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**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**

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Contents

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Foreword

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

Modal verbs terminology

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Introduction

The present document includes necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

The present document covers the request for harmonised spectrum for sensor or radiodetermination applications using UWB technology within the frequency range 120 GHz to 260 GHz. Communications applications or hybrid applications as a combination of sensor and communications applications are not treated within the scope of the present document.

A need for additional spectrum allocations for UWB radiodetermination devices was identified in order to cover measurement tasks which cannot be conducted adequately at the moment due to the limited bandwidth in the existing frequency allocations in the bands 122 GHz - 123 GHz and 244 GHz - 246 GHz although the UWB technology is already available to do so. Therefore a lot of applications with their market potential could be identified and summarized.

The intention of the production of the present document is to create a basis for the industry to facilitate the market launch of new innovative and useful radio products while avoiding any harmful interference with other radio services and equipment.

The present document was developed by ERM TGUWB. The information in it has not yet undergone coordination by ERM. It contains preliminary information.

1 Scope

The present document describes UWB radiodetermination applications within the frequency range 120 GHz to 260 GHz which may require a change of the present frequency designation/utilization within CEPT. The described UWB radiodetermination applications for future systems are split into the following classes and use cases:

- object detection and classification/characterization;
- motion, speed and presence detection;
- distance measurement;
- displacement measurement.

The present document includes in particular:

- market information;
- technical information including expected sharing and compatibility issues;

NOTE: The information on sharing and compatibility issues is required when new spectrum or new spectrum usage is requested.

- 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] CEPT 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) (10-2016): "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] ETSI EN 302 729 (V2.1.1) (10-2016): "Short Range Devices (SRD); Level Probing Radar (LPR) equipment operating in the frequency ranges 6 GHz to 8,5 GHz, 24,05 GHz to 26,5 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.4] ETSI TS 103 361 (V1.1.1) (03-2016): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Receiver technical requirements, parameters and measurement procedures to fulfil the requirements of the Directive 2014/53/EU".

[i.5] FP7-ICT - Specific Programme: "Cooperation": Information and communication technologies; Topic: ICT-2009.3.2 - Design of semiconductor components and electronic based miniaturized systems.

[i.6] SUCCESS: "Silicon-based Ultra Compact Cost-Efficient System Design for mmWave-Sensors".

NOTE: Available at https://cordis.europa.eu/project/rcn/93756/factsheet/en.

[i.7] CATRENE: "Cluster for Application and Technology Research in Europe on NanoElectronics".

NOTE: Available at http://www.catrene.org.

[i.8] NANOTEC: "Nanostructured materials and RF-MEMS RFIC/MMIC technologies for highly adaptive and reliable RF-systems".

NOTE: Available at http://project-nanotec.com/.

[i.9] DOTFIVE: "Towards 0.5 TeraHertz Silicon/Germanium Heterojunction bipolar technology".

NOTE: Available at http://www.dotfive.eu.

[i.10] ITU-R Radio Regulations Articles (2016).

[i.11] ETSI EN 305 550 (V2.1.0): "Short Range Devices (SRD); Radio equipment to be used in the 40 GHz to 246 GHz frequency range".

[i.12] ETSI EN 303 883 (V1.1.1) (09-2016): "Short Range Devices (SRD) using Ultra Wide Band (UWB); Measurement Techniques".

[i.13] CEPT ECC Report 190 (May 2013): "Compatibility between Short-Range Devices (SRD) and EESS (passive) in the 122 to 122.25 GHz band".

[i.14] ETSI EN 301 783 (V2.1.1) (01-2016): "Commercially available amateur radio equipment; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.15] ERC Recommendation 70-03 (13 October 2017): "Relating to the use of Short Range Devices (SRD)".

[i.16] Google Soli Project.

NOTE: Available at https://atap.google.com/soli/.

[i.17] ETSI TR 103 181-2 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB); Transmission characteristics; Part 2: UWB mitigation techniques".

[i.18] ETSI TS 102 754 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics of Detect-And-Avoid (DAA) mitigation techniques for SRD equipment using Ultra Wideband (UWB) technology".

[i.19] Klenner, Mathias: "Multilayer Material Analysis using an Active Millimeter Wave Imaging System". International Radar Symposium, 2013.

[i.20] CEPT/ERC/Recommendation 74-01E (January 2011): "Unwanted Emissions in the Spurious Domain".

[i.21] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC.

[i.22] ECC Recommendation (18)01 (27 April 2018): "Radio frequency/block arrangements for Fixed Service systems operating in the bands 103-134 GHz, 141-148.5 GHz, 151.5-164 GHz and 167-174.8 GHz".

[i.23] ECC Report 282: "Point-to-Point Radio Links in the Frequency Ranges 92-114.25 GHz and 130-174.8 GHz", approved 14 September 2018

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI EN 303 883 [i.12], ETSI TS 103 361 [i.4] and the following apply:

Activity Factor (AF): activity factor of a radiodetermination device is usually defined as the ratio of active measurement periods t_{meas} (bursts, sweeps, scans) within the overall repetitive measurement cycle T_{meas_cycle}

Adaptive Power Control (APC): adaptive power control is an automatic mechanism to regulate the transmitter power

NOTE: It is controlled by the received power within the total receiver bandwidth.

blocking distance: blocking distance is the minimum distance from the target to the antenna of a distance measurement Radar (DMR) sensor which is at least necessary in order to guarantee a reliable measurement

NOTE: If the distance to the target falls below the blocking distance, the measurement may fail because the sensor is less sensitive or "blind" at closer ranges.

Duty Cycle (DC): product of the pulse repetition frequency (PRF) and the pulse duration t_{pulse}

Equivalent isotropically radiated power (e.i.r.p.): e.i.r.p. is conventionally the product of "power fed into the antenna" and "antenna gain related to the isotropic radiator"

Frequency Modulated Continuous Wave (FMCW): modulation scheme which is based on a periodically linear frequency sweep of the transmit signal.

NOTE 1: For distance measurement sensors often a sawtooth or a triangular modulation scheme is used. By mixing the current transmit signal with the reflected signal the round trip time of the individual echoes and thus the distance of the different targets can be determined.

NOTE 2: Although the instantaneous bandwidth of a FMCW Radar is close to zero the recorded power versus time variation results in a wideband spectrum which is clearly not pulsed.

Stepped Frequency Continuous Wave (SFCW): in contrast to the FMCW principle the transmit frequency in an SFCW modulation scheme is not swept in a linear manner but rather in a stepped way with defined frequency increments and with a certain dwell time on each individual frequency step

NOTE: Although the instantaneous bandwidth of an SFCW Radar is close to zero the recorded power versus time variation results in a wideband spectrum which is clearly not pulsed.

3.2 Symbols

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

f_L	lowest frequency of the operating bandwidth
f_H	highest frequency of the operating bandwidth
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:

AF	Activity Factor
APC	Adaptive Power Control
CAGR	Cumulative Annual Growth Rate

CEPT	Conférence européenne des administrations des postes et des télécommunications
DAA	Detect And Avoid
DC	Duty Cycle
DMR	Distance Measurement Radar
DUT	Device Under Test
e.i.r.p.	equivalent isotropically radiated power
ECC	Electronic Communication Committee
EESS	Earth Exploration Service Satellite
FMCW	Frequency Modulated Continuous Wave
FSL	Free Space Loss
GBSAR	Ground Based Synthetic Aperture Radar
HPBW	Half Power BeamWidth
IC	Integrated Circuit
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union - Radio Sector
LBT	Listen Before Talk
LPR	Level Probing Radar
MMW	MilliMetre Wave
PMMA	PolyMethylMethAcrylate
PMP	PolyMethylPentene
POM	PolyOxyMethylene
PRF	Pulse Repetition Frequency
PVC	PolyVinyl Chloride
RAS	Radio Astronomy Station
RF	Radio Frequency
Rx	Receiver
SAR	Synthetic Aperture Radar
SFCW	Stepped Frequency Continuous Wave
SoC	System on Chip
SRD	Short Range Device
SUP	Supplementary Details
TGUWB	Task Group Ultra-wide Band
TLPR	Tank Level Probing Radar
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
USD	United States Dollar
UWB	Ultra Wide Band
WLAN	Wireless Local Area Network

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 the system and technology

5.1 Use cases for future sensor systems

5.1.0 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 provides a high independency of ambient conditions or process properties;
- superior long-term stability resulting from self-calibration mechanisms since devices have always 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 a more efficient and sustainable use of natural resources and higher quality of end-products in different manufacturing industries.

There are already commercially available sensors on the market which partly cover some of the following use cases in clauses 5.1.1 to 5.1.4. Examples of such sensors are:

- Distance Measurement Radar (DMR) sensors, which comprise Level Probing Radars (LPR) [i.3] and Tank Level Probing Radars (TLPR) [i.2] working for example in the frequency band 75 to 85 GHz or in the 122 to 123 GHz ISM band.
- Precipitation sensors working in the 24 to 24,25 GHz ISM band.
- Radiodetermination sensors working as proximity switches, presence detectors or reflex barrier sensors in the 122 GHz to 123 GHz ISM band.

More information about some already existing systems can be found in annex A.

As indicated in the scope of the present document the UWB radiodetermination applications for potential future systems are classified into the following use cases:

- Object detection and classification/characterization.
- Motion, speed and presence detection.
- Distance measurement.
- Displacement measurement.

With industry 4.0 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 in order to maintain product quality and production efficiency.

The sensor systems for industrial automatization need to be small to be easily mounted on vehicles or machines. They further should be equipped with small or even already chip-integrated antennas. The high bandwidth is advantageous to get the necessary resolution for e.g. localization applications. The sensors should also be able to measure within short distances with very low transmit power. Short response times which enable the detection and tracking of fast movements within the observation area 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 120 GHz.

5.1.1 Object detection, classification and characterization

5.1.1.1 Quality assessment

The detection of defects and irregularities is crucial in the production process of high quality plastic materials and of carbon and glass fibre reinforced plastics, respectively. A possible detection system for these irregularities, like air inclusions within the material or delamination of fibres, should be able to measure contactless and with a high accuracy to detect even small inclusions or defects. While optical sensors are only able to detect surface defects and ultrasonic sensors need to be in contact with the material, a millimetre wave radar is able to measure contactlessly and to penetrate the material up to a certain depth. In plastics like PVC, POM, PMMA and PMP small defects have been detected in a depth of up to 100 mm using a W-band (75-110 GHz) FMCW radar with a bandwidth of 25 GHz from a distance of 2 m [i.19].

The small size and lightweight property of millimetre wave radar enables the contactless inspection of e.g. airscrew rotor blades of a small Unmanned Aerial Vehicle (UAV).

Application environment: production factories (indoor).

Aggregation effects: May occur inside a building if numerous sensors are located in close proximity.

