ETSI TR 103 314 V1.1.1 (2017-05)

TECHNICAL REPORT

**System Reference document (SRdoc);
Short Range Devices (SRD) using Ultra Wide Band (UWB);
Technical characteristics for SRD equipment
using Ultra Wide Band Sensor technology (UWB)
based on amended mitigation techniques for UWB**

Reference

DTR/ERM-557

Keywords

SRDoc, UWB

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

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

Siret N° 348 623 562 00017 - NAF 742 C
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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).

Ultra Wide Band technologies enable a very broad set of applications:

- Sensor and imaging applications.
- Communication applications.
- Hybrid application as a combination of sensor and communications.

In order to protect incumbent services in the operational bandwidth of the devices deploying ultra wide band technologies a set of application and band specific mitigation techniques are included in the relevant regulations [i.9], [i.10], [i.12], [i.13] and harmonised standards [i.2], [i.3], [i.4], [i.5]. The related homologation test procedures are or will be included into the ETSI EN 303 883 [i.1].

The present document will summarize these mitigation techniques, will propose new mitigation techniques and will evaluate the deployment of these mitigation techniques to protect incumbent services in the different operational frequency bands and applications.

The present document has been created by ETSI TC ERM TGUWB.

1 Scope

The present document provides information on existing and new mitigation techniques for the protection of incumbent services from harmful interference generated by devices deploying ultra-wide band technologies. It will evaluate the applicability of existing application specific mitigation techniques to other application domains and incumbent services. It will introduce new possible mitigation techniques.

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

- Detailed market information (annex A).
- Technical information (annex B).
- Expected compatibility issues (annex C).

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

[i.2] ETSI EN 302 065-1 (V2.1.1) (11-2016): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 1: Requirements for Generic UWB applications".

[i.3] ETSI EN 302 065-2 (V2.1.1) (11-2016): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 2: Requirements for UWB location tracking".

[i.4] ETSI EN 302 065-3 (V2.1.1) (11-2016): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 3: Requirements for UWB devices for ground based vehicular applications".

[i.5] ETSI EN 302 065-4 (V1.1.1) (11-2016): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 4: Material Sensing devices using UWB technology below 10,6 GHz".

[i.6] CEPT ECC/DEC/(06)04 of 24 March 2006 amended 9 December 2011: "The harmonised conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz".

[i.7] ECC Report 120 (March 2008): "ECC Report on Technical requirements for UWB DAA (Detect and avoid) devices to ensure the protection of radiolocation in the bands 3.1-3.4 GHz and 8.5-9 GHz and BWA terminals in the band 3.4-4.2 GHz".

[i.8] CEPT report 45: "Report from CEPT to the European Commission in response to the Fifth Mandate to CEPT on ultra-wideband technology to clarify the technical parameters in view of a potential update of Commission Decision 2007/131/EC"; Report approved on 21 June 2013 by the ECC. .

[i.9] Commission Decision 2009/343/EC of 21 April 2009 amending Decision 2007/131/EC on allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonized manner in the Community (notified under document number C(2009) 2787) (Text with EEA relevance).

[i.10] ECC/DEC/(07)01: "ECC Decision of 30 March 2007 on specific Material Sensing devices using Ultra-Wideband (UWB) technology (amended 26 June 2009)".

[i.11] ECC Report 170 (October, 2011): "ECC Report on Specific UWB Applications in the Bands 3.4 - 4.8 GHz and 6 - 8.5 GHz Location Tracking Applications for Emergency Services (LAES), Location Tracking Applications Type 2 (LT2) and Location Tracking and Sensor Applications for Automotive and Transportation Environments (LTA)", Tallinn, October, 2011.

[i.12] ECC Recommendation (11)09 on UWB Location Tracking Systems Type 2 (LT2), October 2011.

[i.13] ECC Recommendation (11)10 on Location Tracking Application for Emergency and Disaster Situations, October 2011.

[i.14] ECC Reports 94: "Technical requirements for UWB LDC devices to ensure the protection of FWA System", Nicosia, December 2006.

[i.15] Commission Decision 2014/702/EU of 7 October 2014 amending Decision 2007/131/EC on allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonised manner in the Community (notified under document C(2014) 7083).

[i.16] ETSI TR 103 416 (V1.1.1) (07-2016): "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical characteristics and spectrum requirements for UWB based vehicular access systems for operation in the 3,4 GHz to 4,8 GHz and 6 GHz to 8,5 GHz frequency ranges".

[i.17] ETSI TR 103 181-2 (V1.1.1) (06-2014): "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 103 060 (V1.1.1) (09-2013): "Electromagnetic compatibility and Radio spectrum Matters (ERM);Short Range Devices (SRD); Method for a harmonized definition of Duty Cycle Template (DCT) transmission as a passive mitigation technique used by short range devices and related conformance test methods".

[i.19] ETSI TR 103 181-1 (V1.1.1) (07-2015): "Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical Report Part 1: UWB signal characteristics and overview CEPT/ECC and EC regulation".

[i.20] ECC Reports 175 (March 2012): "Co-existence study considering UWB applications inside aircraft and existing radio services in the frequency bands from 3.1 GHz to 4.8 GHz and from 6.0 GHz to 8.5 GHz".

[i.21] CEPT report 17 (30 March 2007): "Report from CEPT to the European Commission in response to the Mandate to: identify the conditions relating to the harmonised introduction in the European Union of radio applications based on ultra-wideband (UWB) technology".

[i.22] ECC Reports 139 (February 2010): "Impact of level probing radars using Ultra-Wideband technology on radiocommunications services", Rottach-Egern.

[i.23] ECC Report 123 (September 2008): "The impact of object discrimination and characterization (ODC) applications using ultra-wideband (UWB) technology on radio services", Vilnius.

[i.24] ETSI EN 302 066 (V2.1.1) (01-2017): "Short Range Devices (SRD); Ground- and Wall- Probing Radar applications (GPR/WPR) imaging systems; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.25] ETSI EN 302 372 (V2.1.1) (12-2016): "Short Range Devices (SRD); Tank Level Probing Radar (TLPR) equipment operating in the frequency ranges 4,5 GHz to 7 GHz, 8,5 GHz to 10,6 GHz, 24,05 GHz to 27 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.26] ETSI EN 302 729 (V2.1.1) (12-2016): "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.27] ECC Report 253 (September 2016): "Compatibility studies for audio PMSE at 1492-1518 MHz and 1518-1525 MHz".

[i.28] ERC Recommendation 14-01 (May 2015): "Radio-frequency channel arrangements for high capacity analogue and digital radio-relay systems operating in the band 5925 to 6425 MHz".

[i.29] ERC Recommendation 14-02 (September 2014): "Radio-frequency channel arrangements for high, medium and low capacity digital fixed service systems operating in the band 6425 to 7125 MHz".

[i.30] ETSI TS 102 792 (V1.2.1) (06-2015): "Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range".

[i.31] Project HIGHTS Deliverable 2.1 (March 2015): "Use cases and Application Requirements".

[i.32] Recommendation ITU-R P.526-13 (11/2013): "Propagation by diffraction".

[i.33] ETSI TS 103 329 (V1.1.1) (06-2016):" Wireless Industrial Applications (WIA); Radio equipment to be used in the 5,725 GHz to 5,875 GHz frequency range with power level up to 400 mW; Methods and concepts for a WIA system approach to sharing in the 5,725 GHz to 5,875 GHz band".

[i.34] ETSI TS 102 800 (V1.1.1) (01-2011):"Electromagnetic compatibility and Radio spectrum Matters (ERM); Cognitive Programme Making and Special Events (C-PMSE); Protocols for spectrum access and sound quality control systems using cognitive interference mitigation techniques", January 2011.

[i.35] ECC Report 244:" Compatibility studies related to RLANs in 5725-5925 MHz", January 2016.

[i.36] ETSI TR 102 495-7 (V1.1.1) (03-2010): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB); Part 7: Location tracking and sensor applications for automotive and transportation environments operating in the frequency bands from 3,1 GHz to 4,8 GHz and 6 GHz to 8,5 GHz".

[i.37] ETSI EN 301 091-3: "Short Range Devices; Transport and Traffic Telematics (TTT); Radar equipment operating in the 76 GHz to 77 GHz range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU; Part 3: Railway/Road Crossings obstacle detection system applications".

