHz
409 - 411 GHz
416 - 434 GHz
439 - 467 GHz
477 - 502 GHz
523 - 527 GHz
538 - 581 GHz
611 - 630 GHz
635 - 654 GHz
657 - 692 GHz
713 - 718 GHz
729 - 733 GHz
750 - 754 GHz
771 - 776 GHz
823 - 846 GHz
850 - 854 GHz
857 - 862 GHz
866 - 882 GHz
905 - 928 GHz
951 - 956 GHz
968 - 973 GHz
985 - 990 GHz

Detailed data for EESS systems can be taken from [i.25], where the satellite projects working in the frequency ranges identified for use by footnote 5.565 according to [i.4] are described in detail. Most of them are still in the planning stage, however, and thus not fully detailed regarding their system parameters. As a worst-case example, TWICE project's Nadir sensor with a centre frequency of 310 GHz is used for an exemplary MCL calculation here.

If the same MCL approach as in ECC Report 334 [i.17] is applied, the following margins towards harmful interference are reached:

- 70,8 dB for single entry studies (parameters used see Table 9).
- 83,4 dB for aggregate studies (parameters used see Table 10).

Table 9: Single entry MCL calculation for compatibility of RDI-S with TWICE Nadir satellite at 310 GHz

Single-entry study		**TWICE satellite**
Sensor type		Nadir
EESS:	Units	
Assumed centre frequency of EESS	GHz	310
Wavelength of EESS	m	0,000967
Antenna beamwidth	°	0,64
Antenna diameter	m	data not yet available
Reference bandwidth	MHz	200
Orbit altitude	km	400
Angle of incidence at Earth's surface (from zenith)	deg	53,0
Elevation angle at ground	deg	37,0
Off-nadir angle	deg	48,7
Slant path distance	km	633
EESS antenna gain	dBi	48
Size of EESS FOV on Earth's surface	km²	64,35
EESS interference criterion in the reference bandwidth (Recommendation ITU-R RS.2017-0 [i.12])	dBW	-160
Apportionment factor	dB	0
Radiodetermination system (interferer):		
Tx e.i.r.p. spectral density of interferer	dBm/MHz	-4
Tx e.i.r.p. spectral density of interferer	dBW/MHz	-34
Mitigation technique (e.g. duty cycle, adaptive power control)	dB	0
Free space loss between interferer and EESS	dB	198,3
Direct e.i.r.p. spectral density at the EESS antenna	dBW/MHz	-232,3
Atmospheric loss	dB	14
Polarization mismatch loss	dB	3,0
Indoor/outdoor attenuation (lump sum approach as in [i.17]	dB	60,0
Power spectral density at the EESS receiver in a 1 MHz bandwidth	dBW/MHz	-253,8
Corresponding power at the EESS receiver in the reference bandwidth for a single interferer	dBW	-230,8
Margin with reference to Recommendation ITU-R RS.2017-0 [i.12]	dB	70,8

Table 10: Aggregate MCL calculation for compatibility of RDI-S with TWICE Nadir satellite at 310 GHz

Aggregated interference study		**TWICE**
Sensor type		Nadir
EESS:	Units	
Assumed centre frequency of EESS	GHz	310,0
Wavelength of EESS	m	0,0
Reference bandwidth	MHz	200,0
Orbit altitude	km	400,0
Angle of incidence at Earth's surface (from zenith)	deg	53,0
Elevation angle at ground	deg	37,0
Off-nadir angle	deg	48,7
Slant path distance	km	633,2
EESS antenna gain	dBi	48,0
Size of EESS FOV on Earth's surface	km^2	48,0
EESS interference criterion in the reference bandwidth (Recommendation ITU-R RS.2017-0 [i.12])	dBW	-160,0
Apportionment factor	dB	0,0
Radiodetermination system (interferer):		
Tx e.i.r.p. of interferer	dBm	10,0
Bandwidth of interferer Tx signal	GHz	100,0
Tx e.i.r.p. spectral density of interferer	dBm/MHz	-40,0
Tx e.i.r.p. spectral density of interferer	dBW/MHz	-70,0
Mitigation technique (e.g. duty cycle, adaptive power control)	dB	0,0
Average gain of the interferer antenna in the direction of the victim EESS system	dBi	0,0
Free space loss between interferer and EESS	dB	198,3
Direct e.i.r.p. spectral density at the EESS antenna	dBW/MHz	-268,3
Atmospheric loss	dB	14,0
Polarization mismatch loss	dB	3,0
Indoor-outdoor attenuation according to extended model [i.16], 70 % traditional buildings, 30 % efficient buildings, approach used in [i.17]	dB	45,9
Power spectral density at the EESS receiver in a 1 MHz bandwidth	dBW/MHz	-283,2
Corresponding power at the EESS receiver in the reference bandwidth for a single interferer	dBW	-260,2
Number of RDI-S devices per square kilometre with uniform distribution over Europe	1/km^2	0,0133
Aggregate RDI-S device density (uniform distribution weighted with factor 75; according to contribution SE24(20)117)	1/km^2	1,0
Number of aggregate RDI-S devices in the IFOV and active in the reference BW of the satellite		48,0
Corresponding received power at the EESS in the reference bandwidth within the EESS's FOV	dBW	-243,4
Margin with reference to Recommendation ITU-R RS.2017-0 [i.12]	dB	83,4

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-S antenna gain of 0 dBi towards the victim receiver can therefore be assumed Table 10.

These values are reached with the market size numbers from clause 6 and a device density calculated using a uniform distribution over Europe and an industrial factor of 75 of 1 device/km^2, which was done the same way in ECC Report 334 [i.17]. Indoor-to-outdoor attenuation was evaluated with a simplified lump sum of 60 dB as suggested. No apportionment factor was used, but neither was clutter loss considered nor the fact that the RDI-S systems are generally not making use of the full frequency range from 260 GHz to 1 000 GHz. For higher frequencies, the margins increase overall, especially with respect to the atmospheric attenuation. For another satellite ICI 5,6,7 at 325,15 GHz centre frequency [i.25], e.g. the single-entry margin results in a value of 181,3 dB and that for aggregate studies to 185,8 dB.

8.3.4 Radio Astronomy services (RAS)

In Figure 20, the scenario of interference towards of an RDI-S system towards a radio astronomy device is depicted. Table 11 lists the frequency bands identified for use by RAS in [i.4].

Table 11: Frequency bands for RAS in the ITU RR 2020 [i.4], footnote 5.565

Frequency band
275 - 323 GHz
327 - 371 GHz
388 - 424 GHz
426 - 442 GHz
453 - 510 GHz
623 - 711 GHz
795 - 909 GHz
926 - 945 GHz

As far as radio telescopes in the CEPT region are concerned, there are two sites that make use of the two lowermost bands listed in Table 4.