5.1.1.2 Contour detection

Imaging Radar systems are used for 3D visualizing of arbitrary surfaces and objects (contour detection). The principle can be utilized for example for precise volumetric measurements of different bulk solids stored in stockpiles such as sand, gravel, stones, wood chips, coal, corn, fertiliser, etc. These materials shape a characteristic repose angle when stored on a stockpile.

With a one dimensional distance sensor measuring towards only a small area on the surface and assuming the surface to be flat, often the volume expansion of the whole stockpile cannot be determined with sufficient accuracy. This problem can be overcome by installing several distance measurement systems uniformly and densely distributed over the measuring surface. However, this solution is unfavourable in terms of costs and installation effort.

Therefore a single imaging Radar system installed in a suitable position can be used which generates an exact image of the surface contour. This facilitates the calculation of the residual volume on the stockpile.

Imaging Radar systems therefore often use beamforming techniques with phased array antennas providing control of the beam direction (beam steering) and pattern shape including the side lobes without the need for rotating the entire unit mechanically.

Application environment: industrial areas (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.

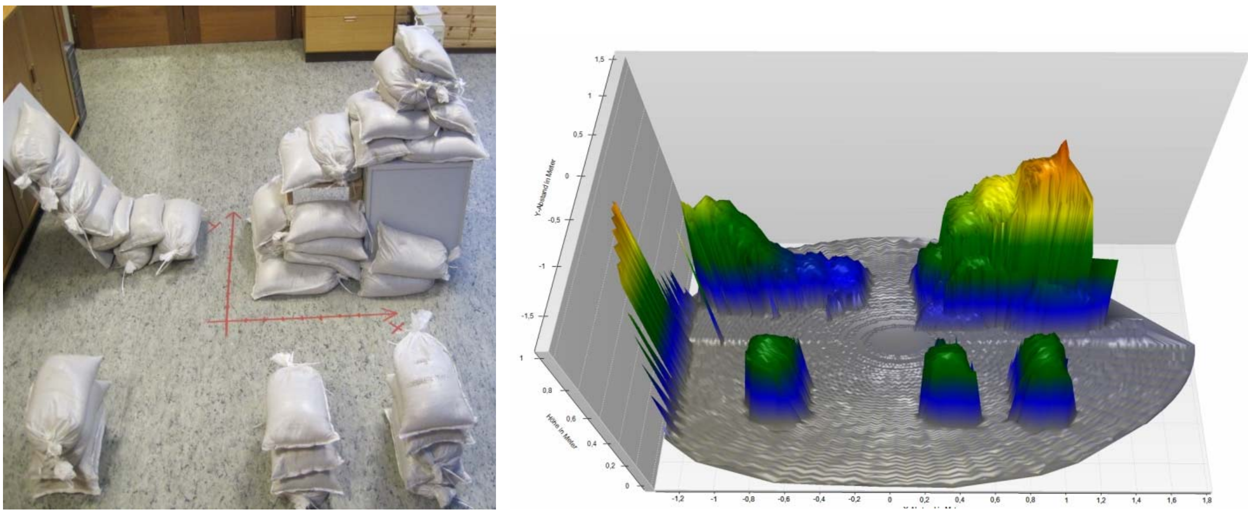

Figure 1: Measurement scenario with sandbags (left) and corresponding Radar image (right)

Radar imaging at higher transmit frequencies and with wider operating bandwidths has several advantages:

- a better range resolution;
- a smaller beamwidth of the antenna;
- a better resolution of the resulting 3D image;
- very compact Radar imaging sensors with multiple antennas possible.

5.1.2 Motion, speed and presence detection

5.1.2.1 Microwave barrier sensing

The microwave barrier sensor is suitable for example for non-contact point level detection of liquids and bulk solids of any kind. Even point level detection of high-purity liquids through a microwave translucent container wall is possible. When it comes to bulk solids, the microwave barrier lends itself well for heavy and dust-generating media or for blockage detection in conveying systems.

The use of microwave sensing technology allows point level detection without a direct contact with the measured product. Dirt, build-up, and abrasion on the sensor are eliminated, allowing a wear and maintenance-free operation.

The microwave barrier works virtually like a light barrier. If the microwave beam between transmitter and receiver is attenuated or even blocked by the rising medium, the received signal power decreases. This change is detected by the receiver and converted eventually into a switching signal.

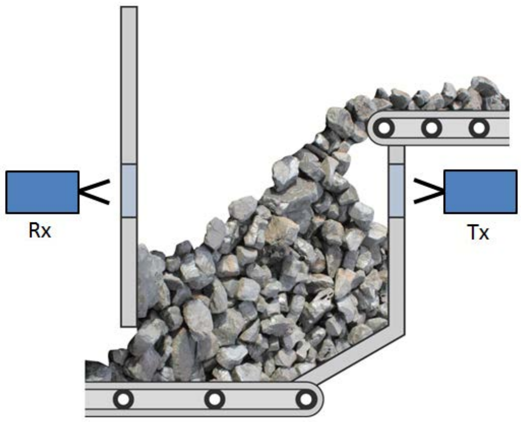

Figure 2: Microwave barrier sensing in a backwater vessel

Application environment: industrial areas (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.

Current microwave barrier sensors are narrowband systems operating in the 24 to 24,25 GHz or 122 to 123 GHz ISM bands.

Microwave barrier sensors on higher transmit frequencies and with wider operating bandwidths have several advantages and enable to introduce new and more sophisticated features:

- narrower beam angles of the Tx- and Rx-antennas;
- less diffraction effects at the medium and thus less switching errors;
- a wider bandwidth enables the use of multiple channel access methods to separate different barriers located close to each other and thereby also reducing the false alarm rate;
- new features conceivable like speed measurements, measuring material characteristics like density or permeability, communication link between transmitter and receiver, etc.

5.1.2.2 Living object detection and surveillance

Figure 3 shows the detection range of a living object detection application for parked vehicles. It prevents harm when moving the vehicle is intended or if the vehicle is being charged wirelessly. The sensor operation requires a bandwidth of more than 1 GHz in order to provide enough resolution in the detection range.

Further applications could be sensors for monitoring the constitution of a car driver while driving or an alarm application in case of an infant remained alone in an abandoned vehicle.

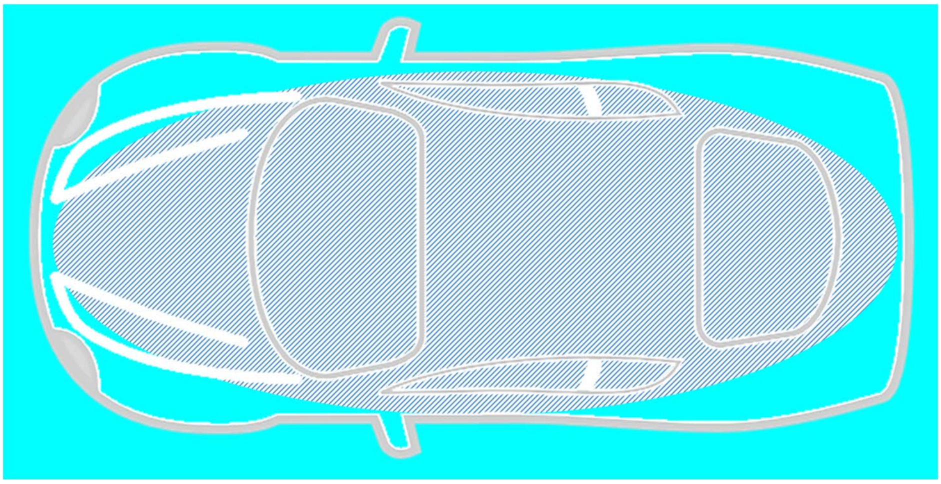

Figure 3: Living object detection below and around a parked vehicle

Another application is the presence and intrusion surveillance and people counting, as shown for example in Figure 4. Using a Radar sensor, the presence of persons can be reliably detected. In contrast to video surveillance, the privacy of the persons is respected. Additionally, the number of people moving in a corridor or present in a room can be counted. For this application a high bandwidth of several GHz is required in order to allow discrimination between several persons sojourning in different distances and angles. Furthermore concealed objects could simultaneously be revealed carried by the persons being captured within the detection range of the sensor.

Application environment: urban areas (indoor and outdoor).

Aggregation effects: May occur indoors and outdoors if numerous sensors are located in close proximity.

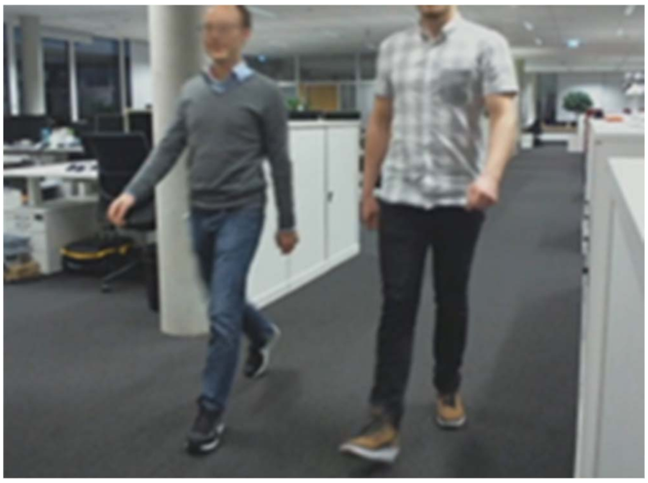

Figure 4: Presence or intrusion detection and counting of people

5.1.2.3 Contactless flow measurement

The flow rate measurement in flumes, rivers and other running water bodies plays a prominent role for example in wastewater treatment, municipal water supply and especially in flooding prevention. With an accurate measurement of the flow rate in rivers in combination with the water level an exact flood forecasting is possible. This helps to take early measures against severe harm to infrastructure and people due to an impending flood.

The flow rate measurement sensor measures the speed of the waves at the surface of the flume for example by means of a doppler measurement and evaluation. Due to the fact that in most cases the width of the flume is known (dimension A in Figure 5) a simultaneous level measurement would be desirable in order to determine the depth (dimension B in Figure 5) of the watercourse. With the known cross section of the flume at the point of measurement the overall volume flow can therefore be calculated.

Higher transmit frequencies allow narrower beam angles of the Tx- and Rx-antennas and thus the possibility of producing very compact sensors. These sensors enable the monitoring of very small and also remote watercourses which often appear in the mountains. In these territories effective flooding observation and prevention are highly desirable.

A disadvantage of today's sensors however is the limited bandwidth since it is not possible to measure close to the surface of the liquid due to the inherent blocking distance. A higher bandwidth allows for a precise detection of neighbouring wave crests and subsequently a more accurate determination of the flow rate. Furthermore, the distance to the surface can be significantly reduced which enables the measurement in small pipes.

Application environment: remote rural areas, wastewater treatment plants (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.