[i.38] "Smart Parking Systems - Sensor and Communications Hardware, Software, Services, and Smart City Applications: Global Market Analysis and Forecasts" report by Navigant Research.

[i.39] "Global Electric Vehicle Charger Market 2016-2020" report by Technavio.

NOTE: Available at http://www.technavio.com/report/global-automotive-electronics-electric-vehicle-charger-market?utm_source=T4&utm_medium=BW&utm_campaign=Media.

[i.40] Wireless Charging REady for Burgeoning Mass Market in EVs, 18th August 2015.

NOTE: Available at http://www.wiseharbor.com/pdfs/WiseHarbor%20Spotlight%20Report%201%20Efficacy%202015Aug18.pdf.

[i.41] IEEE 802.15.4-2011TM: "IEEE Standard for Local and metropolitan area networks -- Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)".

[i.42] ETSI TR 102 495-3: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB); System Reference Document Part 3: Location tracking applications operating in the frequency band from 6 GHz to 9 GHz".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in ETSI EN 303 883 [i.1] and the following apply:

activity factor: reflects the effective transmission time ratio

active mitigation technique: mitigation technique based on some measurement or feedback from the channel or the operating environment where the transmitting device is operating

detect and avoid: active mitigation technique consisting in listening potential victim service in the transmission channel and, if any potential victim is detected, reducing the transmitted power accordingly

listen before talk: active mitigation technique consisting in listening potential victim service in the transmission channel before initiating a transmission and, if any potential victim is detected, avoid the transmission until the channel is free

(low) duty cycle: ratio of T_{on} and T_{period}: (L)DC = T_{on} / T_{period} = T_{on} /(T_{on} + T_{off})

NOTE: The duty cycle is conventionally referred as "low" duty cycle in case of small values (typically lower than 10 %).

mitigation technique: technique of controlling radiated power of a transmitting device, having the goal to reduce harmful interferences against potential victim services or applications operating in the same bandwidth of the transmitting device

passive mitigation technique: mitigation technique based on some a priori knowledge of the channel, the interferer transmitter, and the potential victim service or application to be protected

range resolution: ability to resolve two targets at different ranges

transmitter on time (T_{on}): duration of a burst irrespective of the number of pulses contained

transmitter off time (T_{off}): time interval between two consecutive bursts when the UWB emission is kept idle

3.2 Symbols

For the purposes of the present document, the symbols defined in ETSI TR 103 181-2 [i.17] apply.

3.3 Abbreviations

For the purposes of the present document, the abbreviations defined in ETSI TR 103 181-2 [i.17] and the following apply:

LIAT Location and industrial asset tracking

4 Comments on the System Reference document

Void.

5 Existing mitigation techniques

5.1 Background information

During the development of the UWB regulation frame work a broad range of coexistence studies have been carried out resulting in a set off regulations [i.9], [i.10], [i.12], [i.13] for a broad range of applications and frequency bands. In all of these regulation specific sets of mitigation factors and active mitigation techniques have been taken into account to protect the incumbent services in the operational band. A detailed technical summary of the existing mitigation techniques and the related parameters are given in ETSI TR 103 181-2 [i.17]. In some frequency ranges only a limited set of mitigation techniques are defined. In the following clauses the existing mitigation factors and techniques will be introduced and explained. This description will then be used to evaluate the potential of these techniques or factors for the protection of other incumbent systems not yet considered. As a result a harmonised view of the existing mitigation techniques will be developed. These existing techniques will then be complemented by new mitigation techniques described in clause 6.

5.2 Low Duty Cycle

5.2.1 Technical description

Duty Cycle (DC) is a passive mitigation technique often used in radio regulation and harmonised standards in order to enable spectrum sharing between different radio devices and/or radio applications. A duty cycle regulation is normally stated as a limitation to activity of a transmitter within certain time and power boundaries, e.g. allowing a defined percentage of transmission activity at some predefined levels of transmitted power.

In 2012 ETSI provided a technical specification, ETSI TS 103 060 [i.18], having the goal to harmonize different DC definitions existing in different standards. According to ETSI TS 103 060 [i.18], DC is defined as follows:

"*in very generic terms, Duty Cycle (DC) is a signal property that is the time spent in an active state as a fraction of the total time under consideration*".

Therefore, formally defined, the duty cycle, DC, is calculated as follows:

$$DC = \frac{T_{on}}{T_{on} + T_{off}}$$

In ETSI TS 103 060 [i.18] a more general parameter is defined, therein called *Duty Cycle Template* (DCT), which differs with respect to Duty Cycle are described as follows:

"DCT consists of an active transmission interval followed by an inactive idle interval. The combination of these two provides the basis for a mitigation technique to share spectrum. [...] *The crucial difference in the definition of DCT* [with respect to DC] *is that here DCT is defined not purely as a technical fraction of transmitter activity in a given period of time and on a given channel, but as an overall interference mitigation technique. In that sense, it requires transgressing the limits of a single transmission cycle and single channel, instead considering aggregate activity over a sufficiently long reference observation time and, if relevant, over multiple channels falling within the operational bandwidth of existing radio communication systems. As a result, the DCT requirement should define limits on individual transmission parameters in such a way, as to avoid harmful interference to victim system receivers even if they are operated in close physical proximity and in the same radio spectrum bandwidth.*"

A possible usage of DC (or DCT) as a passive mitigation technique, beyond the fact to impose a certain limit to a predefined transmitter, is that, given predefined power limits imposed over transmitting equipment by a standard, adoption of additional or more stringent Duty Cycle limits may allow that equipment to increase the level of emitted power, or vice-versa, reducing the transmitted power levels may allow the device to use a higher Duty Cycle.

In figure 1 duty cycle parameters are described. It can be noted that T_{on} and T_{off} are referred to the entire duration of the UWB pulse frame and they are not related to the pulse repetition time.