The first is the IRAM NOEMA radio telescope situated in the French Alps. Its currently highest frequency band in use goes from 260 GHz up to 373 GHz (one receiver observing the frequency range from 200 - 276 GHz and one that from 275 - 373 GHz).

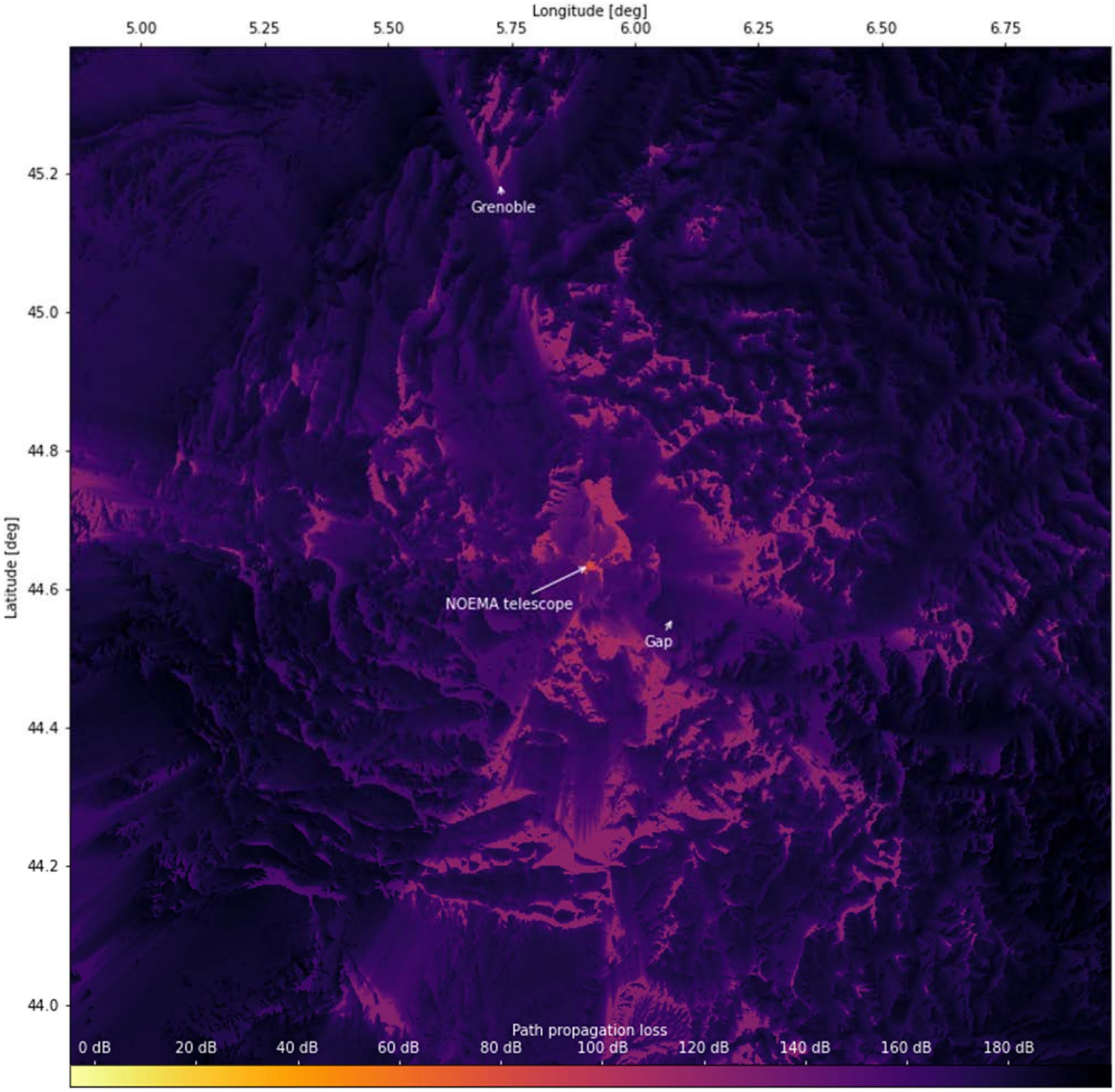


Figure 23: Path propagation loss for NOEMA radio telescope

Figure 23 shows the path propagation loss for the NOEMA radio telescope site in the French Alps according to [i.26], using the CRAF-supplied scripts [i.9]. The nearest village of Gap and the town of Grenoble are included for reference purposes. Clutter losses are not taken into account. The IRAM 30 m radio telescope in Spain makes use of the same frequency ranges (one receiver observing the frequency range from 220 - 280 GHz and one from 277 - 375 GHz).