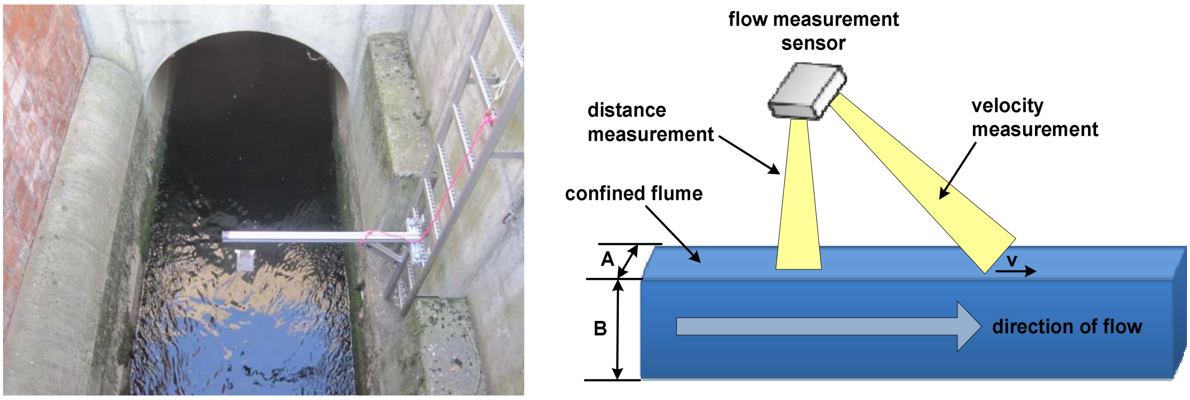

Figure 5: Contactless flow measurement in a confined flume

5.1.2.4 Gesture control and recognition

Another potential application is the precise gesture recognition of individual fingers in short distances to a sensor used for example for augmented reality purposes. This enables touchless gestures, similar to the ones shown in the Google Soli project [i.16]. To achieve good recognition performance, a high bandwidth of 10 GHz is essential. Due to the short range, low power operation is feasible.

Application environment: urban areas (indoor).

Aggregation effects: May occur if numerous sensors are located in close proximity.

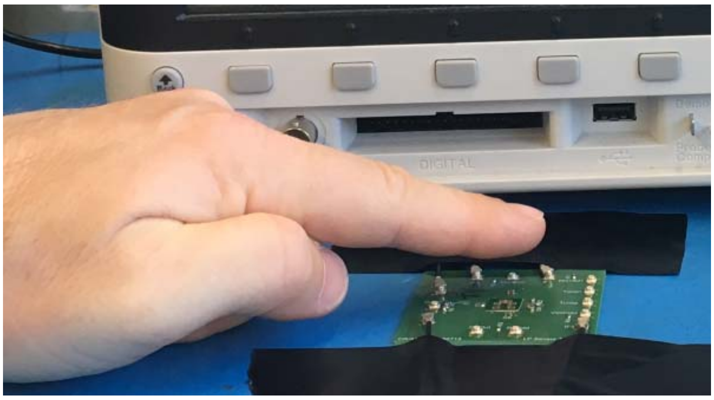

Figure 6: Gesture recognition of individual fingers

5.1.3 Distance measurement

5.1.3.1 Level probing

The examples in clauses A.1.1 and A.1.2 show two use cases where distance measurement radars (DMR) can successfully be applied under harsh conditions.

However, there are still many measurement tasks which cannot be solved yet with the current 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 industry.

The blocking distance of such sensors should be as small as possible in order 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 beamwidths 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 7 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

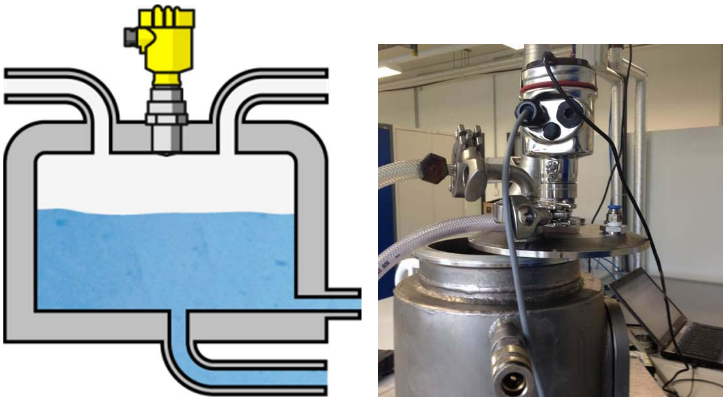

Figure 7: Level measurement in a small pharmaceutical mixing vessel

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.

5.1.3.2 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 120 GHz allows for a smaller antenna beamwidth 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 beamwidths. With a 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.

Application environment: industrial areas, construction sites (indoor and outdoor).

Aggregation effects: highly unlikely due to the metallic shielding of the cylinders.

5.1.4 Displacement measurement

5.1.4.1 Thickness Measurements

During the fabrication of plastic pipes in highly efficient facilities (see Figure 8), the thickness of the pipes around the entire perimeter has to be determined rapidly during processing. This can be accomplished with high-resolution Radar sensor arranged around the pipe located after the nozzle of the machine.

The operating principle of thickness measurements of hollow pipes with 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. Accuracy and minimum thickness that can be measured strongly depends on the available bandwidth of the Radar signal. The higher the bandwidth the better is the resolution that can be obtained for the system. Because of the extremely expensive machinery for the extrusion of plastic pipes the thickness measurement system needs to be adaptable for measuring small and large thicknesses almost simultaneously.

The small absolute bandwidth available at lower transmit frequencies limits the use of the Radar principle to pipes with high wall thicknesses only.

Applying a thickness measurement system operating at higher transmit frequencies and with wider operating bandwidths has several advantages:

- a compact measurement system with the possibility for mounting many Radar sensor heads on the circumference around the pipe;
- a better accuracy of the thickness measurement;
- a smaller beamwidth 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 thicknesses can be reliably measured.

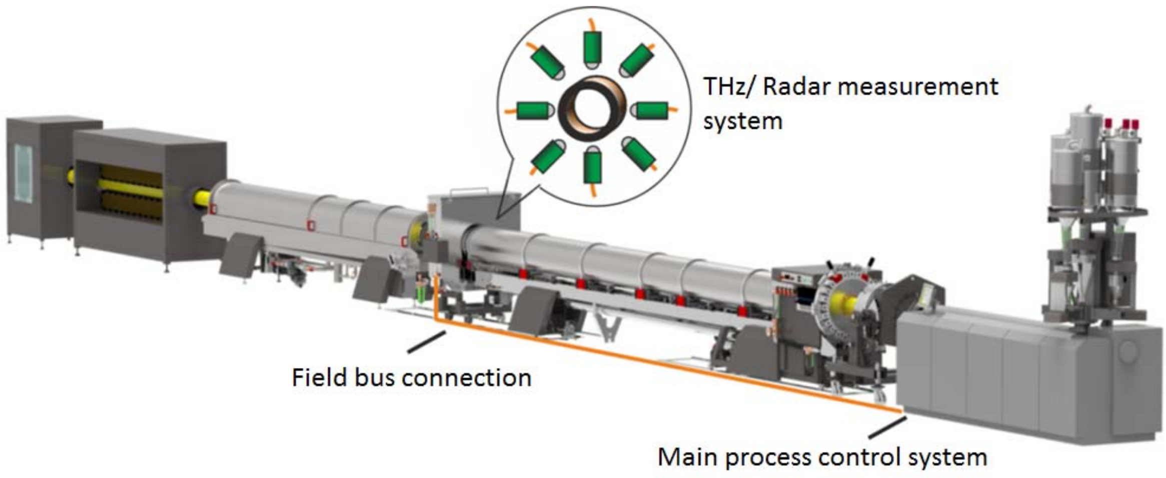

Figure 8: Extruder for plastic pipes with a Radar thickness measurement system

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.

In order to measure plastic workpieces down to a thickness of only a few millimetres, a bandwidth of 25 GHz or higher is required.

A further application could be the exact determination of the thickness of a brake disc coating during the production process. This ensures a constant quality in the production process by avoiding a coating layer too thin, which is critical for example in terms of an increased corrosion during the later utilization, or a layer too thick which is equivalent to the dissipation of valuable resources and an unnecessary environmental burden.

Application environment: production factories (indoor).

Aggregation effects: may occur inside a building if numerous sensors are located in close proximity.

5.1.4.2 Building deformation measurements with interferometric Radar

The use of a monitoring system based on the radar technology (GBSAR) is not new and allows to remotely monitor the displacements of thousands of points over a surface with a high accuracy and without the need of installing any reflector. Therefore, this radar has the potential to be a perfect tool to assess the stability of buildings in a wide range of applications (e.g. during excavation works, for analysing the resistance in the event of an earthquake etc.). A further application concerns the deformation monitoring of large structures (e.g. dams, bridges, etc.).

Unfortunately, current technology (and regulations) impose the use of signals with a main emission around 17 GHz and this does not permit to achieve a very high resolution and neither to measure the displacement of the building in 3D.

On the contrary, availability of technology for frequency sources/receivers in the millimetre band (> 30 GHz) has been opening new scenarios and exploitations for the GBSAR; a millimetre wave technology (W-band) is theoretically able to provide both range and angular measurements with a very high accuracy (< 0,1 millimetres). This technology is theoretically exploitable for monitoring the stability of a structure providing the capability of obtaining a fast acquisition, a large field of view and a very accurate three-dimensional spatial resolution (range, azimuth, elevation); all this permits to correctly identify the position of possible displacements over the whole building surface.

It is expected that the radar signal is continuously transmitted and received while the sensor is rotating at a pre-determined rotational speed.

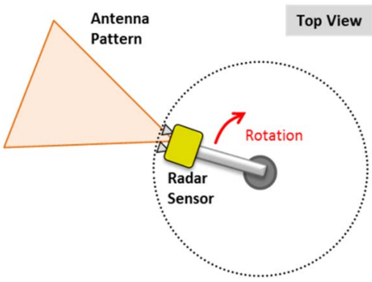

Figure 9: Arc SAR acquisition

In this way a bi-dimensional image of the monitored scenario is provided; the two dimensions are determined by the range resolution and the angular resolution capability.

Ideally a 10 GHz bandwidth located at 140 GHz should be used for this application in order to have a radar range resolution in the order of centimetres; in this case, the range resolution ΔR that is determined by the bandwidth of the emitted signal ($\Delta R = c/2B$), would be equal to 0,015 m, whereas the angular resolution ΔAz is around 4 mrad assuming a rotation radius of 0,5 m.

Then, the combination of range and angular resolution allows the creation of a bi-dimensional image (Figure 10), where each resolution cell is a measurement point providing a real-time displacement information with submillimetre accuracy thanks to the interferometric technique.