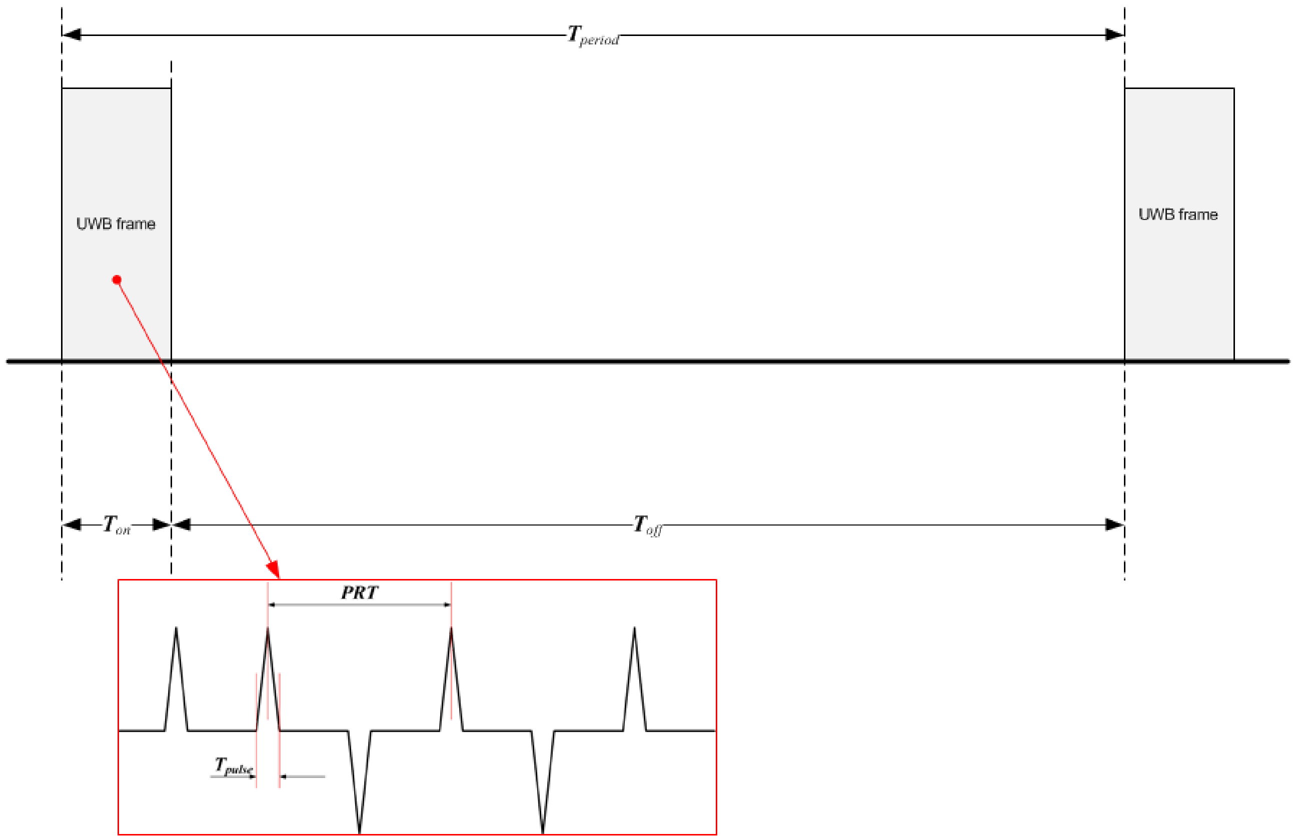


Figure 1: Duty Cycle parameters definition

In addition the duty cycle can be traded against the transit power as investigated in CEPT report 45 [i.8]. Based on the results in CEPT ECC WGSE, linear trading of LDC against transmitted power as shown in table 1 **and within these boundaries only** is considered to provide equivalent protection to the LDC limits stated in EC DEC(06)04 [i.6] as amended in 2011 for a specific set of victim services and environments. The grey row represents current limits stated by EC DEC(06)04 [i.6], the other rows represent other traded limits, considered as equivalent mitigation.

Table 1: Trade-off between power and duty cycle from CEPT Report 45 [i.8]

Mean PSD Limit	Long Term Duty Cycle	Short Term Duty Cycle	Max Ton	Mean Toff	Max ∑Ton	Min ∑Toff
dBm/MHz	Seconds within 1 hour	% in 1 second	ms	ms	ms	ms
-41,3	**18-180**	**5**	**5**	**38**	**50**	**950**
-44,3	36-360	10	10	38	100	900
-47,3	72-720	20	20	38	200	800
-50,3	144-1 440	40	40	38	400	600
-51,3	180-1 800	50	50	38	500	500

5.2.2 Protected Incumbent services

A duty cycle restriction in the form of LDC can protect different services. In the first place the overall reduction and limitation of the duty cycle reduces the aggregated interference effects for incumbent systems like Fixed Satellite Systems and passive earth exploration satellite services (EESS). For the aggregated interference case the trade-off between duty cycle and power is an efficient mechanism. In addition LDC can significantly reduce the potential interference effects into systems with non-continuous transmission characteristics in time, like TDMA based communication systems.

5.3 Detect and Avoid (DAA)

5.3.1 Technical description

Detect and Avoid (DAA) mechanisms identify the presence of signals from other radio systems and reduce the transmitted power of the device to a level where it does not cause interference to the reception of other systems. Fixed broadband wireless access (including WiMAX), mobile services (e.g. UMTS)) and radar systems are examples of such other radio systems. Therefore, before transmitting, a system should sense the channel within its operative bandwidth in order to detect the possible presence of other systems. If another system is detected (the potential victim), the first system (the interferer) should avoid transmission until the detected victim system disappears.

More details are included in clause 5.2 of ETSI TS 103 181-2 [i.17].

5.3.2 Protected Incumbent services

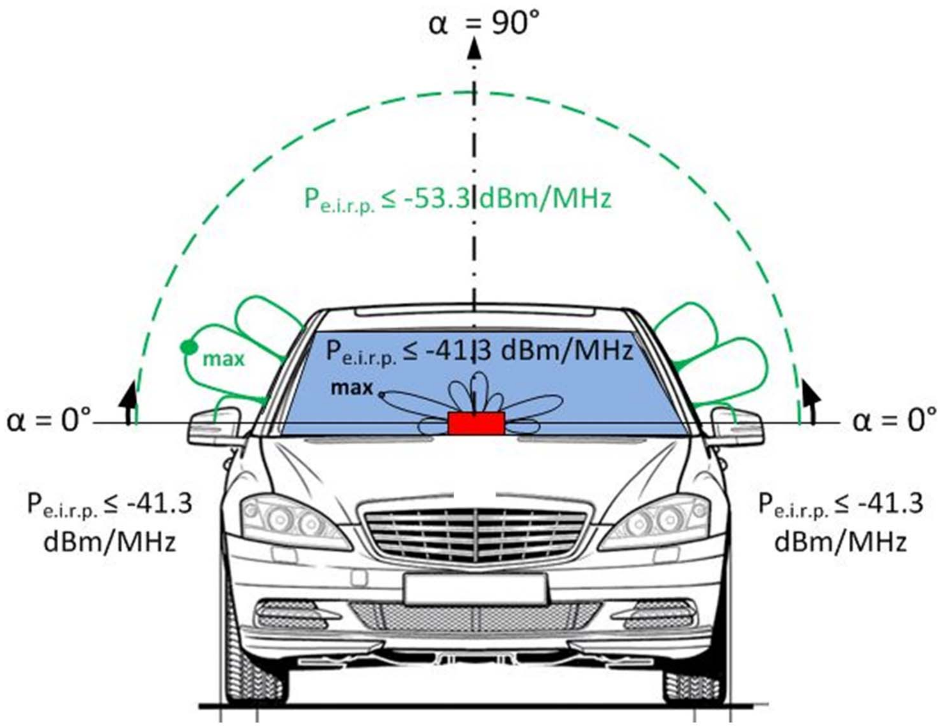
The DAA mechanisms mainly protects incumbent services with single entry interference sensitivity like radar or close proximity communication devices. The DAA approach can only be deployed for active services. More details can be found in clause 5.2.2. of ETSI TS 103 181-2 [i.17].

5.4 Exterior Limits

5.4.1 Technical description

The exterior limit is defined, for each UWB device installed in a road or rail vehicle, as the maximum mean e.i.r.p. spectral density for the emissions outside the vehicle at elevation angles higher than 0 degree (Commission Decision 2014/702/EU [i.15] and CEPT report 45 [i.8]).

The reference plane for the 0 degree is the sensor mounting height. Figure 2 shows the principle of these regulations.



NOTE: The exterior limit refers to the maximum mean spectral density e.i.r.p. measured outside the vehicle and every local maximum should be below the limits.

Figure 2: Principle of the regulations (CEPT Report 45 [i.8])

A similar approach could be taken to protect other services in the UWB bands. More details can be found in ETSI TS 103 181-2 [i.17], clause 6.1.2.7.

5.4.2 Protected Incumbent services

The limitation of the exterior UWB emissions can protect both services sensitive against single entry interference and aggregated interference, respectively.

5.5 Power control

5.5.1 General

Power control, also known under the terms Adaptive Power Control (APC) or Transmit Power Control (TPC), is often used in radio regulation and harmonized standards. It is an automatic mechanism to avoid interference to other radio services and applications. The Power Control mitigation technique basically uses the received energy or power within the total receiver bandwidth of the UWB device in order to adjust the transmitter power to control emissions. In general the Power Control mechanism turns down the transmitter power to a value which minimises the emissions but maintains a certain receive level which is still sufficient to enable a reliable operation of the individual UWB device.

5.5.2 Protected Incumbent services

Power control techniques can protect all services where aggregation is relevant e.g. satellite, EESS (earth exploration satellite systems).

5.6 Total radiated power (TRP)

5.6.1 Technical description

The Total Radiated Power (TRP) is the integration of the power flux density of the radiated signal (e.g. e.i.r.p.) across the entire spherical surface enclosing the UWB sensor under test. From the measured e.i.r.p. values the TRP can be calculated as follows:

$$TRP = \int_{\Theta=0}^{\pi} \int_{\Phi=0}^{2\pi} \frac{e.i.r.p.(\Theta,\Phi)}{4\pi} \sin(\Theta)\, d\Theta\, d\Phi$$

with Θ and Φ being the two angles of the spherical coordinate system.