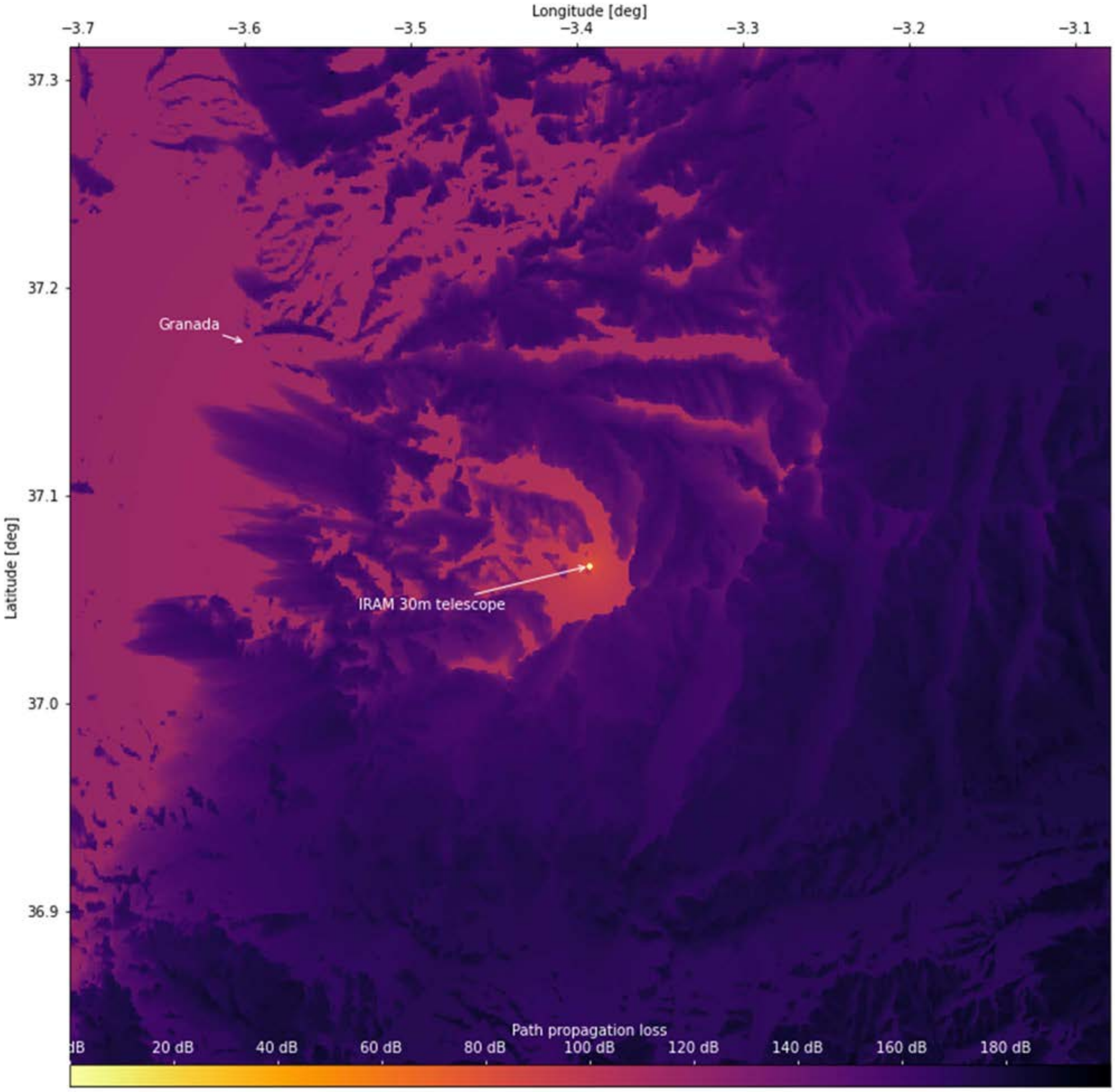


Figure 24: Path propagation losses due to terrain for IRAM 30 m telescope in the Sierra Nevada

Figure 24 shows the path propagation path losses according to [i.26] for the IRAM 30 m telescope situated in the Sierra Nevada using [i.9]. The town of Granada is also shown for reference purposes. Clutter losses are not considered.

No other radio telescope in the CEPT region listed in [i.24] by CRAF makes use of frequencies beyond 116 GHz.

Using the same approach for MCL calculations as in ECC Report 334 [i.17], taking into account only free space loss from Recommendation ITU-R P.525-4 [i.23], equation (3) and disregarding clutter, atmospheric attenuation and so on, the minimum separation distances for RDI-S systems (according to the values from Table 8) from these two sites calculate to a worst case of 1,2 km for continuum observation with an assumed centre frequency of 270 GHz. The value for the minimum separation distance decreases with increasing frequency and can be viewed as a worst-case example for protection requirements regarding RA service. As for the aggregated interference scenario, the same holds true for RA: RDI-S devices can be almost arbitrarily aligned in their measurement scenario, an average RDI-S antenna gain of 0 dBi towards the victim receiver can therefore be assumed.

9 Regulations

9.1 Current regulations

Currently, there are no regulations with respect to Short Range Devices in the frequency range that is the subject of the present document.

9.2 Proposed regulation

This new request for RDI-S in the frequency range from 260 GHz to 1 000 GHz is an extension to the existing regulation for RDI-S in ECC/DEC(22)03 [i.27], Annex A2.6, and thus a similar regulation is expected. The key points of such a new regulation are outlined in clause 8.1.

The use of the RDI-S applications should be based on article 4.4 of the ITU Radio Regulations [i.4], which means that the use is subject to no harmful interference being caused to any radiocommunication service, and that no claim may be made for the protection against harmful interference originating from radiocommunication services.

Annex A:
Relation to existing spectrum regulation

At present, there are no international allocations for radiocommunication service above 275 GHz in the ITU Radio Regulations (RR's) 2020 [i.4]. However, footnote No. **5.565** does make identifications for radio astronomy, earth exploration-satellite (passive) and space research (passive) services. Recent advances in microwave technology make possible the use of this spectrum by active services for communications and related uses. Consistent with footnote No. **5.565**, frequencies for fixed and land mobile use could be utilized above 275 GHz, provided that "all practicable steps" are taken to protect passive services.

The frequency band 275 - 323 GHz is identified for radio astronomy service applications, and the frequency bands 275 - 286 GHz, 296 - 306 GHz and 313 - 356 GHz for Earth exploration-satellite service (passive) and space research service (passive) applications. In the frequency range below 275 GHz, the band 265 - 275 GHz is allocated to FS, FSS (Earth-to-space), MS and RAS, where No. 5.149 applies [i.3].

No. 5.565 of the ITU Radio Regulations 2020 [i.4] was amended to identify frequency bands for use by administrations for passive service applications, such as radio astronomy service, earth exploration-satellite service (passive) and space research service (passive) at WRC-12. Footnote No. 5.565 of [i.4] is shown below:

5.565 The following frequency bands in the range 275 - 1 000 GHz are identified for use by administrations for passive service applications:

- radio astronomy service: 275 - 323 GHz, 327 - 371 GHz, 388 - 424 GHz, 426 - 442 GHz, 453 510 GHz, 623 - 711 GHz, 795 - 909 GHz and 926 - 945 GHz;
- Earth exploration-satellite service (passive) and space research service (passive): 275 - 286 GHz, 296 - 306 GHz, 313 - 356 GHz, 361 - 365 GHz, 369 - 392 GHz, 397 - 399 GHz, 409 - 411 GHz, 416 - 434 GHz, 439 - 467 GHz, 477 - 502 GHz, 523 - 527 GHz, 538 - 581 GHz, 611 - 630 GHz, 634 - 654 GHz, 657 - 692 GHz, 713 - 718 GHz, 729 - 733 GHz, 750 - 754 GHz, 771 - 776 GHz, 823 - 846 GHz, 850 - 854 GHz, 857 - 862 GHz, 866 - 882 GHz, 905 - 928 GHz, 951 - 956 GHz, 968 - 973 GHz and 985 - 990 GHz.

The use of the range 275 - 1 000 GHz by the passive services does not preclude the use of this range by active services. Administrations wishing to make frequencies in the 275 - 1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275 - 1 000 GHz frequency range.

All frequencies in the range 1 000 - 3 000 GHz may be used by both active and passive services. (WRC-12).