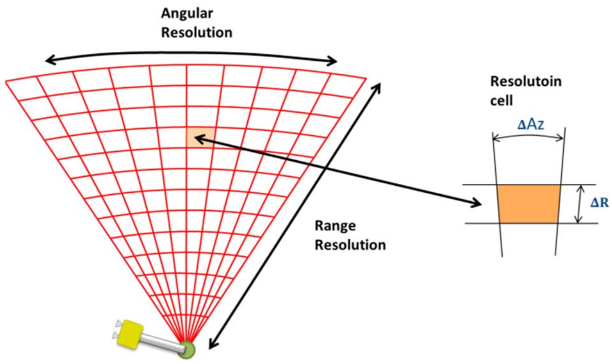

Figure 10: Spatial resolution

The most suitable frequency range for this technology should also consider the atmospheric attenuation above 100 GHz; as a matter of fact, peaks in absorption at specific frequencies exist due to atmosphere constituents such as water vapour (H_2O) and molecular oxygen (O_2). Therefore the permitted frequency range for this technology should start above 120 GHz.

Finally to allow a useful detection range of up to 200 metres (that permits to effectively monitor a quite large building) the emitted power should be in the order of 30 dBm.

Application environment: construction sites, disaster areas (outdoor).

Aggregation effects: Highly unlikely due to a low density of measuring sites, the increased FSL in the higher frequency bands and large distances between different sensors.

5.2 Publicly funded projects and available technologies

5.2.1 SUCCESS-project

SUCCESS was supported by the European Commission through the Seventh Framework Programme for "Design of Semiconductor Components and Electronic Based Miniaturized Systems" [i.5]. From December 2009 to May 2013, nine project partners worked towards a miniaturized millimetre-wave Radar sensor. SUCCESS targeted to develop a technology platform and best-practice design methods to enable the breakthrough of silicon mm-Wave system on chips (SoCs) for high-volume applications. The project was driven by the vision of high-resolution millimetre wave sensors for distance, speed and angle measurement as miniaturized, highly integrated systems.

Within the SUCCESS project, the research teams achieved a milestone towards low-cost, miniature Radar sensors. Several prototypes of fully integrated Radar sensors at frequencies beyond 120 GHz were designed, fabricated, and successfully used for demo purposes.

Details can be found on the SUCCESS website [i.6] and in the various conference and journal papers as well as in the press releases of the project partners and the SUCCESS consortium.

5.2.2 RF2THz SiSoC project

To meet the needs of future radio frequency (RF) and high-speed equipment, the CATRENE RF2THz project aimed to develop silicon technology platforms for emerging RF, millimetre-wave (MMW) and THz consumer applications such as 77/120 GHz automotive Radars, MMW imaging and sensing, fast measurement equipment, 60 GHz wireless networking and fast downloading systems, 400 Gbit/s fibre optics data communications systems, 4G photonic mobile communications and high performance RF wireless communication systems as well as two-way satellite communications systems. It also targeted MMW and THz applications in health science, materials science, genetic screening, security and industrial automation.

To meet the needs of future Radio Frequency (RF) and high-speed equipment, the CATRENE RF2THz project aimed to investigate the potential and capability of three advanced technology platforms: 55 nm SiGeC BiCMOS from STMicroelectronics; the newest NXP BiCMOS which integrates Elite Passive devices; and the photonic devices based on the IHP SiGe BiCMOS.

It subsequently developed silicon technology platforms for emerging Radio Frequency (RF), MilliMetre-Wave (MMW) and TeraHertz (THz) consumer applications, such as:

- 77/120 GHz automotive Radars;
- MMW imaging and sensing, fast-measurement equipment;
- 60 GHz wireless networking and fast-downloading systems;
- 400 Gbit/s fibre optics data communications systems;
- 4G photonic mobile communications and high performance RF wireless communication systems;
- Two-way satellite communications;
- Label-free biosensing.

It also targets MMW and THz applications in health science, materials science, genetic screening, security and industrial automation.

More information concerning this project such as reports or press releases and other publications can be found on the project website [i.7].

5.2.3 NANOTEC project

The aim of the NANOTEC project was to significantly enhance the reliability of RF-MEMS switches by using nanostructured materials (e.g. as dielectrics) as well as to demonstrate highly adaptive and miniaturized telecommunication and RF-sensing circuits, antenna front-ends and systems enabled by monolithical integration of low-loss RF-MEMS switches in GaN/GaAs/SiGe IC foundry processes from OMMIC, IHP and TRT.

Future smart systems for communication and RF-sensing will have to achieve autonomous and self-reconfigurable operations, for real-time and efficient self-optimization of their performance. The needs for such reconfigurable systems are not only to overcome the design trade-offs that current analogue components should endure, but also to realize new and more efficient systems with improved functionality (i.e. better performance) as well as reduced size, weight, power and cost. The aim of the NANOTEC project was to develop new technology approaches and methodologies for existing as well as future generations of such highly adaptive and also reliable RF-systems to be integrated within T/R modules, smart active/passive and reflect array antennas, etc.

NANOTEC was funded by the European Commission by the FP7-ICT-2010-7 Theme 3. More information about this project can be found on the project website [i.8].

5.2.4 DOTFIVE project

DOTFIVE was aiming to establish a leadership position for the European semiconductor industry in the area of SiGe HBTs (Silicon-Germanium Heterojunction Bipolar Transistors) for millimetre wave applications, where semiconductor manufacturers like STMicroelectronics and Infineon Technologies are involved. Emerging high-volume millimetre wave applications encompass, for example, 77 GHz automotive Radar applications and 60 GHz WLAN (Wireless Local Area Network) communication systems.

In addition to the still evolving market for Radar based anti-collision systems in cars, DOTFIVE technology set out to be a key enabler for silicon-based millimetre wave circuits penetrating the so-called THz gap, enabling enhanced imaging systems with applications in the security, medical and scientific area.

The DOTFIVE project is finished since July 2011 and was supported by the European Commission through the Seventh Framework Programme for Research and Technological Development. More information can be found on the DOTFIVE project website [i.9].

6 Market information

6.1 Overview

The provision of new frequency bands above 120 GHz for applications like those identified in clause 5.1 goes along with the utilization of new semiconductor technologies. The SUCCESS-project [i.6] showed that the necessary semiconductor technologies are already available but the currently available frequency regulation is not yet usable for most of the proposed applications. The 1 GHz available bandwidth in the 122 GHz to 123 GHz ISM-band and the 2 GHz wide ISM band from 244 GHz to 246 GHz are in most cases not sufficient to solve the specific measurement task. The manufacturers of sensor equipment face therefore the current situation where a missing regulation constrains the development of new sensors although the technology is ready.

Therefore an exact market analysis and a prediction into 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 is existent.

6.2 Market potential for thickness measurement sensors in the plastic pipes production industry

According to market research company Freedonia Group Inc. in 2010 eight Billion metres of plastic pipes were produced. This means processing of 15,8 Million tons of expansive and more and more scarce raw material. This number will be doubled by the year 2020. The rise in plastic pipes production will be doubled from 3,4 % in 2010 to 7,3 % in 2015. Pipes made of plastic have advantages in comparison with materials like Aluminium, copper, steel or concrete. These are for example:

- lightweight;
- corrosion-free;
- high chemical resistance;
- convenient handling;
- low cost installation;
- long lifetime;
- high security level.

This is the reason why plastic pipes have a growing importance and in some application fields, e.g. for water supply they are essential. There are also effects of substitution of metal and concrete pipes by plastic pipes. Different applications require pipes with diameters from 0,5 mm, e.g. in medical applications, to large pipes with diameters up to 2,5 m for gas or water. The extruded plastics market is projected to grow from USD 184,34 Billion in 2016 to USD 291,74 Billion by 2026, at a CAGR of 4,7 % between 2016 and 2026 (source: MarketsandMarkets).

Because of economic and ecological reasons, manufacturers of pipes focus to innovative pipe-structures for example with layers of foamed materials. Traditional measurement techniques such as ultrasonic reach their limit for conventional pipes and fail completely for innovative pipes with multi-layer construction.

The solutions are measurement principles with wideband UWB techniques. The advantages are: completely contact-free operation, non-ionizing radiation and temperature-independent results. With the exact measurement of wall thicknesses, large amounts of raw material can be saved. According to the Freedonia Group, 438 000 tons of raw materials could be saved in the year 2020. Thus, in one large production line for big pipes the yearly expenses can be reduced by several 100 000 €.

7 Technical information

7.1 Detailed technical description

7.1.0 General information

The technical parameters in the following clauses 7.1.1 to 7.1.4 are applicable to all use cases identified in clause 5.1. It is proposed to divide the different applications into three categories relating to the severity of their interference potential to other spectrum users.

Type A is intended for applications where the individual sensors may radiate into the open sky outside a shielded environment or housing and is therefore most critical. Type A applications can be divided into outdoor and indoor use. Examples for type A applications are living object detection and surveillance (clause 5.1.2.2) or building deformation measurements with interferometric Radar (clause 5.1.4.2).

For this type of application typical environments are urban areas (indoor and outdoor). Aggregation effects may only occur in case of the living object detection and surveillance application if numerous sensors are located in close proximity. In other use cases aggregation effects are very unlikely because of the unsynchronized nature and low duty cycle of the individual devices.

Type B is intended for outdoor applications where the sensors always radiate in a downward direction towards the ground (and thus not directly into the open sky) outside a shielded environment or a housing. Type B applications are less critical in terms of interference compared to type A. Examples for type B applications are contour detection (clause 5.1.1.2), level probing (clause 5.1.3.1) or contactless flow measurement (clause 5.1.2.3).

For this type of application typical environments are industrial areas (indoor and outdoor). Aggregation effects are highly unlikely due to a low density of devices, the increased FSL in the higher frequency bands, the larger distances between individual sensors and the unsynchronized nature and low duty cycle of the individual devices.

Type C is intended for indoor and outdoor applications emitting inside a confined and shielded environment or housing. Because of radiating inside or into a shielded environment type C applications are least critical. Examples for type C applications are (Tank) level probing Radar e.g. inside a closed metallic or concrete tank (clause 5.1.3.1) or high precision distance measurements in pneumatic cylinders (clause 5.1.3.2).

For this type of application typical environments are industrial areas and construction sites (indoor and outdoor). Aggregation effects are not possible due to the electromagnetic shielding of the environment.

The following technical parameters are divided into transmitter and receiver parameters (clauses 7.1.1 and 7.1.2) as well as antenna requirements (clause 7.1.3) and mitigation techniques (clause 7.1.4).

Suitable limits and regulations for all these parameters allow the limitation of the emissions and the mitigation of interference against other spectrum users as well as the definition of the resilience against interfering signals from other radio services.

7.1.1 Transmitter Parameters

7.1.1.1 Permitted frequency range of operation

The permitted frequency ranges of operation are the assigned frequency bands for the individual device under test. The proposed frequency bands for the different type A, B and C sensor applications are defined in clause 8.

7.1.1.2 Operating bandwidth

The operating bandwidth includes all frequencies on which the equipment is authorized to operate within one or more of the permitted frequency ranges of operation. The operating bandwidth is measured for example as the 10 dB bandwidth.