The TRP represents the total TX power of the device taking into account antenna and cable effect. In contrast to the TX power of a device this parameter can also be measured for devices with integrated antennas.

More technical details are given in ETSI TS 103 181-2 [i.17], clause 6.2.1.

5.6.2 Protected Incumbent services

The Total Radiated Power mitigation technique imposes this integral to be limited within certain values. This kind of mitigation was developed to protect:

- the mobile service band/RAS band in the 2,5 GHz to 2,69 GHz;
- the passive radio astronomy bands (RAS) in 2,69 to 2,7 GHz and 4,8 to 5 GHz; and
- the broadband wireless access (BWA) application in the range 3,4 GHz to 3,8GHz.

The measurement of the e.i.r.p. will be done (automatically) on the spherical surface enclosing the device at discrete measurement points as shown in figure 3.

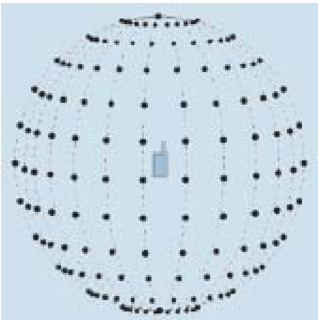


Figure 3: Measurement points across the spherical surface

5.7 Emission directivity

5.7.1 Technical description

Radiation patterns may be used for mitigation purposes if it has directional characteristics that reduce the radiation to systems outside the operating area. To this purpose, the intended device should have radiation patterns that cover only the regions where the radiation is useful. This applies only to devices with well-defined position and orientation within its area when operating. If position and orientation can be changed arbitrarily during device operation, then radiation to regions outside the operating area cannot be controlled.

Accurate control and/or shaping of the radiation pattern usually require antennas with a size of several wavelengths. This is particularly true with regard to the side-lobes. However these are not very large at UWB frequencies, and the size of the antennas can remain acceptable. In any case, the materials and surroundings around the antenna should be carefully considered because they can have a significant effect on the radiated pattern.

Automotive and railway, Location Tracking Type 2, Material Sensing Devices, fixed installations, and Level Probing Radars, LIAT are applications that implement this category of mitigation.

More technical details are given in ETSI TS 103 181-2 [i.17], clause 6.2.2.

5.7.2 Protected Incumbent services

The antenna directivity can be used to protect fixed radars, fixed links and also FSS. Another service which can be protect by the techniques is the radio astronomy services.

5.8 Listen-before-talk

5.8.1 Technical description

The technical basis behind the LBT mitigation technique is that if the UWB device detects a potential victim radio service, and the radio service signal is over a specified and regulated level, the transmitter will react with a defined action, e.g. switch off the signal or reduce the transmitted power.

LBT is comparable in principle with DAA, but not as complex.

5.8.2 Protected Incumbent services

The LBT mitigation technique was developed to protect:

1) the radio determination services in the frequency ranges: 1,215 GHz to 1,4 GHz and 2,7 GHz to 3,4 GHz (e.g. radars in L and S band);

2) the land mobile service in the range 2,5 GHz to 2,69 GHz (e.g. UMTS);

3) the mobile satellite radio service in the range 1,61 GHz to 1,66 GHz (MSS).

5.9 Activity factor

5.9.1 Technical description

The activity factor is an average duration of operation given as the time ratio between the overall life time of the UWB device and transmission-on-time. The detailed definition is dependent on the application where the UWB device is used, e.g. for a transportation location device the activity factor is around 10 % (see ETSI TR 102 495-7 [i.36]).

In contrast to the duty cycle definition the activity factor covers the system and operational aspects of the device and not the signal characteristics.

5.9.2 Protected Incumbent services

The activity factor of a set of UWB devices is an important mitigation factor for the protection of incumbent services sensitive against aggregated interference effects like FSS, radio astronomy and fixed links.

5.10 Frequency domain mitigation

5.10.1 Technical description

There are UWB modulation techniques where the instantaneous bandwidth of the transmit signal is close to zero. The frequency modulated continuous wave (FMCW) or stepped frequency continuous wave (SFCW) modulation schemes are two examples for that property. Thus, the mitigation naturally offered by FMCW/SFCW is the very narrow instantaneous bandwidth. The swept band over longer time intervals is not able to generate simultaneous interferences to the victim receivers within the whole operating bandwidth.

For example, a stepped frequency continuous wave Radar (SFCW) consecutively sweeps 1 000 steps within a period of 100 ms and a step bandwidth of 1 MHz. At each step the Radar transmits a different frequency with a dwell time of 100 μs and a bandwidth of 1 MHz leading to an overall bandwidth of 1 000 MHz. For a 10 MHz victim receiver bandwidth, the equivalent duty cycle is 10×100 μs / 100 ms = 1 %. This is equivalent to a mitigation factor of 20 dB.

The frequency domain mitigation method can be used to fulfil the LDC limits given in clause 5.2.2.

5.10.2 Protected Incumbent services

The protected systems are the same as the ones protected by LDC, see clause 5.2.2.

5.11 Shielding mitigation

5.11.1 Technical description

Emissions caused by UWB devices can be reduced by shielding due to a special installation environment.

For level probing Radar (LPR) such a special installation environment may be for example an external floating roof tank. These tanks are commonly used to store large quantities of petroleum products like crude oil, gasoline, kerosene, etc. It comprises an open-topped cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid. The floating roofs are usually made of metallic materials such as aluminium.

Furthermore, the metallic walls may make the emissions in the direction around the horizontal circumference quite small according to the calculations from Recommendation ITU-R P.526-13 [i.32]. No openings above the floating roof exist in practice. This mitigation applies to all emissions above 3 GHz. LPR equipment installed in such a shielded environment may therefore use higher emission levels. The manufacturer should provide sufficient information about the possible combination of emission levels and shielded installation environments.

5.11.2 Protected Incumbent services

The shielding effects can protect all incumbent services.

5.12 Summary and conclusion

In this clause an overview of the existing mitigation techniques for UWB technologies and the protected incumbent services have been given. The different mitigation techniques have been developed independent of the regulation processes covering the specific applications and requirements. Most of these mitigation techniques could be deployed in other application domains and scenarios leading to a significant additional level of protection. The extension of the validity of available mitigation techniques towards other UWB applications, operational frequencies and scenarios will increase the application area of UWB devices, simplify the overall regulation and the corresponding standardization.

6 New Mitigation techniques

6.1 Overview

In this clause new potential mitigation factors and techniques will be introduced which will complement the existing techniques and factors descripted in clause 5.

6.2 Centralized LBT/DAA UWB systems

In contrast to the existing LBT and DAA definition, the centralized LBT/DAA mitigation technique uses a centralized sensing device to identify potential victim systems to be protected. This centralized sensing unit can implement more efficient sensing capabilities than the individual UWB devices and can be positioned in a more suitable position related to the potential victim systems. The sensing results are used to control the individual UWB devices in a cluster or network using a control channel, which can be based on UWB technologies or other communication technologies.

A similar concept has been developed by the Wireless Industrial Community in ETSI TS 103 329 [i.33]. Figure 4 depicts the concept proposed by the ETSI ERM TG41 (Wireless Industrial). The central coordination points sense the channels to be deployed by the UWB devices in the cluster and controls the networked devices using a control channel.