Figure A.1 to Figure A.4 below provide the current allocations according to the ITU Radio Regulations 2020 [i.4] from 260 GHz to 1 000 GHz divided into bands 260 - 275 GHz, 275 - 455 GHz and 450 - 1 000 GHz).

Abbreviations used in the following figures are:

MSS	Mobile-Satellite Service
RNSS	RadioNavigation-Satellite Service
RAS	Radio Astronomy Service
EESS	Earth Exploration Satellite Service
SRS	Space Research Service
FS	Fixed Service
MS	Mobile Service
RNS	RadioNavigation Service
GB-PAS	Ground-Based Passive Atmospheric Sensing
LMS	Land Mobile Service

Annotation in square brackets refers to the corresponding footnote from the ITU Radio Regulations 2020 [i.4] respectively.

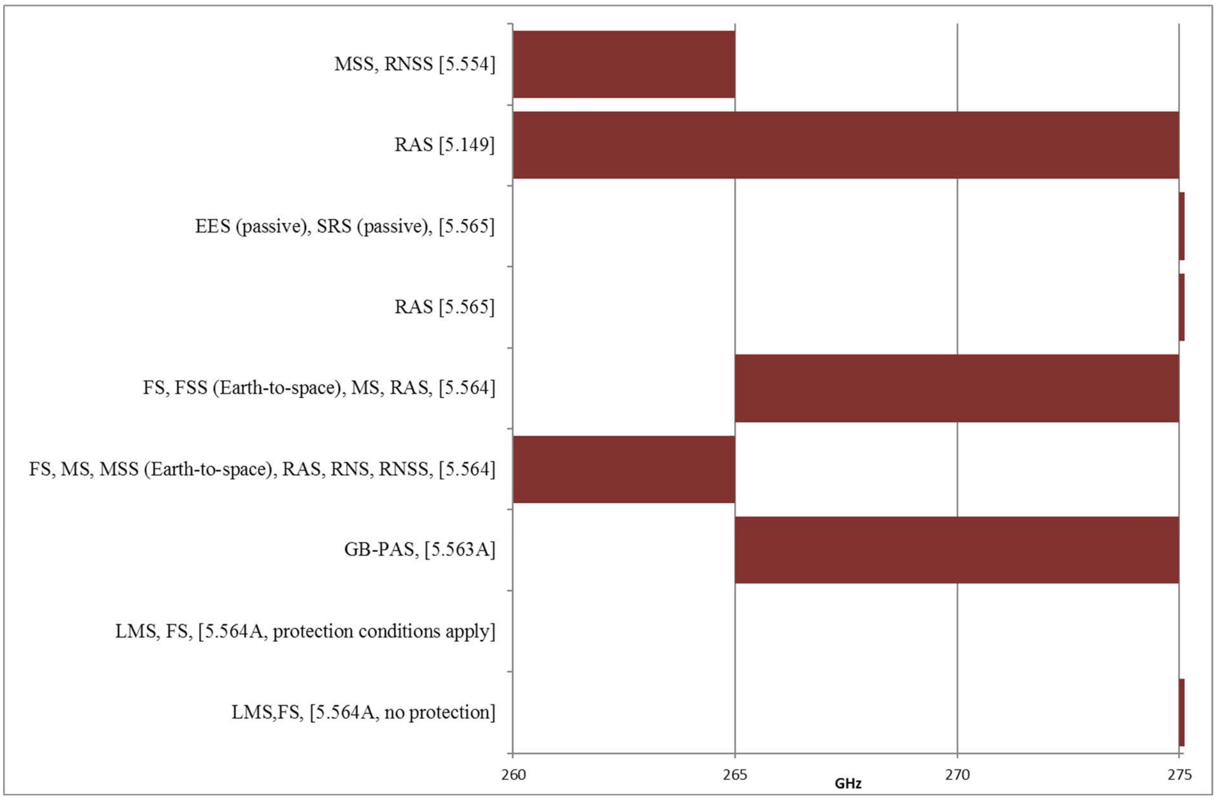


Figure A.1: Identification of frequency bands in the 260 - 275 GHz range for use by the radiocommunication services according to the ITU Radio Regulations 2020 [i.4], footnote 5.565

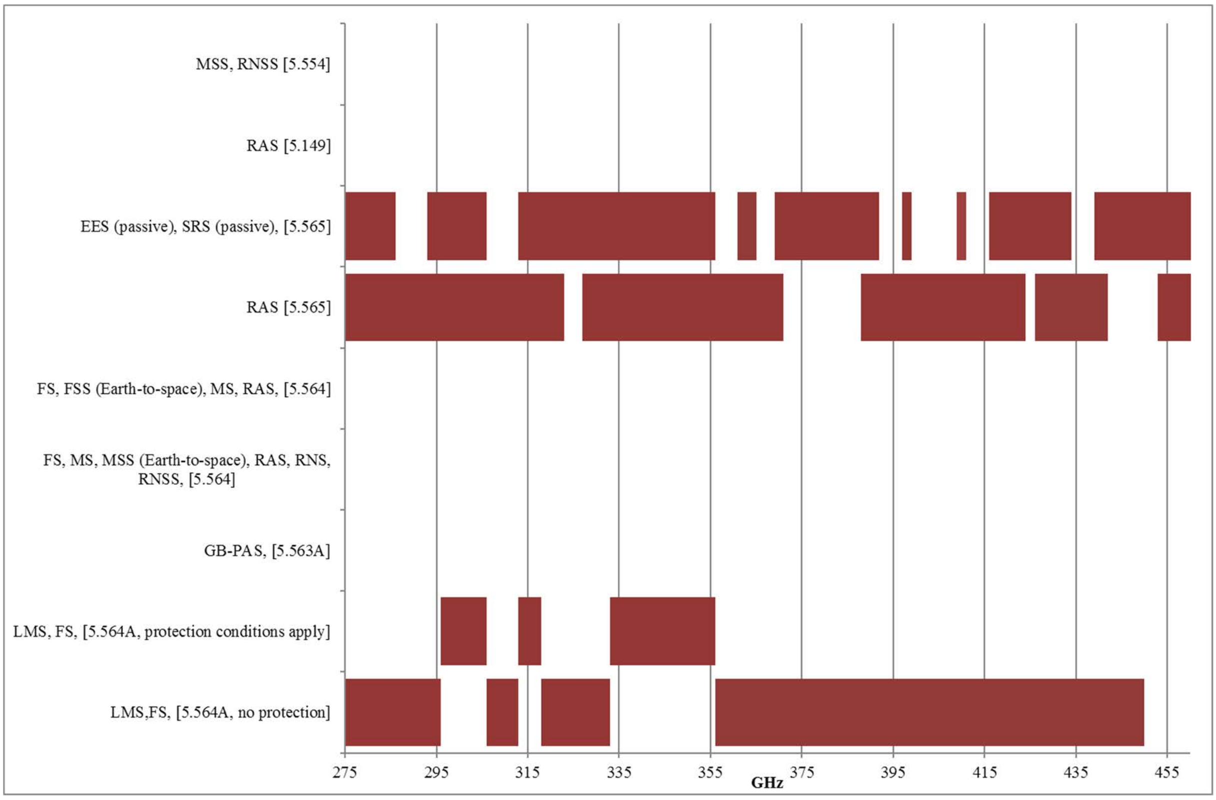


Figure A.2: Identification of frequency bands in the 275 - 455 GHz range for use by the radiocommunication services according to the ITU Radio Regulations 2020 [i.4], footnote 5.565