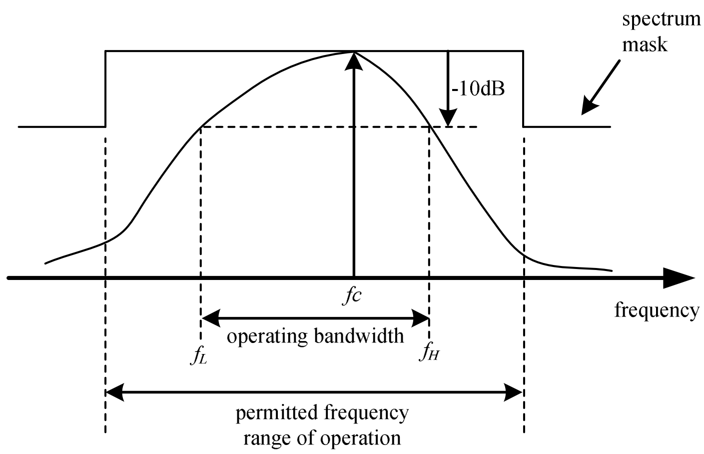

Figure 11: Definition of the operating bandwidth

The desired operating bandwidth should be at least 20 GHz or 15 % of the start frequency. With more than 20 GHz bandwidth the benefit-cost-ratio (range resolution, doppler resolution, smaller sensor size, reduced minimal measurement distance, better angular resolution vs. sensor costs) compared to systems operated at lower frequencies with smaller bandwidths will increase significantly.

7.1.1.3 Transmitter emissions within the operating bandwidths

The **maximum value of peak power** is defined as the equivalent isotropically radiated power (e.i.r.p.) contained in a 50 MHz bandwidth within the permitted frequency range of operation, radiated in the direction of main radiation (main lobe of the antenna).

The **maximum mean power spectral density (**specified as the equivalent isotropically radiated power e.i.r.p.) of the radio device under test at a particular frequency is the average power per unit bandwidth centred on that frequency radiated in the direction of main radiation (main lobe of the antenna).

The maximum peak power and the maximum mean power spectral density can effectively be measured in the direction of 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 DUT exhibits a suitable antenna connector.

Based on the current available technologies the conducted peak power can reach values up to 10 dBm. Present ASICs are designed to target a conducted peak output power of 5 dBm. First sample chips already showed up to 2 dBm peak power where an increase is shortly expected.

In frequency ranges above 120 GHz compact antenna designs with a maximum gain of 40 dB are feasible, thus a maximum value of peak power of 50 dBm e.i.r.p. (measured in 50 MHz bandwidth) should be aspired.

For type B and C applications (Figure 12 and Figure 13), the half sphere concept describes a practical approach to ensure for example the limitation of the maximum mean power spectral density (e.i.r.p), seen by a victim Rx antenna outside a half sphere area around the sensor installation, to for example -41,3 dBm (e.i.r.p). This value is equivalent to an electrical field strength of 500 µV/m in a distance of 3 m.

Inside the half sphere area and especially inside the shielded environment (for type C applications), emissions higher than the proposed limit of -41,3 dBm (e.i.r.p.) may occur. This may particularly arise within the main lobe of the DUT's antenna.

Due to the reflection accompanied by an attenuation of the Tx-signal at the surface of the target (Figure 12) or due to the shielding property of the tank wall (Figure 13), the limit is then fulfilled on any half sphere around the sensor installation where other spectrum users may be located.

The correlation between the transmitter emissions measured on the half sphere and the values which are measured in the direction of main radiation (within the main lobe of the DUT's antenna), that means the reflection losses at the surface of the target and the tank wall attenuation, should be determined by studies or simulations (see [i.1], Annex 2).

The radius R of the half sphere (Figure 12 and Figure 13) should be determined from case to case based on the application and on the operating frequency.

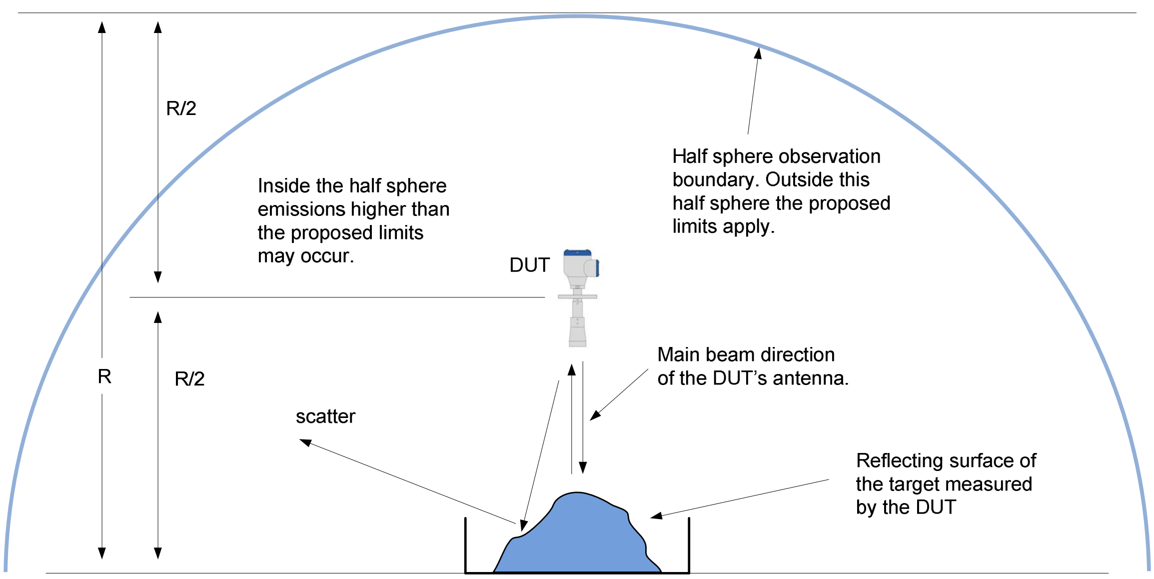

Figure 12: Illustration of the half sphere concept for type B applications

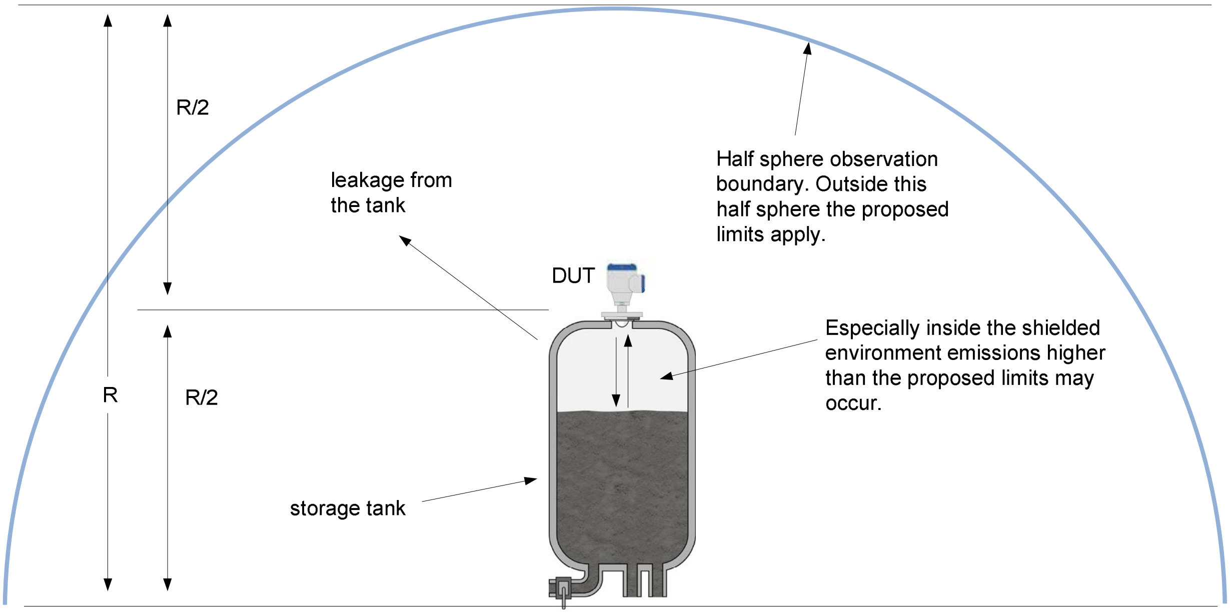

Figure 13: Illustration of the half sphere concept for type C applications

For type A applications due to their potential radiation into the open sky it may occur that other spectrum users are located within the main beam of the antenna. The limits for the transmitter emissions within the operating bandwidths should reflect this circumstance. In addition to that specific mitigation techniques could be developed to overcome potential arising interference effects in such constellations.

7.1.1.4 Transmitter (unwanted) emissions outside the operating bandwidths

The transmitter unwanted emissions are emissions from the radio device under test originating from the transmitter but outside the operating bandwidths. It is the average power per unit bandwidth (centred on that frequency) radiated in the direction of main radiation (main lobe of the antenna).

They are measured as maximum mean power spectral density (specified as e.i.r.p.) in the direction of main radiation of the radio device under test usually over a frequency range from 30 MHz to 2 $\times$ carrier frequency except for the operating bandwidth of the DUT.

The limit for the transmitter unwanted emissions outside the operating bandwidths is proposed to be 20 dB less than the maximum mean power spectral density within the operating bandwidths. This value is adopted from ETSI EN 302 729 [i.3], clause 4.3.8.

7.1.1.5 Other emissions

Transmitters often emit very low power radio signals, comparable with the power of spurious emissions from digital and analogue circuitry. If it can be clearly demonstrated that an emission from the DUT is not a transmitter emission (e.g. by disabling the device's transmitter) or it can clearly be demonstrated that it is impossible to differentiate between other emissions and the transmitter (unwanted) emissions, that emission or aggregated emissions should be considered against the other emission limits.

The proposed limits for other emissions can be found in Table 1. The limits are in line with the recommended values in CEPT/ERC/REC 74-01 [i.20].

Table 1: Proposed limits for other emissions

Frequency range	Limit
30 MHz to 1 GHz	-57 dBm (e.i.r.p.)
above 1 GHz	-47 dBm (e.i.r.p.)

7.1.2 Receiver Parameters

7.1.2.1 Receiver spurious emissions

Receiver spurious emissions are emissions of the receiver of the DUT when the equipment is in a receive-only mode or is a receive-only device. Consequently, receiver spurious emission testing should apply only when the equipment can work in a receive-only mode or is a receive-only device.

For collocated Tx/Rx equipment that does not have a receive-only mode, the receiver spurious emissions are usually considered within the scope of the transmitter parameter "other emissions".

The proposed limits for receiver spurious emissions can be found in Table 2. The limits are in line with the recommended values in CEPT/ERC/REC 74-01 [i.20].

Table 2: Proposed limits for receiver spurious emissions

Frequency range	Limit
30 MHz to 1 GHz	-57 dBm (e.i.r.p.)
above 1 GHz	-47 dBm (e.i.r.p.)