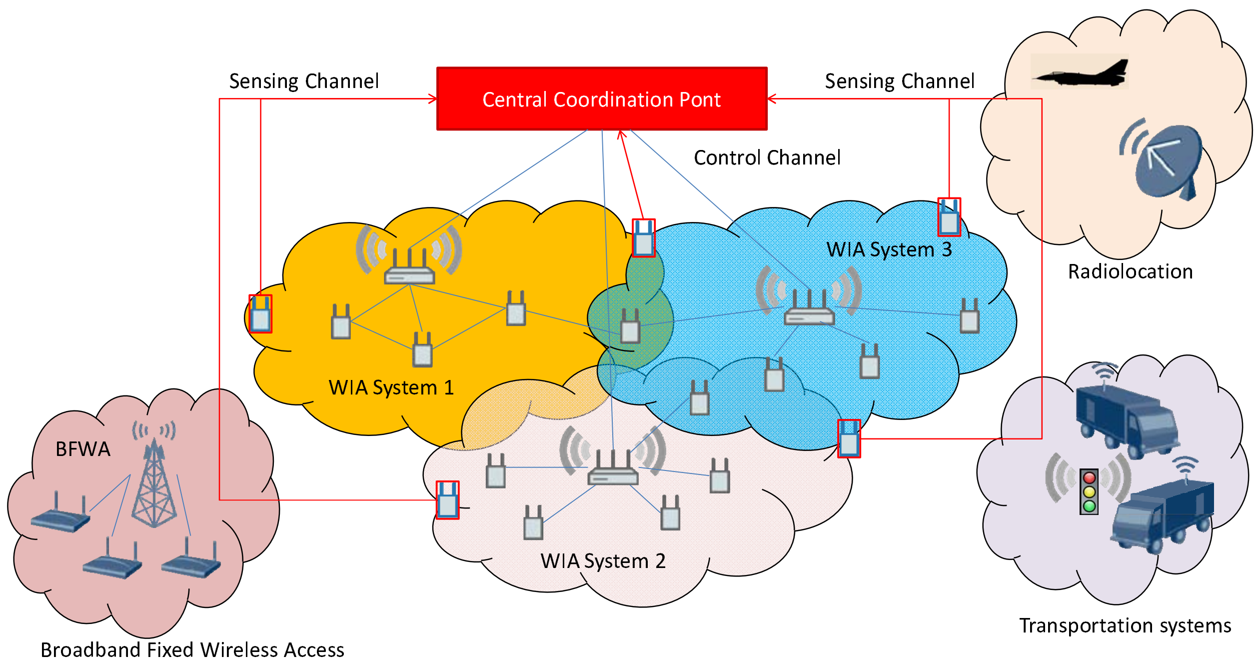


Figure 4: Central Coordination Point controlled WIA systems and incumbent services and applications using centralized LBT/DAA concepts from ETSI TS 103 329 [i.33]

All UWB devices relying on the CCP information need to be connected to a network. This concept can be deployed in industrial areas, home systems or office buildings where several UWB devices operate as a networked system.

6.3 Geolocation databased

The concept of a geolocation database would be a solution for UWB devices which are continuously connected to the internet or networked devices where a single master device can get the required mitigation positions and the position of the active UWB network.

This concept is part of the cognitive PMSE solution [i.34] and the mitigation solution between ITS and tolling in the 5,8 GHz and 5,9 GHz band [i.30]. The geolocation database solution is mainly suitable for fixed incumbent services like radio astronomy, fixed satellite, fixed radar and fixed links. In combination with an internet connection (networked UWB devices) the database could be updated on a regular bases. This approach could be useful for industrial and professional installations.

6.4 Trigger-before-talk

6.4.1 Technical description

The trigger-before-talk has been proposed in a recent SRDoc covering the requirements for a vehicle access system deploying UWB technologies. ETSI TR 103 416 [i.16] gives a detailed technical description of the proposed method.

The core characteristic of these systems is that **UWB transmissions are triggered by the system following a user event** and the **communication time is very short** (e.g. just a single or few UWB transmissions):

- Trigger-before-talk:
  - UWB transmission is only initiated when necessary, in particular if the system indicates that UWB devices are in range.
  - Wake-up mechanism for polling is not UWB.
  - Only the physical proximity of a key triggers UWB communication.

The UWB communication may be initiated on either side:

1) Triggered UWB communication, initiated by key: Key is being activated by the car (e.g. LF beacon after user touching the door handle), and is triggering the UWB transmission (see figure 5).

2) Triggered UWB communication, initiated by car: Car system is activated by the key (e.g. user pushing a key button), and is triggering the UWB transmission (see figure 6).

UWB communication ("UWB link") may comprise the exchange of several frames.

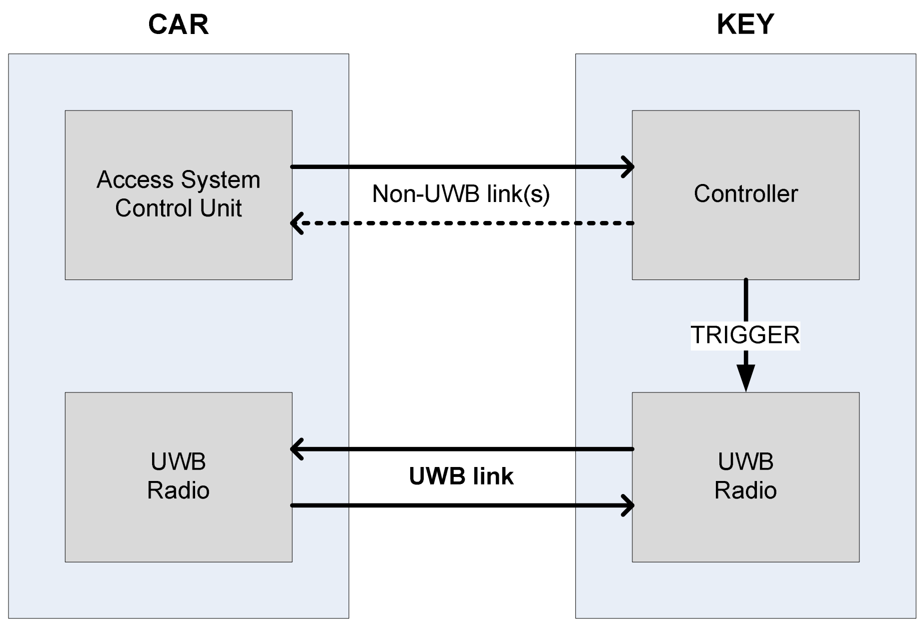


Figure 5: Triggered UWB communication, initiated by key

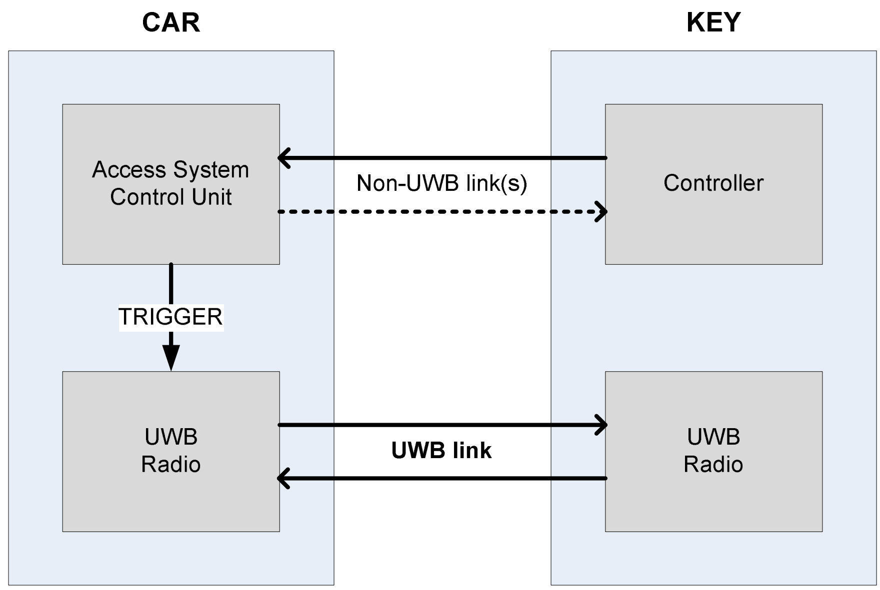


Figure 6: Triggered UWB communication, initiated by car

The mitigation techniques trigger-before-talk can significantly reduce the overall activity factor of the UWB devices and thus aggregated interference. Furthermore, the effect of a potential single entry interference will be reduced due to the very limited operational time of the UWB transmitter.

6.5 Revision of indoor-to-outdoor attenuation

For the calculation of the mitigation factors for indoor only usage a single attenuation factor of 12 dB has been taken into account in all investigations for the complete frequency range from 2,2 GHz (BMA) up to 9 GHz. In actual interference investigation e.g. ECC Report 253 [i.27] and ECC report 244 [i.35] much higher factors have been used.

Especially for the frequency range above 6 GHz no realistic measurements exists, but it can be assumed that the higher frequency ranges will lead to a significant increase in attenuation.