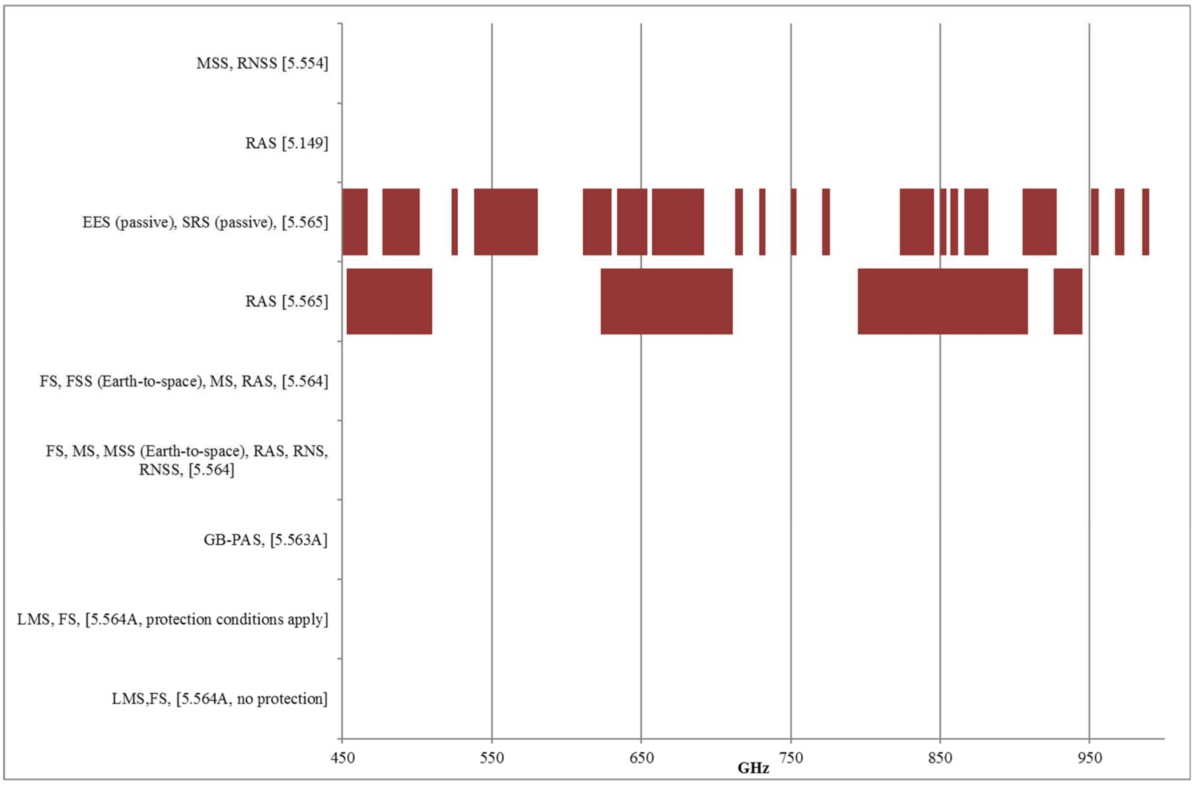


Figure A.3: Identification of frequency bands in the 450 - 1 000 GHz range for use by the radiocommunication services according to the ITU Radio Regulations 2020 [i.4], footnote 5.565

For further expansion of Land-mobile and fixed service as well as wave imaging and radio location service towards higher frequencies, additional bands have been identified by WRC-19 (Figure A.4).

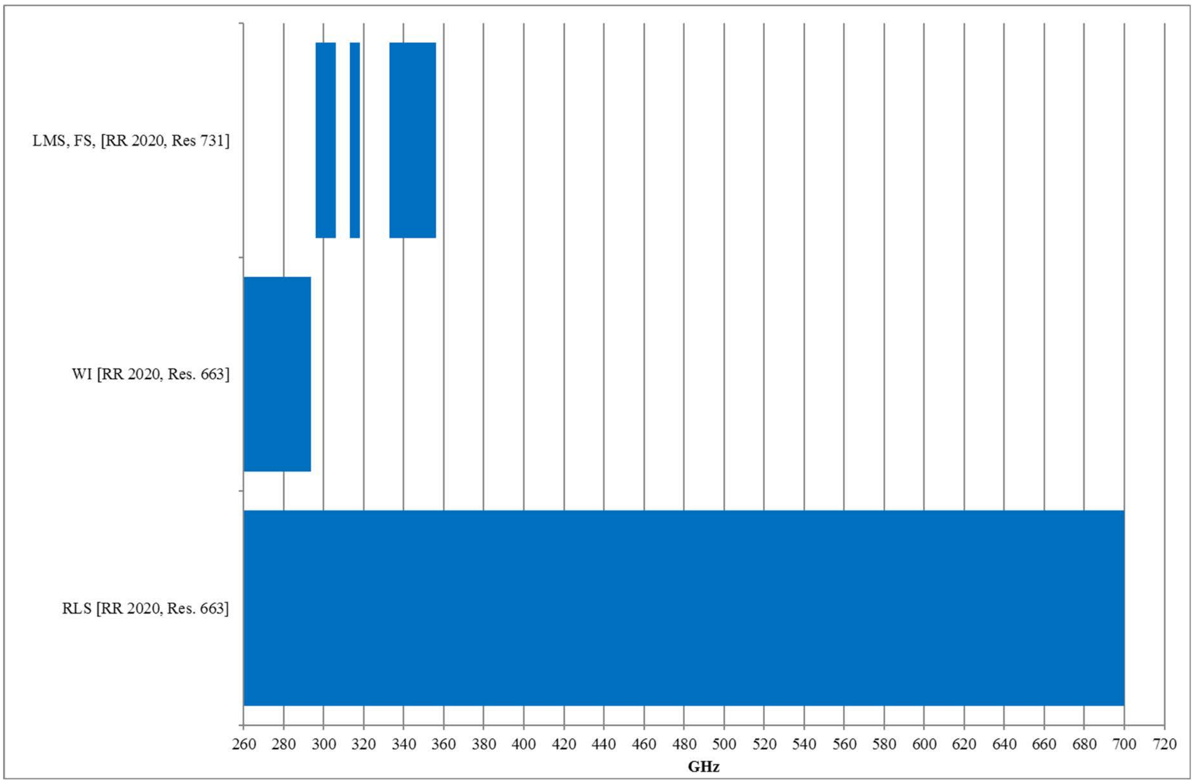


Figure A.4: Frequency bands for expansion studies according to ITU Radio Regulations 2020 [i.4], Resolutions 663 and 731