7.1.2.2 Interferer signal handling

Interferer signal handling is defined as the capability of the radio device under test to properly operate in the presence of an interfering input signal at the receiver without exceeding a given degradation. The allowed degradation should be determined application specific for every individual use case.

This quality of the radio device under test ensures a proper operation in an environment where several users share an assigned frequency band and demonstrates the efficient use of radio spectrum by way of an increased resilience against harmful interference in its operating bandwidth.

The concept of interferer signal handling is currently being revised by the ETSI Specialist Task Force (STF) 541 "Signal interferer handling, a new RX requirement to cover the essential requirements of article 3.2 of the RED directive [i.21]". The outcome of this work should be taken into account. Because of this pending process further details and limits for this Rx parameter are not yet proposed.

7.1.3 Antenna requirements

The restriction of the DUTs' antenna parameters may help to fulfil the limits defined in the half sphere concept (see Figure 12 and Figure 13) and thus may effectively ensure the protection of other radio users from sidelobe emissions and reflections or scattering of the transmit signal from the surface or object under surveillance in a sharing environment.

The antenna parameters which may be a subject of restriction are for example:

- the use of highly directional antennas;
- the requirement of a minimum antenna gain;
- the orientation of the antenna (e.g. maximum elevation angle);
- the sidelobe suppression of the antenna;
- the maximum beamwidth (HPBW) of the antenna.

The necessity of certain antenna requirements should be determined at a later date in compatibility studies and/or simulations.

7.1.4 Mitigation techniques

7.1.4.0 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 radio services and applications in sharing environments. The application of mitigation techniques are mainly aimed at reducing the transmitter emissions within the operating bandwidths (see clause 7.1.1.3). However, also the transmitter (unwanted) emissions outside the operating bandwidths 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.

7.1.4.1 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 S/N ratio which is needed for a reliable measurement, the transmit power can be reduced until the minimum S/N 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 CEPT 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.

7.1.4.2 Activity factor (AF) and duty cycle (DC)

The **activity factor (AF)** is defined as the ratio of active measurement periods t_{meas} (bursts, sweeps, scans, etc.) within the overall repetitive measurement cycle T_{meas_cycle}, i.e.

$$AF = \frac{t_{meas}}{T_{meas\_cycle}}$$

The activity factor is also sometimes referred to as "duty cycle resulting from user" in some sources dealing with UWB devices. The technique of spreading subsequent Tx pulses on different frequencies can be used as an additional mitigation technique.

EXAMPLE (with typical values):

> FMCW Radars which use single frequency ramps or short sequences of frequency ramps usually apply ramp duration times between 100 µs and 2 ms. The repetition rates of single ramps or ramp sequences typically lie between 1 to 25 per second. This results in a typical (maximum) activity factor of:

$$AF = \frac{25 \times 2ms}{1000\ ms} = 5\ \%.$$

The **duty cycle (DC)** is defined as the product of the pulse repetition frequency (PRF) and the pulse duration (t_{pulse}) during an active measurement period t_{meas}.

For pulse modulation for example, the transmit signal is periodically switched on for a short time (called pulse duration) and switched off during the subsequent reception period until the next pulse is transmitted.

For FMCW modulation for example a duty cycle smaller than 100 % is existent if the overall frequency sweep is interrupted several times with the transmit signal switched off during this interruption period. This modulation scheme is closely related to the stepped frequency continuous wave (SFCW) modulation technique.

In sources dealing with UWB devices the duty cycle is sometimes called "duty cycle resulting from modulation" and is defined as:

$$DC = PRF \times t_{pulse} = \frac{t_{pulse}}{PRI}$$

The activity factor and duty cycle can easily be implemented in sensor architectures and can as well serve as an effective method to reduce the probability of interference against other spectrum users.

7.1.4.3 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 bandwidth (clause 7.1.1.2) 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 (with typical values):

- SFCW modulation:
  - A DMR sensor with a stepped frequency continuous wave (SFCW) modulation sweeps 4 000 steps within a period of 80 ms. At each consecutive step the DMR sensor transmits a 2,5 MHz increased frequency with a dwell time of 20 µs. These parameters result in a total operating bandwidth of 10 GHz.
  - For a 250 MHz victim receiver bandwidth the equivalent frequency domain mitigation yields:

$$\frac{100\ steps \times 20\ \mu s}{80\ ms} = 2{,}5\ \%.$$

  - The value of 2,5 % is equivalent to a mitigation factor of -16 dB.

- 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 10 GHz is swept within a ramp duration of 2 ms, a 250 MHz victim receiver is only affected within the time period of:

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

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

$$\frac{50\ \mu s}{2\ ms} = 2{,}5\ \%$$

or -16 dB.

7.1.4.4 Shielding effects

The wall shielding of a tank or a pipe made out 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, Annex E [i.2].

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 out of metal or concrete or a floating roof tank inside a cylindrical metallic wall can serve in this case as additional shielding.

An additional shielding effect could be provided by the outer walls and other structures of a building if the device is only used indoors and the victim receiver is located outdoors. In the ECC Report 139 the additional attenuation in case of indoor use is stated as 10 dB at 7 GHz, 15 dB at 24 GHz, 20 dB at 57 GHz, 25 dB at 75 GHz (CEPT ECC Report 139 [i.1], clause 2.2, page 10). Based on these numbers, in the proposed frequency bands in clause 8, a significantly higher shielding attenuation of a building can be expected.

7.1.4.5 Detect And Avoid (DAA)

The detect and avoid mechanism is an active mitigation technique for the protection of sensitive potential victim systems in the vicinity of the DUT based on a sensing approach including an active reduction of the interference potential if required (see ETSI TR 103 181-2 [i.17] and ETSI TS 102 754 [i.18]).

7.1.4.6 Listen-Before-Talk (LBT)

Listen-Before-Talk (LBT) is a specific Detect And Avoid (DAA) mechanism (see clause 7.1.4.5) where a given (operating) bandwidth is made "unavailable" because an interfering signal was detected before any transmission in that frequency band has been conducted.

Other forms of DAA mechanisms are possible where for example a given (operating) bandwidth is made "unavailable" or the start/stop frequency of FMCW-systems will be adjusted because an interfering signal was detected after transmissions in that frequency band have been conducted.

It should be noted that the mitigation techniques DAA and LBT are considered not reasonable for the shielded type C applications (see clause 7.1). They might be optionally applied for certain type A and B applications where necessary and feasible.

7.1.4.7 Equivalent mitigation techniques

Equivalent mitigation techniques which are currently not yet available can be taken into account as a placeholder. These hypothetical future mitigation techniques should be at least as effective as the demanded traditional ones and should result at least in the same mitigation factor.

7.2 Status of technical parameters

7.2.1 Current ITU and European Common Allocations

According to ITU Radio Regulations 2016 [i.10] the following allocations to services apply.

119.98-151.5 GHz		
Allocation to services		
Region 1	**Region 2**	**Region 3**
119.98-122.25	EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562C SPACE RESEARCH (passive) 5.138 5.341	
122.25-123	FIXED INTER-SATELLITE MOBILE 5.558 Amateur 5.138	
123-130	FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) RADIONAVIGATION RADIONAVIGATION-SATELLITE Radio astronomy 5.562D 5.149 5.554	
130-134	EARTH EXPLORATION-SATELLITE (active) 5.562E FIXED INTER-SATELLITE MOBILE 5.558 RADIO ASTRONOMY 5.149 5.562A	
134-136	AMATEUR AMATEUR-SATELLITE Radio astronomy	
136-141	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.149	
141-148.5	FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149	
148.5-151.5	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	

151.5-158.5 GHz		
Allocation to services		
Region 1	**Region 2**	**Region 3**
151.5-155.5	FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149	
155.5-158.5	EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.562F 5.562G	

158.5-200 GHz		
Allocation to services		
Region 1	**Region 2**	**Region 3**
158.5-164	FIXED FIXED-SATELLITE (space-to-Earth) MOBILE MOBILE-SATELLITE (space-to-Earth)	
164-167	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	
167-174.5	FIXED FIXED-SATELLITE (space-to-Earth) INTER-SATELLITE MOBILE 5.558 5.149 5.562D	
174.5-174.8	FIXED INTER-SATELLITE MOBILE 5.558	
174.8-182	EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562H SPACE RESEARCH (passive)	
182-185	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	
185-190	EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562H SPACE RESEARCH (passive)	
190-191.8	EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive) 5.340	
191.8-200	FIXED INTER-SATELLITE MOBILE 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.149 5.341 5.554	

200-248 GHz		
Allocation to services		
Region 1	**Region 2**	**Region 3**
200-209	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 5.563A	
209-217	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY 5.149 5.341	
217-226	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.341	
226-231.5	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340	
231.5-232	FIXED MOBILE Radiolocation	
232-235	FIXED FIXED-SATELLITE (space-to-Earth) MOBILE Radiolocation	
235-238	EARTH EXPLORATION-SATELLITE (passive) FIXED-SATELLITE (space-to-Earth) SPACE RESEARCH (passive) 5.563A 5.563B	
238-240	FIXED FIXED-SATELLITE (space-to-Earth) MOBILE RADIOLOCATION RADIONAVIGATION RADIONAVIGATION-SATELLITE	
240-241	FIXED MOBILE RADIOLOCATION	
241-248	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.138 5.149	

Footnotes:

5.138 *The following bands:*

6 765-6 795 kHz	*(centre frequency 6 780 kHz),*
433.05-434.79 MHz	*(centre frequency 433.92 MHz) in Region 1 except in the countries mentioned in No.* ***5.280****,*
61-61.5 GHz	*(centre frequency 61.25 GHz),*
122-123 GHz	*(centre frequency 122.5 GHz), and*
244-246 GHz	*(centre frequency 245 GHz)*

are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant Recommendation ITU-R Recommendations.