Furthermore, the typical propagation conditions in the frequency band above 6 GHz will lead to an addition mitigation factor for the protection of incumbent services in this band (mainly fixed links).

At the moment, the definition of indoor is very restrictive. Other situations could lead to similar or even higher mitigation factors for the protection of incumbent services. Here the use of UWB location tracking and communication devices in stadiums could be an example. In this case the mitigation factor to protect fixed links would be significantly higher than assumed for the indoor-to-outdoor penetration loss of 12 dB.

6.6 Power reduction for fixed outdoor use

In some bands the fixed outdoor use is not permitted but a generic indoor use is allowed. Taking into account the assumed indoor to outdoor attenuation of 12 dB a simple mitigation factor to protect the incumbent services would be to reduce the maximum allowed TX power of fixed outdoor devices to -53,3 dBm/MHz. This would then give the same protection level as the indoor deployment. This solution could be an appropriate method in in the band above 6 GHz.

6.7 Extended DAA or LBT in the band 6 GHz to 8,5 GHz

In the band 6 GHz to 8,5 GHz the main incumbent users are fixed links. These links could be detected using a simple DAA or LBT mechanism with a threshold of [-65dBm]. The signals to detect are continuous signals with a bandwidth between 5 MHz to around 1 00 MHz [i.28] and [i.29]. Especially for fixed installed devices the detection and avoidance of a specific occupied channel should be possible.

6.8 Antenna techniques

Directional antennas can be used as a fixed installation mitigation technique. This technique focuses the energy in a specific direction resulting in reduced energy in all other directions, see also LT2 [i.3]. Therefore, if a location tracking application uses fixed transmitting antennas that are all focused down and inward in an application such as tracking sports personnel within a stadium, the emissions outside the stadium will be significantly reduced.

The total radiated power or TX power into the antenna in the direction of the focal point, and the corresponding reduction in directions other than the focused direction will result in a mitigation effect. Another mitigation effect of fixed antennas is the installation height and the direction relative to the incumbent systems.

An additional mechanical or electrical steering can be interpreted from the interfered receiver as a dwell time/silent time or duty cycle pattern (Ton/Toff) as given in clause 5.2.2.

6.9 Specific applications in remote and controlled areas

The power of UWB falls off rapidly because of its high frequency. Therefore, use in remote areas such as an oil tank field, oil derrick, mining or an automotive factory provide spatial mitigation. This is because there are no potential victims within range of the intentional transmissions.

Applications that would use this mitigation technique include:

- Personnel tracking for safety in an oil field or on an oil derrick - provides the ability to locate personnel in a fire or other such emergency event.
- Asset tracking for increased business efficiency in an oil field or on an oil derrick - locate tools, and transmit data from automated equipment.
- Asset and vehicle tracking at an automotive factory - locate specific vehicles within a vehicle parking lot, locate tools outdoors.

This mitigation method would require adding specific installation and operational instructions into the relevant ETSI harmonised standards, e.g. ETSI EN 301 091-3 [i.37], clause 4.5 and annex B.

7 Application examples

7.1 Introduction

In this clause a set of different applications will be presented that could benefit from the proposed set of mitigation techniques. The broader deployment of the existing and new mitigation techniques depicted in the present document could facilitate a large number of additional UBW based applications in Europe without increasing the interference potential towards existing and future services and applications in the jointly used bands.

7.2 Motion and presence detection

7.2.1 General

Motion and presence detection in the field of home automation is a fast growing application sector. Current technologies like passive infrared or continuous wave radar sensors have different drawbacks like sensitive lenses, coarse recognition qualities or temperature dependencies. Ultra-wideband sensors can combine advantages of different sensor technologies. These can be invisible mount behind non-metallic covers, high-precise detection and distance measurements of moving objects. Such features make an UWB sensor outstanding for outdoor motion and presence detection.

7.2.2 System requirements

Here the basic technical requirements of the application are given:

- Bandwidth up to 2,5 GHz.
- Pulse based Sensor: 10 MHz PRF.
- Location precision 0,1 m to 1 m.
- Spectrum band 6,0 GHz - 8,5 GHz.
- LDC parameter: < 2 %.
- Antenna parameter: Gain < 4 dB, Directivity 90° horizontal and vertical pattern.
- Average 8 devices per building.

7.2.3 Technical description

- House with mounted detector installed outside at the Height = (2 - 3) m; antenna tilted by 12° down from horizon; Radiated Pulse width ~ 2 ns with Low Duty cycle < 1 %; Motion detector could be active 24 hours per day.
- Angle of detection: 90° in horizontal plane and vertical plane.
- Detected distance: 15 m - 18 m.

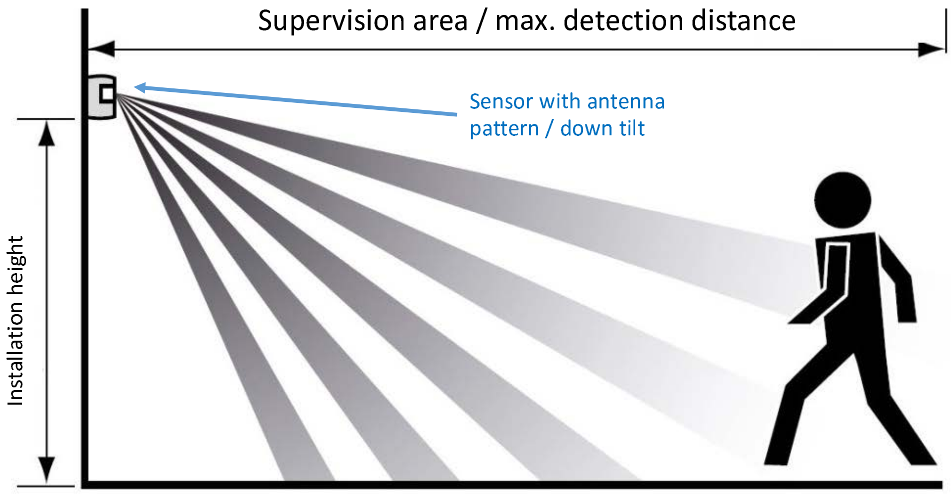


Figure 7: Motion and presents sensor for home applications

7.2.4 Mitigation factors

To enable the motion and present detection application some of the following mitigation techniques could be used:

- Duty cycle restrictions:
  - Optional like in 3,1 GHz - 4,8 GHz band.
  - < 5 %.
- Power restriction:
  - TPR limitation -47,3 dBm/MHz.
  - Power restrictions outside the supervision area.

    - TPC dependent on the range of supervision area and object characteristics.

- Antenna angle: down tilt towards the supervision area.
- Antenna height limitation for fixed out door installations: e.g. 2 m or 5 m.

All proposed mitigation techniques are already in use and qualified for different applications and frequency bands (e.g. ETSI EN 302 065-3 [i.4]).

7.2.5 Applications specific market information

Applications specific market information can be found at www.statista.com.

7.3 Localization for a Robotic Lawn Mower

7.3.1 Introduction

Robotic Lawn Mowers (RLMs) are becoming popular in European markets for several key advantages they offer over the manual lawn mower status quo. RLMs:

- improve the health and safety of consumers;
- are better for the environment than gasoline powered mowers;
- make lawn cutting more accessible to the elderly and disabled; and
- give people free time to spend with their families and loved ones.

However, current RLM installations require placement of a boundary wire to confine the working area of the robot. This requires consumers to dig or otherwise stake wire around the perimeter of the area to be cut, or consumers need to hire someone to perform this task. This cumbersome and costly process has limited the public's adoption of RLM technology.

UWB undustry is designing an RLM that will not require buried wire, but instead will rely on short portable beacons in the yard that transmit signals used by the robot to determine its location within a designated mowing area and to stay within the designated mowing area. The beacons utilize ultra-wideband (UWB) technology to generate precise ranges between the beacons and the mobile robot for localization. After placing beacons in the yard, a user will teach the robot the boundary of the working area by traversing the working area. A typical yard will require about 6 beacons (depending on the complexity of the space), and the beacons will only communicate to an assigned mower and will not communicate with each other or any other device.

A nominal beacon installation process and subsequent perimeter/confined area RLM training is shown in figure 8.