Annex B: Detailed justification for the proposed RDI-S parameters

B.1 Requirement of a large bandwidth in RDI-S systems

RDI-S applications are high precision radiodetermination applications that can be compared to network analyser measurements for industrial applications with a high measurement rate.

To ensure use for crucial applications, the RDI-S category should 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 should not be allowed to be operated as RDI-S devices. Similar to network analyser systems the latter 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. For example, 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 more easily exclude already regulated and populated 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 include, e.g. 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 [i.14].

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 beyond 100 GHz is needed. This is essential to achieve a suitable range resolution to distinguish between different material layers for a large number of materials. A bandwidth of 100 GHz allows, depending on the material permittivity, a resolution of pipe wall thicknesses of down to 1 mm. With a bandwidth of 200 GHz the systems are getting close to a measurement capability of 0,5 mm wall thickness. Bandwidths like these open up very important market applications 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 corresponding minimum. Less bandwidth leads to a significantly 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 utilization 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.

B.2 Reasons for a large bandwidth - example SAR imaging

Figure 29 shows an example to illustrate the argumentation above for an SAR imaging example. A synthetic aperture radar image of a parking disk as a representative thin multi-layer is measured once with 32,5 GHz and once with 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. Please note that this example is not an endorsement of using a maximum of 55 GHz, but to illustrate the possibilities higher bandwidths.

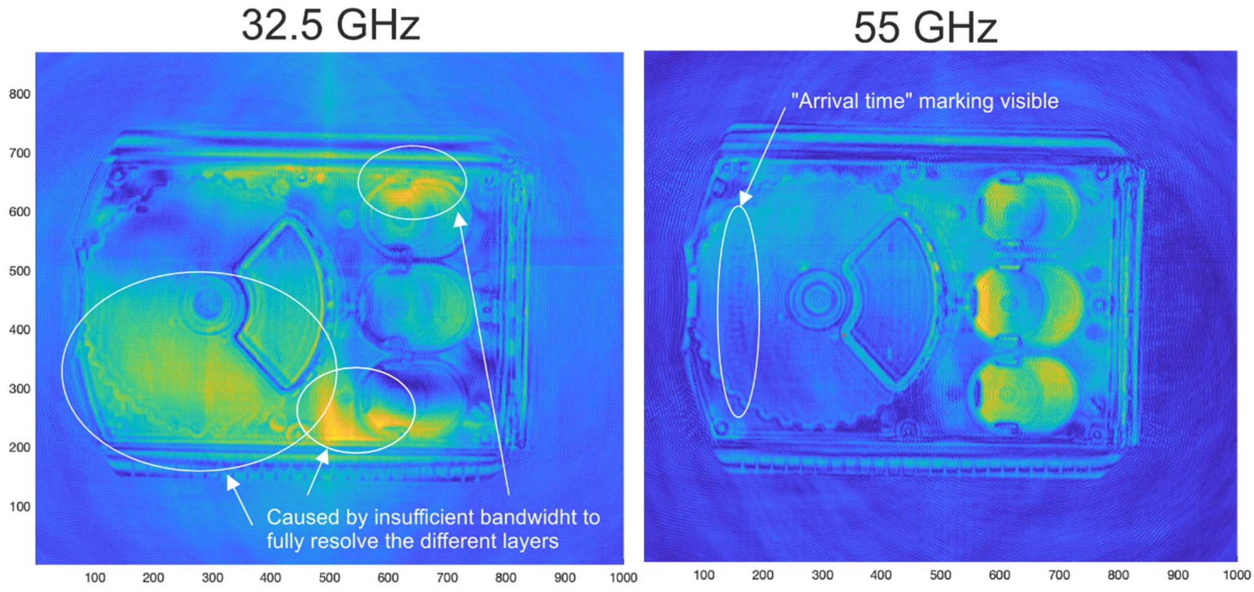


Figure B.1: Bandwidth comparison (32,5 GHz and 55 GHz modulation bandwidth) for thin layer SAR-image (n is unknown, Tukey window function)

To conclude, 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, 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. Especially for thin layers in pipe or sheet production, 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, and the measurement range should not have notched out parts (see also clauses B.3 and B.4).

B.3 Reasons for a large bandwidth - example of plastic layer measurements

A further example is given for plastic layer measurements. Plastic pipes or sheets are used in a huge range of products as different kind of infrastructural pipes (e.g. gas pipes, drinking water, wastewater, cable protection, insulation, 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 should 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 as pointed out in clause B.1.