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)*

5.340 *All emissions are prohibited in the following bands:*

1 400-1 427 MHz,

2 690-2 700 MHz, *except those provided for by No. **5.422**,*

10.68-10.7 GHz, *except those provided for by No. **5.483**,*

15.35-15.4 GHz, *except those provided for by No. **5.511**,*

23.6-24 GHz,

31.3-31.5 GHz,

31.5-31.8 GHz, *in Region 2,*

48.94-49.04 GHz, *from airborne stations*

50.2-50.4 GHz,

5.340.1 *The allocation to the Earth exploration-satellite service (passive) and the space research service (passive) in the band 50.2-50.4 GHz should not impose undue constraints on the use of the adjacent bands by the primary allocated services in those bands. (WRC-97)*

52.6-54.25 GHz,

86-92 GHz,

100-102 GHz,

109.5-111.8 GHz,

114.25-116 GHz,

148.5-151.5 GHz,

164-167 GHz,

182-185 GHz,

190-191.8 GHz,

200-209 GHz,

226-231.5 GHz,

250-252 GHz. (WRC-03)

5.341 *In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin.*

5.554 *In the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 123-130 GHz, 191.8-200 GHz and 252-265 GHz, satellite links connecting land stations at specified fixed points are also authorized when used in conjunction with the mobile-satellite service or the radionavigation-satellite service. (WRC-2000)*

5.558 *In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No.* ***5.43****). (WRC-2000)*

5.562A *In the bands 94-94.1 GHz and 130-134 GHz, transmissions from space stations of the Earth exploration-satellite service (active) that are directed into the main beam of a radio astronomy antenna have the potential to damage some radio astronomy receivers. Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible. (WRC-2000)*

5.562B *In the bands 105-109.5 GHz, 111.8-114.25 GHz, 155.5-158.5 GHz and 217-226 GHz, the use of this allocation is limited to space-based radio astronomy only. (WRC-2000)*

5.562C *Use of the band 116-122.25 GHz by the inter-satellite service is limited to satellites in the geostationary-satellite orbit. The single-entry power flux-density produced by a station in the inter-satellite service, for all conditions and for all methods of modulation, at all altitudes from 0 km to 1 000 km above the Earth's surface and in the vicinity of all geostationary orbital positions occupied by passive sensors, shall not exceed -148 dB(W/(m^2 · MHz)) for all angles of arrival. (WRC-2000)*

5.562D *Additional allocation: In Korea (Rep. of), the frequency bands 128-130 GHz, 171-171.6 GHz, 172.2-172.8 GHz and 173.3-174 GHz are also allocated to the radio astronomy service on a primary basis. Radio astronomy stations in Korea (Rep. of) operating in the frequency bands referred to in this footnote shall not claim protection from, or constrain the use and development of, services in other countries operating in accordance with the Radio Regulations. (WRC-15)*

5.562E *The allocation to the Earth exploration-satellite service (active) is limited to the band 133.5-134 GHz. (WRC-2000)*

5.562F *In the band 155.5-158.5 GHz, the allocation to the Earth exploration-satellite (passive) and space research (passive) services shall terminate on 1 January 2018. (WRC-2000)*

5.562G *The date of entry into force of the allocation to the fixed and mobile services in the band 155.5-158.5 GHz shall be 1 January 2018. (WRC-2000)*

5.562H *Use of the bands 174.8-182 GHz and 185-190 GHz by the inter-satellite service is limited to satellites in the geostationary-satellite orbit. The single-entry power flux-density produced by a station in the inter-satellite service, for all conditions and for all methods of modulation, at all altitudes from 0 to 1 000 km above the Earth's surface and in the vicinity of all geostationary orbital positions occupied by passive sensors, shall not exceed –144 dB(W/(m^2 · MHz)) for all angles of arrival. (WRC-2000)*

5.563 *(SUP - WRC-03)*

5.563A *In the bands 200-209 GHz, 235-238 GHz, 250-252 GHz and 265-275 GHz, ground-based passive atmospheric sensing is carried out to monitor atmospheric constituents. (WRC-2000)*

5.563B *The band 237.9-238 GHz is also allocated to the Earth exploration-satellite service (active) and the space research service (active) for spaceborne cloud radars only. (WRC-2000)*

7.2.2 Sharing and compatibility studies already available

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 radio communication 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 could easily be used as reference for the higher frequency ranges requested in the present document.

ECC Report 190 [i.13] (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 reference for potential studies against EESS (passive) in the bands 120-260 GHz.

7.2.3 Sharing and compatibility issues still to be considered

The request in the present document is to get a continuous amount of spectrum in the range 120-260 GHz according to clause 8. Therefore the compatibility situation depends on the selected frequency range. Below is a summary of the most relevant primary radio users and frequencies.

EESS (passive) and Radio astronomy:

Most allocations are according to the following footnotes of the ITU-R Radio Regulations [i.10]:

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

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

When considering these two ITU-R Radio Regulations [i.10] footnotes then the situation is as follows in the range 120-260 GHz:

- Bands protected by the very strict footnote 5.340: 148,5-151,5 GHz, 164-167 GHz, 182-185 GHz, 190-191,8 GHz, 200-209 GHz, 226-231,5 GHz and 250-252 GHz.

- Bands with the less restrictive footnote 5.149: 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.

Other radio users:

The use of the band 120-260 GHz by other radio users is not fully clear yet. One known activity was recently conducted in CEPT regarding the Fixed Service. CEPT has studied in SE19 the possible use of the Fixed Service in the range 130-175 GHz. This work was suggested by ETSI ISG mWT in 2015. The SE19 work item (SE19_38) contains the following:

- Deliverable: ECC Recommendation (18)01 [i.22] and ECC Report 282 [i.23] containing guidelines on deployment of fixed services operating in the allocated bands 130-134 GHz, 141-148,5 GHz, 151,5-164 GHz and 167-174,8 GHz.
- The bands 130-134 GHz, 141-148,5 GHz, 151,5-164 GHz and 167-174,8 GHz are already allocated for fixed services in RR.
- The study has been conducted in order to examine future requirements in the fixed services (e.g. deployment scenarios, propagation models, radio channel arrangements, etc.).
- Sharing and compatibility was also considered as required. Doc.SE19(15)29 for background.
- A single ECC Report 282 [i.23] has been produced and approved in September 2018 to respond to work items SE19_37 and SE19_38.

7.3 Information on relevant standards

Table 3: Information on relevant standards

Type	Application	Frequency Ranges [GHz]	ETSI Standard	Status	Remark	Responsible ETSI TC ERM
Generic	Short Range Devices (SRD)	40 to 246 GHz	ETSI EN 305 550 [i.11]	EN Approval Procedure (ENAP) started	RED compliant	TG28
SRD	Tank Level Probing radar (TLPR)	4,5 to 7 GHz, 8,5 to 10,6 GHz, 24,05 to 27 GHz, 57 to 64 GHz, 75 to 85 GHz	ETSI EN 302 372 [i.2]	Cited in the OJEU	RED compliant	TGUWB
SRD	Level Probing Radar (LPR)	6 to 8,5 GHz, 24,05 to 26,5 GHz, 57 to 64 GHz, 75 to 85 GHz	ETSI EN 302 729 [i.3]	Cited in the OJEU	RED compliant	TGUWB
Amateur	Commercially available amateur radio equipment	not specified in the standard	ETSI EN 301 783 [i.14]	Cited in the OJEU	RED compliant	TG26

8 Radio spectrum request and justification

The future use cases considered in the scope of the present document (see clause 5.1) can be rated as fixed or quasi-fixed radiodetermination applications and can be categorized into three types based on the severity of their interference potential:

- **Type A:** Applications emitting into free space outside a shielded environment or a housing. Type A applications can be divided into outdoor and indoor use. In case of an indoor use an additional indoor to outdoor attenuation should be taken into account (see clause 7.1.4.4):
  - Examples: Living object detection and surveillance (clause 5.1.2.2) or building deformation measurements with interferometric Radar (clause 5.1.4.2).

Table 4: Proposed limits for maximum peak power and mean power spectral density for type A applications

maximum peak power	50 dBm e.i.r.p.	in the direction of main radiation
maximum mean power spectral density	-41,3 dBm/MHz e.i.r.p.	in the direction of main radiation

EXAMPLE:

A reduction from 50 dBm e.i.r.p. maximum peak power to a mean power spectral density of -41,3 dBm/MHz can only be achieved by applying several mitigation techniques (see clause 7.1.4). For the following calculation example the activity factor and the frequency domain mitigation are applied with suitable values.

An FMCW Radar uses a single frequency ramp with a duration time of 1 ms. If a bandwidth of for example 10 GHz is swept within the ramp duration of 1 ms, a 1 MHz victim receiver is only affected within the time period of:

$$\frac{1\ \text{MHz}}{10\ \text{GHz}} \times 1\text{ms} = 100\ \text{ns}.$$

This results in a frequency domain mitigation factor of

$$\frac{100\ \text{ns}}{1\ \text{ms}} = 0{,}01\ \%$$

or equal to -40 dB.

In order to achieve an additional reduction of 51,3 dB a very low activity factor could be applied for example. This means in fact that the FMCW Radar transmits a single linear ramp (of duration 1 ms) every 135 seconds.

There are of course other mitigation techniques (see clause 7.1.4) which can be applied in this case in order to sustain a higher activity factor.

- **Type B:** Outdoor applications emitting in a downward direction towards the ground outside a shielded environment or housing:
  - Examples: Contour detection (clause 5.1.1.2), level probing (clause 5.1.3.1) or contactless flow measurement (clause 5.1.2.3).

Table 5: Proposed limits for maximum peak power and mean power spectral density for type B applications

maximum peak power	50 dBm e.i.r.p.	in the direction of main radiation
maximum mean power spectral density	-41,3 dBm/MHz e.i.r.p.	outside a half sphere area around the sensor installation (Figure 12: Illustration of the half sphere concept for type B applications)

- **Type C:** Applications emitting inside a confined and shielded environment or a housing. Type C applications can also be operated indoors (e.g. tank level probing Radar inside a closed metallic tank which is located inside a factory building). In case of an indoor use an extra (indoor to outdoor) attenuation of > 40 dB in addition to the inherent attenuation of the shielded environment should be taken into account (see clause 7.1.4.4):
  - Examples: (Tank) level probing Radar e.g. inside a closed metallic or concrete tank (clause 5.1.3.1) or high precision distance measurements in pneumatic cylinders (clause 5.1.3.2).

Table 6: Proposed limits for maximum peak power and mean power spectral density for type C applications

maximum peak power	50 dBm e.i.r.p.	in the direction of main radiation
maximum mean power spectral density	-41,3 dBm/MHz e.i.r.p.	outside a half sphere area around the sensor installation and outside the shielded environment (see Figure 13: Illustration of the half sphere concept for type C applications)

Type A applications are most critical since up to -41,3 dBm/MHz e.i.r.p.(mean) and 50 dBm e.i.r.p (peak) could be emitted into free space. Mitigation techniques have to be developed (antenna requirements, indoor to outdoor attenuation, activity factor and duty cycle, etc.). Outdoor coexistence with the fixed service sharing the same band could be challenging. Therefore the bands under investigation in SE19 (130-134 GHz, 141-148,5 GHz, 151,5-164 GHz and 167-174,8 GHz) should be discussed with SE19. The coexistence with the RAS according to footnote 5.149 in clause 7.2.3 should be studied and possibly adequate mitigation factors need to be developed:

- Reasonable bands for type A applications with more than 10 GHz BW could be: 209-226 GHz or 231,5-250 GHz.
- Reasonable bands for type A applications with up to 10 GHz BW could be in addition: 120-130 GHz, 134-141 GHz, 174,8-182 GHz.

Type B applications are much less critical compared to type A. Much experience is available from ECC Report 139 [i.1] and ECC/DEC(11)02. Type B applications are able to coexist according to ECC Report 139 [i.1] with the fixed service and radio astronomy service (RAS). In addition the path loss is increasing with 20dB/decade so that an additional mitigation factor applies (e.g. 20 dB additional path loss at 240 GHz compared to 24 GHz). However, maximum elevation angles of the antenna main beam direction relative to the strict vertical downward orientation should be determined. So, for type B applications it should be no problem to use the bands listed under footnote 5.149 in clause 7.2.3 for the protection of RAS and also to use the bands under development for the fixed service:

- The desired bandwidth should be 20 GHz or 15 % of the start frequency. With less than 10 GHz bandwidth, the advantages of the new bands are questionable.