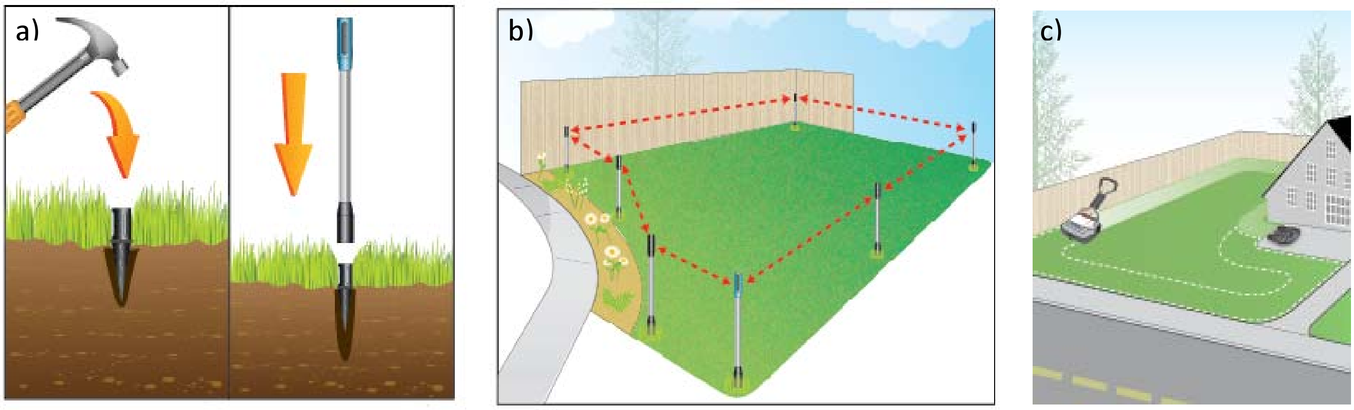


Figure 8: Typical installation process for a RLM utilizing UWB beacons
a) Installation of the fixed stake and portable UWB beacon
b) Installation of beacons throughout the yard area
(beacons do not have to be installed on the perimeter of the yard)
c) Teaching the RLM the confined area

7.3.2 System requirements

The basic system requirements can be summarized as follows:

- One single communication channel between beacons and mower.
- Range: up to 60 m.
- Short duration communication to conserve power in battery powered beacons.
- Accurate two way ranging message between robot and beacons.
- Unique identifiers for beacons.

7.3.3 Technical description

The working parameters of the RLM localization system are given in table 2. The system uses a single 500 MHz channel around 6,5 GHz. Transmit powers comply with current ETSI limits for indoor and mobile devices on this channel. The beacons and mower are also very low duty cycle; during mowing each beacon has a transmit duty cycle of 0,096 % which significantly drops when the mower is not actively cutting the lawn. Total system duty cycles (using 6 beacons for this example) are also given.

Table 2: Technical parameter of the lawn mower application

Property	Value/Type
Center Frequency	6,4896 GHz
Bandwidth	500 MHz
Channel Spacing	Single Channel
Max Mean Spectral Density e.i.r.p.	-41,3 dBm/MHz
Max Peak Spectral Density in 50 MHz	0 dBm
Transmit Duty Cycle **per beacon** during mowing	0,096 %
Transmit Duty Cycle **per beacon** during non-mowing	0,0048 %
Transmit Duty Cycle **total system** during mowing	0,864 %
Transmit Duty Cycle **total system** during non-mowing	0,0288 %
Duplex Direction	1/2 Duplex
Type of Antenna	Single Sleeved Dipole with 2 dBi Gain

7.3.4 Mitigation factors

Several characteristics of the system give inherent mitigation factors to prevent interference to other devices. While no active methods are provided to prevent interference, it is believed that the characteristics below will make interference to incumbent devices a non-issue:

- Any particular beacon only communicates with the mower it is paired with; there is no beacon-beacon (or mesh networking) type of communication in the system.
- Beacons are very low to the ground (~61 cm) and transmit omnidirectional in the azimuth plane.
- Beacons in the yard are removable and consumers will be instructed to remove the beacons and store them indoors for the non-mowing season to protect the beacons from environmental damage.
- The entire communication system is very low duty cycle as shown in table 2, especially when the mower is not mowing which is the vast majority of time:
    - Low activity factor.
- The RLM system is intended for residential use only and will be labelled as such. Residential settings are typically in areas where other users of this frequency are not located.

7.4 Dynamic street lighting sensor

7.4.1 Introduction

Dynamic street lighting control using presence sensors may help reduce energy in the future. Due to the high range resolution and robustness against destructive interference compared to conventional CW systems, Ultra Wide Band radar technology is well suited for such purposes. In addition to detecting presence and distance other information like speed and direction may also be measured adding further value to the application.

7.4.2 System requirements

Here the technical requirements of the application given:

- Bandwidth up to 2,5 GHz.
- Pulse based Sensor: 10 MHz PRF.
- Location precision: 0,1 m to 1 m.
- Range: 3 m to 15 m.
- Spectrum band: 6,0 GHz - 8,5 GHz.
- Antenna heights: < 5 m.

7.4.3 Technical description

Typically the sensor will be mounted within the lightning source and facing downwards. The sensor will detect cars, pedestrians and similar objects that should trigger the light to turn on. Small objects like cats, birds, etc., should leave the light off.

Since the sensor is facing down it will not detect the presence before the object is relatively close to the sensor, which could be impractical. This will be handled through wireless communication between light sources to allow one light source to trigger another just in time for the object to approach.

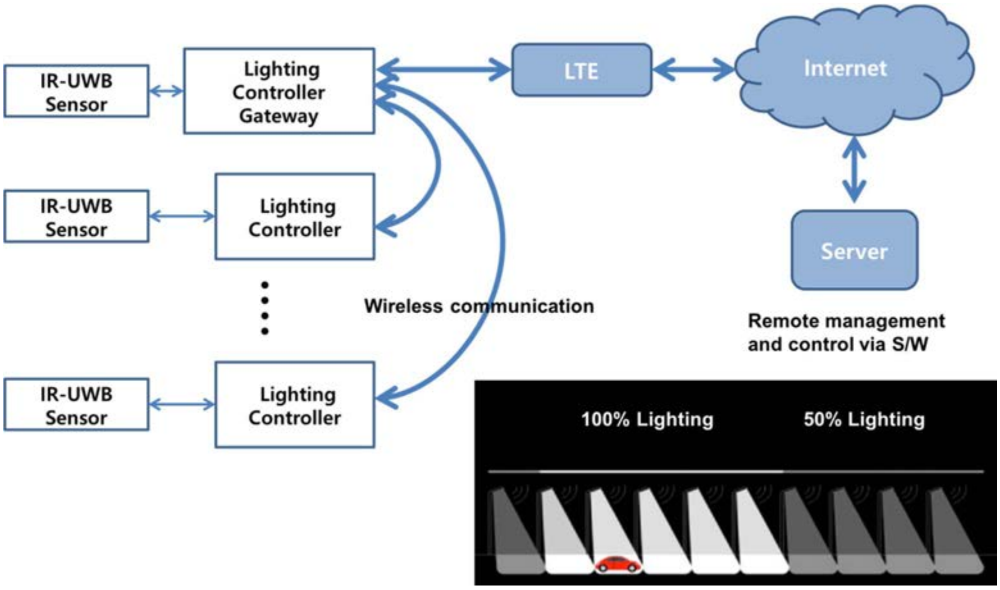


Figure 9: System level concept description of a UWB based dynamic street lighting system

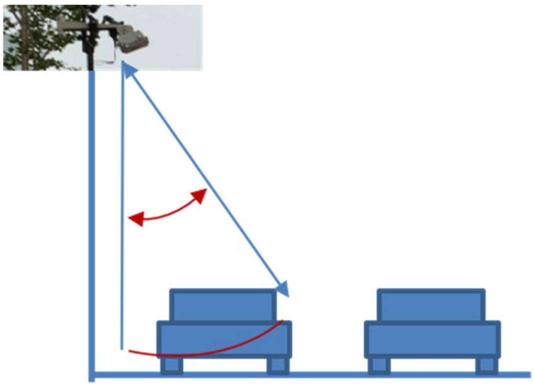


Figure 10: Dynamic street lighting system; sensor location and antenna view angle
The antenna will be directed downwards with a narrow beam
to avoid detecting cars in the opposite lane

7.4.4 Mitigation factors

Possible mitigation factors are:

- Duty cycle restrictions:
  - Optional like in 3,1 GHz - 4,8 GHz band.
  - < 5 %.
- Power restriction:
  - TPR limitation -47,3 dBm/MHz.
  - Power restrictions outside the supervision area.
  - TPC dependent on the range of supervision area and object characteristics.
- Antenna angle: down tilt towards the supervision area.
- Antenna height limitation for fixed out door installations: e.g. 2 m or 5 m.