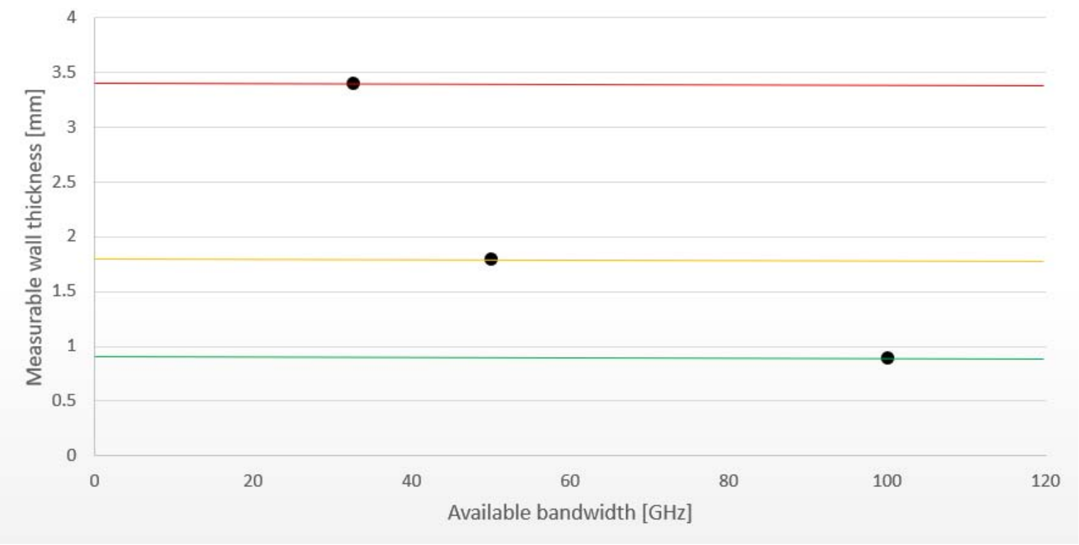
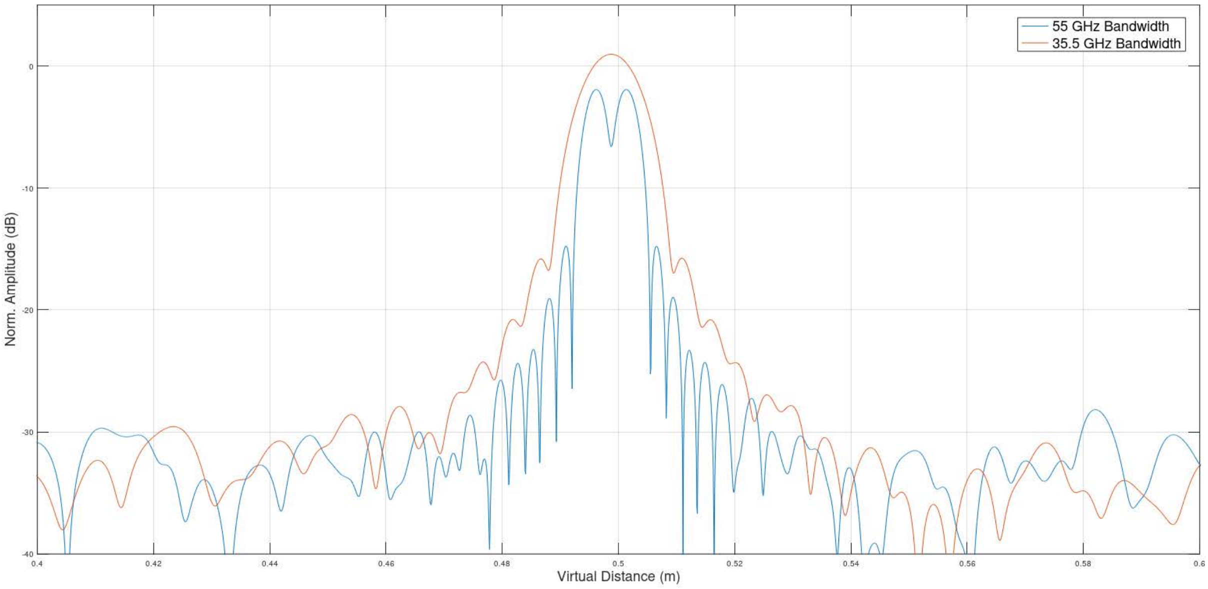


Figure B.2: Measurable wall thickness for 32,5 GHz, 50 GHz, and 100 GHz, respectively (n=1,5, rectangular window function, evaluated with Fabry-Pérot principle)

Figure B.2 shows this behaviour for three different bandwidth scenarios as currently under discussion.



NOTE: 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).

Figure B.3: Simulation of two targets with 5 mm distance, which reflects a typical high precision thin layer measurement task

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 [i.17] 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.

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.

B.4 Notching of frequency bands

Notching out bands in the requested frequency region from 260 GHz to 1 000 GHz is not a viable option, since this impacts 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.

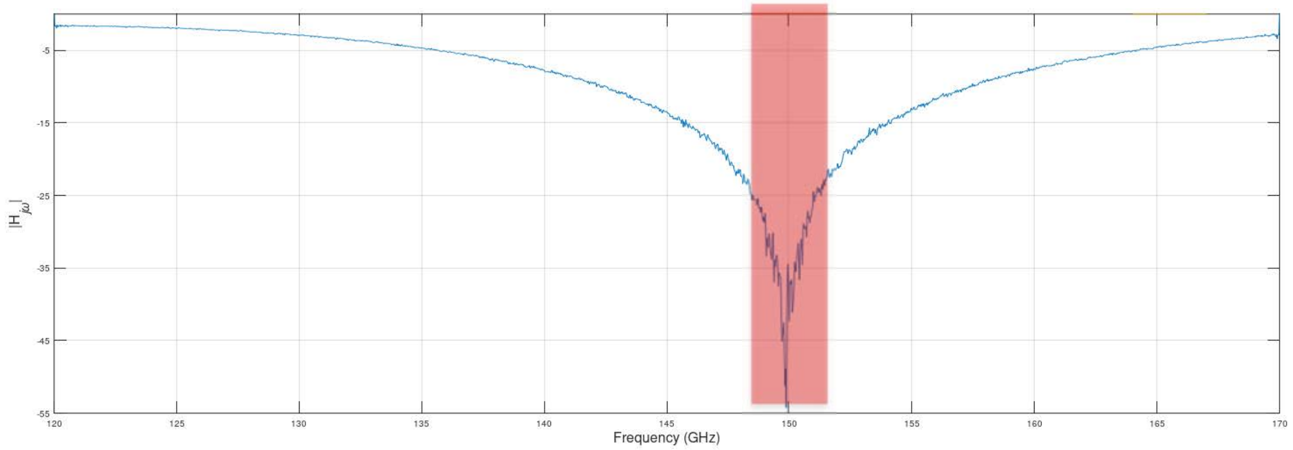


Figure B.4: Simulated magnitude of a RDI-S frequency response (FMCW up-ramp from 120 GHz to 170 GHz) with a Fabry-Pérot thin layer target with the minimum inside ITU RR FN 5.340 bands (red) (demonstration example, assumed n=1, rectangular window function, evaluated with Fabry-Pérot principle)

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 B.4. 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.

This is true for all RDI-S applications which have similar restrictions regarding missing in-band information. Notching might be acceptable for non-precision measurement tasks (which would not require the wide absolute bandwidth anyway), but is not an option for high performance radiodetermination applications. Consequently, missing sub-bands are not acceptable for most RDI-S applications. A network analyser measurement of a filter component with missing frequency ranges is also not an option if the important 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.