  Reasonable bands for type B applications could be: 120-148,5 GHz, 151,5-164 GHz, 167-182 GHz, 209-226 GHz or 231,5-250 GHz.

Type C applications are least critical compared to type A and B since they are exclusively operated inside shielded environments such as concrete containers or pneumatic cylinders made out of metal for example. For such applications adequate installation requirements should be developed and made compulsory for the users and installers of the devices. An example for specific installation requirements for tank level probing Radar equipment can be found in ETSI EN 302 372 [i.2], annex E.

In addition to that the requirements for a typical shielded environment should be defined for the respective use case for testing the individual device. These requirements will then be used by test-houses for testing the equipment in the correct situation and environment. A similar concept is pursued with the test tank for tank level probing Radars in ETSI EN 302 372 [i.2], annex F:

- For type C applications the full bandwidth from 120 to 260 GHz should be considered.

9 Regulations

9.1 Current regulations

There are currently only Short Range Devices (SRD) frequency allocations from 122 to 123 GHz and 244 to 246 GHz intended for non-specific short range devices [i.15]. These frequency bands with bandwidths of 1 GHz and 2 GHz, respectively, are not sufficient to achieve the desired measurement objectives which are described in clause 5.1.

9.2 Proposed regulation

Table 7: Proposed regulatory parameters for the different frequency bands in dependence on ERC Recommendation 70-03 [i.15], Annex 6

Frequency Band	Power/Magnetic Field	Spectrum access and mitigation requirements	Modulation/ maximum occupied bandwidth	Notes
120-130 GHz 134-141 GHz 174,8-182 GHz 209-226 GHz 231,5-250 GHz	50 dBm peak e.i.r.p. in the direction of main radiation -41,3 dBm/MHz mean e.i.r.p. in the direction of main radiation	To be defined (see clause 8)	Not specified	For type A applications. Indoor and outdoor use possible.
120-148,5 GHz 151,5-164 GHz 167-182 GHz 209-226 GHz 231,5-250 GHz	50 dBm peak e.i.r.p. in the direction of main radiation -41,3 dBm/MHz mean e.i.r.p. outside the half sphere area	To be defined (e.g. max. elevation angle, see clause 8)	Not specified	For type B applications. Definition of half sphere area necessary.
120-260 GHz	50 dBm peak e.i.r.p. in the direction of main radiation -41,3 dBm/MHz mean e.i.r.p. outside the shielded test environment and outside the half sphere area	Not specified	Not specified	For type C applications. Definition of half sphere area and shielded test environment necessary. Indoor and outdoor use possible.

Annex A: Commercially available sensor systems

A.1 (Tank) level probing Radar

A.1.0 General

Today the use of Radar for distance measurement is a state-of-the-art technology and in many applications the most reliable and accurate measuring technique available. The development of such Radar sensors has been supported by the evolution of microwave technology over the last 25 years.

The currently available harmonised frequency bands for (T)LPR applications are summarized in Table A.1.

Table A.1: Current available harmonised frequency bands for (T)LPR equipment

<table>
<tr><th>Tank level probing Radar (TLPR)</th><th>Level probing Radar (LPR)</th></tr>
<tr><td>4,5 to 7 GHz</td><td rowspan="2">6 to 8,5 GHz</td></tr>
<tr><td>8,5 to 10,6 GHz</td></tr>
<tr><td>24,05 to 27 GHz</td><td>24,05 to 26,5 GHz</td></tr>
<tr><td>57 to 64 GHz</td><td>57 to 64 GHz</td></tr>
<tr><td>75 to 85 GHz</td><td>75 to 85 GHz</td></tr>
</table>

Tank Level Probing Radar (TLPR) and Level Probing Radar (LPR) sensors are used in many industries concerned with process control to measure the amount of various substances (mostly liquids and solids). Due to different chemical or physical properties of different liquids or solids, (T)LPR sensors are installed in a large variety of different storage, processing or transportation containers including:

- metallic tanks or tanks made of similar material (tankers, concrete silos, etc.);
- non-metallic tanks (plastic, glass);
- open air (dams, pools, piles, rivers, channels, etc.).

In many of these installations, (T)LPR devices provide process- safety critical, real-time information to protect humans, equipment and the environment. Examples of process- safety critical applications include:

- hydrological services (river or dam levels, wave height, tides, etc.);
- storing or processing hazardous substances (flammable and/or corrosive substances, acids, bases, etc.);
- storing solids in piles (sand, pebble stones, gravel, coal, pellets, wood chips, etc.).

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

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

Most of the applications where (T)LPRs are used can be found in the following industries:

- chemical plants;
- petrochemical plants like refineries, fuel depots;
- pharmaceutical plants;
- food and beverage industry;
- power plants (oil, coal, woodchips, hydro, etc.);

- building materials;
- cement industry;
- metal production;
- water and sewage treatment;
- oil and gas offshore;
- paper production industry;
- recycling and waste treatment;
- hydrological services (river monitoring, wave height monitoring, tsunami warning, etc.).

The main purposes of using (T)LPRs are:

- to increase industrial efficiency, quality and process control;
- to increase reliability by preventing harm and damage to humans and infrastructure;
- to improve environmental conditions in industrial production processes;
- to improve the efficient use of natural resources and of scarce goods.

(T)LPRs are the preferred measurement tool to achieve the above goals for the following reasons:

- Non-contact measurement methods are needed to measure aggressive, corrosive or poisonous substances or substances in extreme temperature or pressure conditions or in explosive atmospheres.
- Radar sensor technology is very robust against contamination and other adverse process conditions (like temperature, pressure, dust, air turbulence, corrosiveness, viscosity, mechanical forces, etc.) while other alternative solutions like ultrasonic or optical sensors may often be too sensitive and vulnerable in harsh environments.
- Superb measurement accuracy and repeatability even in difficult environments.

A.1.1 Level measurement in wood pellet silos

Until they are delivered, wood pellets are stored in silos of corrugated sheet metal up to 30 m high. The large storage capacity allows the supplier to respond to the increased demand during the heating season and utilize their production equipment continuously throughout the year. Reliable measurement of silo contents is necessary for optimized planning of material logistics. Unaffected by dust, temperature fluctuations and the corrugated vessel walls, it detects the filling height of the pellets in the storage silos with good reliability.

Measurement conditions:

Measurement range:	up to 30 m
Process temperature	-20…+40 °C
Process pressure:	1 bar
Measurement difficulties:	high dust levels, temperature fluctuations, corrugated container walls

Figure A.1: Level measurement in a wood pellet silo

A.1.2 Sea level measurement at the harbour wall

Tsunamis travel quickly and cause great damage when they hit land. So it is vital that tsunami warnings are issued early. Tsunami information centres continuously evaluate simultaneous data from seismic and sea level measuring stations. Such a sea level measuring station is operated by an oceanographic centre in a ferry and cargo-ship terminal. The measurement has to reliably and accurately detect the sea level and forward the data directly to the central monitoring system.

Measurement conditions:

Measurement range:	up to 10 m
Process temperature	+4…+20 °C
Process pressure:	1 bar
Measurement difficulties:	aggressive seawater, outdoor use

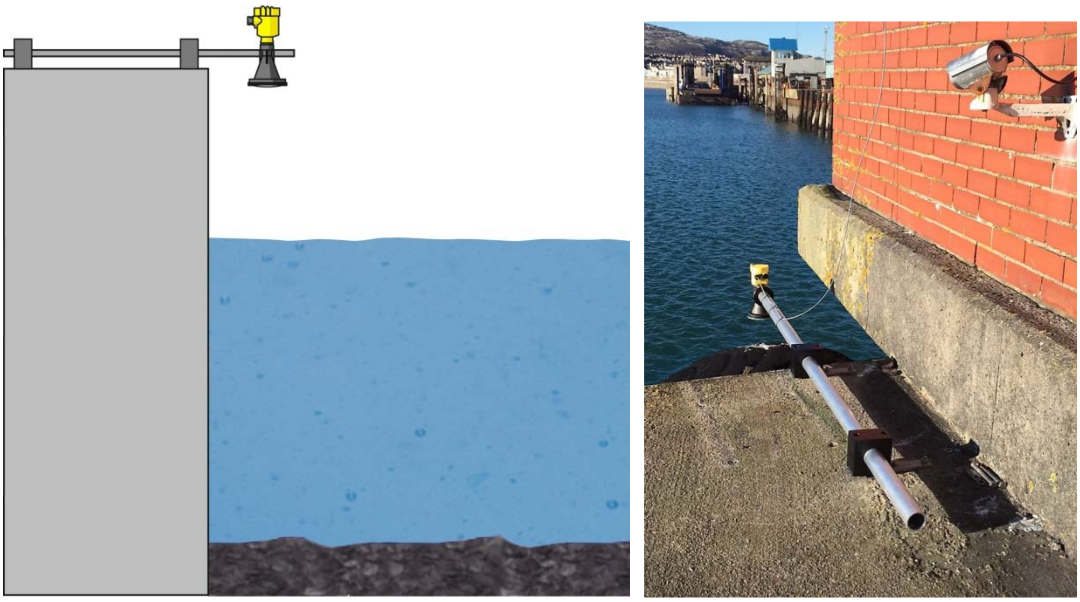

Figure A.2: Tsunami warning system at the harbour wall

Annex B: Bibliography

- ERC Recommendation 74-03 (2011): "Unwanted Emissions in the Spurious Domain", Cardiff.
- ETSI TR 103 181-3 (V1.1.1) (08-2016): "Short Range Devices (SRD) using Ultra Wide Band (UWB); Part 3: Worldwide UWB regulations between 3,1 and 10,6 GHz".
- European Commission Decision 2013/752/EU 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).

Annex C: Change History

Date	Version	Information about changes
22.03.2017		Creation of the document
29.03.2017		Outcome of ERMTGUWB#37 inserted
18.04.2017	1.1.1 0.0.1	Early draft - Outcome of ERMTGUWB-Drafting ETSI TR 103 498
27.06.2017	1.1.1 0.0.2	Early draft - Updated version in ERMTGUWB#39
15.09.2017	1.1.1 0.0.3	Early draft - Updated version for ERMTGUWB#40
13.11.2017	1.1.1 0.0.4	Early draft for ERMTGUWB#41
29.11.2017	1.1.1 0.0.5	Outcome TG UWB#41
26.01.2018	1.1.1 0.0.6	Stable draft for TG UWB remote consensus to collect final comments
22.03.2018	1.1.1 0.1.0	Stable draft with the comments from the remote consensus inserted for discussion in TGUWB#43
23.03.2018	1.1.1 1.0.0	Final draft for publication

History

Document history		
V1.1.1	February 2019	Publication