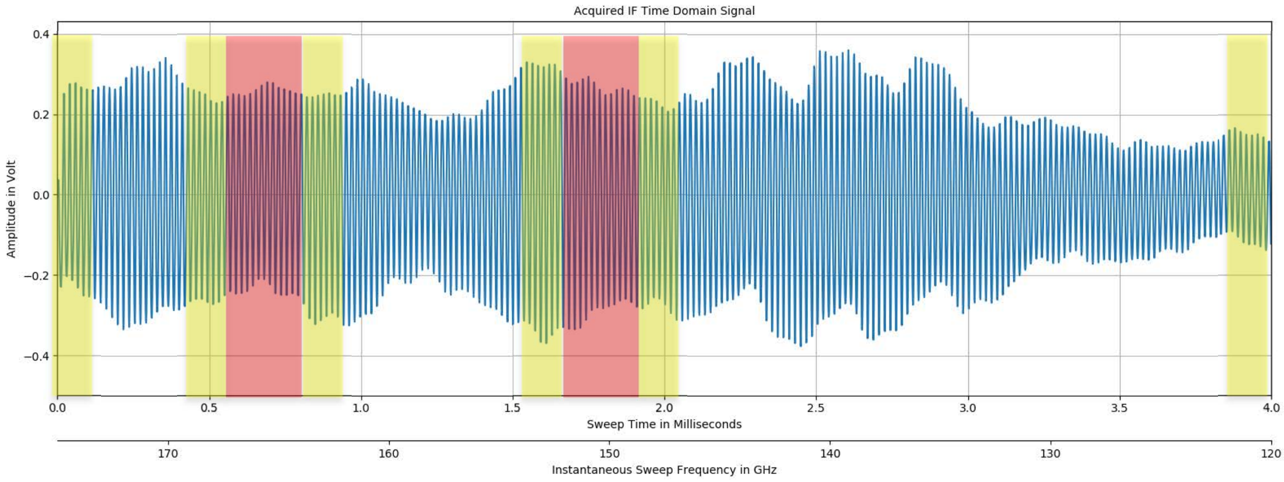


Figure B.5: Measured RDI-S IF signal for FMCW down-ramp from 175 GHz to 120 GHz with highlighted degraded ramp linearity regions (yellow) due to PLL settling effects if notching (red bands) is required

Additionally, the high sweep-rate (e.g. 4 ms for a complete 100 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 bands, this would result in degraded sweep performance close to the notched-out regions due to the fact that Phase Locked Loops (PLL) exhibit an analogue settling behaviour (Figure B.5).

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 notched-out bands might be the consequence of PLL locking and settling processes at the FMCW start and stop regions. 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.

To conclude, notching out 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 measurement tasks, notching is acceptable (if at all needed). In particular, for applications that require only low speed sweep slopes, notching can be an option.

B.5 Suitability of the frequency range from 260 GHz to 1 000 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 260 and 1 000 GHz is suitable for this purpose, because the attenuation of MilliMetre Waves (MMW) by materials made of PE or PP as well as PVC still allows for the measurement of a wide product range. The resolution of individual layers in the frequency range of 260 GHz to 1 000 GHz is made possible for thinner layer thicknesses provided sufficient bandwidths are made available. Also, the frequency range addressed in the present document allows for easier and better focussing of the radar wave using relatively small antennas, leading to less unwanted emissions.

B.6 Conservation of resources and CO_2 reduction, increased efficiency

Using large bandwidth radar technology in the frequency range that is the subject of the present document, e.g. for a plastics extrusion line, cost savings of around 250 000 euros to 300 000 euros a year can be realized. This is based on an improved production yield, saving material, energy and time. The exemplary savings sum mentioned above is based on a material price of 1,1 euro/kg of polyethylene (which is a very conservative number). The application of the improved measurement technology leads to material savings of 225 tons to 270 tons/year. This is not only cost effective, but also equals an amount of 500 tons to 1 500 tons of CO_2 less released during production of the raw material (depending on the refinery process).

Another point is that with increasing width of the operating frequency range, this technology can also act as a replacement for X-RAY measurement technology, having advantages in favour of cost and security relevance.

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, making better use of raw materials and energy which is especially crucial faced with the challenges of climate change.

Annex C: Bibliography

- ITU Resolution 767 (WRC-15): "Studies towards an identification for use by administrations for land-mobile and fixed services applications operating in the frequency range 275-450 GHz".
- Report Recommendation ITU-R F.2416-0 (11/2017): "Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz".
- Report Recommendation ITU-R SM.2352-0 (06/2015): "Technology trends of active services in the frequency range 275-3 000 GHz".
- Recommendation ITU-R SM.1757 (05/2006): "Impact of devices using ultra-wideband technology on systems operating within radiocommunication services".
- Report Recommendation ITU-R M.2417-0 (11/2017): "Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz".
- Report Recommendation ITU-R SM.2057 (2005): "Studies related to the impact of devices using ultra-wideband technology on radiocommunication services".
- Report Recommendation ITU-R F.2323-0 (11/2014): "Fixed service use and future trends".
- 2013/752/EU: "Commission Implementing Decision of 11 December 2013 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2005/928/EC".
- ECC Decision (07)01 (03/2019): "The harmonised use, exemption from individual licensing and free circulation of Material Sensing Devices using Ultra-Wideband (UWB) technology".
- APT/AWG/REP-66: "APT Report on :Short Range Radiocommunication Systems and Application Scenarios operating in the Frequency Range 275 - 1 000 GHz", First Revision 2018.

Annex D:
Change history

Date	Version	Information about changes
March 2020	V0.0.1	First generation of document, contribution for web-meeting
April 2020	V0.0.2	Rework after web-meeting and for contribution to ERMTGUWB#53
May 2020	V0.0.3	Revised version after second rapporteur's meeting
July 2020	V0.0.4	Editorial updated version for TG UWB#54
October 2020	V0.0.5	Revised version after third rapporteur's meeting for TG UWB#55
October 2020	V0.0.6	Some further corrections for TG UWB#55
February 2022	V0.0.7	Rework of scope and contents in accordance with the rapporteur's meeting in 12/21 for contribution to TG UWB#60
April 2022	V0.0.8	Current version after rapporteur's meeting #3 in 04/2022
June 2022	V0.0.9	Contributed version for rapporteur's meeting #4 in 06/2022
July 2022	V0.0.10	Current version after rapporteur's meeting #5 in 07/2022
August 2022	V0.0.11	Reworked according to rapporteur's meeting #5 comments and suggestions
July 2023	V0.1.0	Stable draft after rapporteurs meeting at 4 July 2023
September 2023	V1.0.0	Agreed version by TGUWB#65 to start ETSI internal inquiry

History

Document history		
V1.1.1	January 2024	Publication