All proposed mitigation techniques are already in use and qualified for different applications and frequency bands (e.g. ETSI EN 302 065-3 [i.4]).

7.4.5 Applications specific market information

According to the PRNewswire report "Global LED & Smart Street Lighting Market (2015-2025)" there are currently 304 million total streetlights in the world. This number will grow to 352 million total streetlights by 2025. The public outdoor lighting market is currently undergoing a period of change where legacy streetlights are being replaced with new and more efficient LED, or solid-state lighting technology. Taking this new technology a step further, these LED streetlights are also being networked together with communications to become "smart" streetlights. The estimated market opportunity is 63,5 billion USD.

EXAMPLE: http://www.currentbyge.com/cities/ and http://www.comlight.no/home.

7.5 Smart cities parking system sensor

7.5.1 Introduction

In large cities drivers seeking an available parking space represent a significant pollution source. In addition time is wasted and traffic jams may occur. To improve logistics and help reduce pollution, intelligent infrastructure systems within the framework of Smart Cities have started to evolve. An important component of such systems is a sensor capable of detecting if a parking lot is occupied or not. Current technology is mainly based on inductive sensing which has some limitations under certain conditions reducing its reliability. By introducing UWB based sensors either stand-alone or dual in dual technologies, the error rate will be significantly reduced.

7.5.2 System requirements

The main technical requirements relevant to the application for coexistence investigations are given:

- Bandwidth up to 2,5 GHz.
- Pulse based Sensor: 16 MHz PRF.
- Location precision: < 0,1 m.
- Range: < 1 m.
- Spectrum band: 6,0 GHz - 8,5 GHz.

7.5.3 Technical description

The sensor will be battery operated and buried in the pavement/concrete/asphalt with a protective and RF attenuating shielding that may be opened for service and battery replacement. Under operation it will detect if there is a vehicle in the parking space and also report the closest distance to the vehicle. This information will be transferred to a cloud service connected to the overall infrastructure system including traffic signs etc. to dynamically direct drivers to parking lots with available spaces.

Figure 11: Deployment scenario for parking system sensor: Kauffman Stadium (by Dean Hockman, Flickr) https://www.flickr.com/photos/deanhochman/16161860403/in/photolist-qCaL2z-rFaE6M

7.5.4 Mitigation factors

Possible mitigation factors are:

- Duty cycle restrictions:
  - Optional like in 3,1 GHz - 4,8 GHz band.
  - Duty cycle below 1 %.
- Power restriction:
  - Power restriction possible to -51,3 dBm/MHz for systems with up tilt antennas.
- Antenna techniques.
- Shielding by car.

All proposed mitigation techniques are already in use and qualified for different applications and frequency bands (e.g. ETSI EN 302 065-3 [i.4]).

7.5.5 Applications specific market information

The report "Smart Parking Systems - Sensor and Communications Hardware, Software, Services, and Smart City Applications: Global Market Analysis and Forecasts" from Navigant Research [i.38] analyzes the evolution of smart parking technology and the smart parking systems market, including global market forecasts for smart parking systems hardware, software, and services through 2024.

Today, the parking industry is being transformed by new technologies that are enabling cities to reduce levels of congestion significantly. Sensor networks that detect vehicle occupancy are providing the basic intelligence behind smart parking systems, which provide real-time parking availability information to make it easier for drivers to find a parking space. According to this report, the installed base of sensor-enabled on-street smart parking spaces is expected to surpass 1 million worldwide by 2024.

EXAMPLE: http://www.fastprk.com.

7.6 Train crossing security sensor

7.6.1 Introduction

Vehicles or persons may unintentionally be located on the railway track at train crossings, either stuck between the gates or at crossings without gates which are not uncommon outside larger cities. Every year a large number of incidents are reported representing a high cost for the society. There are radar products available in the market today, but the relative short range and wide coverage angle makes UWB sensors a good alternative. The purpose is a system that detects unwanted obstacles at the crossing and alerts the train driver or automatically train security system in order to stop the train to avoid a collision.

7.6.2 System requirements

The main technical requirements relevant to the application for coexistence investigations are given:

- Bandwidth up to 2,5 GHz.
- Pulse based Sensor: 10 MHz PRF.
- Location precision: 0,1 m to 1 m.
- Range: 1 m to 15 m.
- Spectrum band: 6,0 GHz to 8,5 GHz.
- Antenna heights: 2 m.

7.6.3 Technical description

The sensor will typically be mounted on a pole facing down towards the railway crossing. It will scan the target area and detect/track potential unwanted obstacles. If the obstacle(s) remains in the target area for too long compared to the remaining time to impact, a signal will be triggered in order to stop the train.

Figure 12: Deployment scenario for railway crossing sensor: Gilman Street, Berkeley, CA (by Paul Sullivan, Flickr) https://www.flickr.com/photos/pfsullivan_1056/15709376016/in/photolist-oriPKF-oeeDQK-pWRzMj-rbzWhw-pFRuMT-b18TVZ-pWbEbC-qwn9Q4-oeeDHR-aVRNHR-pYMhVV-6NvnWa-b18Sjg-rt2YhX-aUUUie-aVRJTr-jTkqAu-oeeqR8-6NUv5d-oeeE5T-pGwrFe-6m5375-aWiuo2-dgbhK4-s7mTVQ-pXGy6z-RRdNqM-RRdPG4-QJ7aR9-S39gaM-Qujpvv-jR1nDD-jR29bH-JtH3Zn-F1j3Mw-x62ikd-aUUWCv-6m536Y-6yBhSB-aVRH5n-aVRLKc-6yFpjN-pFRumx-oeeE8P-QpzDff-JqFJRu-577V95-4Swccy-BycebY

7.6.4 Mitigation factors

Possible mitigation factors are:

- Duty cycle restrictions:
  - Optional like in 3,1 GHz to 4,8 GHz band.
  - < 5 %.
- Power restrictions:
  - TPR limitation -47,3 dBm/MHz.
  - Power restrictions outside the supervision area.
  - TPC dependent on the range of supervision area and object characteristics.
- Antenna angle: down tilt towards the supervision area.
- Antenna heights limitation for fixed out door installations: e.g. 2 m or 5 m.
- Very often remote from highly populated areas.

All proposed mitigation techniques are already in use and qualified for different applications and frequency bands (e.g. ETSI EN 302 065-3 [i.4]).

7.6.5 Applications specific market information

In 2014 close to 2000 people were killed in the EU caused by railway accidents. A large share of these accidents occurred at level-crossings clearly indicating the need of more advanced security systems. For more details see: http://ec.europa.eu/eurostat/statistics-explained/index.php/Railway_safety_statistics.

EXAMPLE: https://aerospace.honeywell.com/en/products/navigation-and-sensors/honeywell-radar-scanner.

7.7 UWB in enclosed environments

7.7.1 Introduction

The current UWB regulations make a distinction between indoor and outdoor environments. While enclosed environments do not have a roof, when it comes to interference scenarios, the surrounding walls provide the same attenuation as indoor applications.

EXAMPLE: A location tracking system for athletes and spectators in a sport stadium currently has to obey the ban on outdoor fixed transmitters. However, since all the action takes place inside the stadium, antenna patterns for fixed transmitters would be chosen to maximize the energy towards the centre of the stadium, while the outer walls protect services the same as if the stadium had been covered by a roof, see figure 13.

7.7.2 System requirements

The main technical requirements relevant to the application for coexistence investigations are given:

- Bandwidth 500 MHz or more.
- Data rate application depended, usually in the order of 100 kbps to 10 Mbps.
- Location precision 10 cm to 1 m range.
- Spectrum band: 3,1 GHz to 4,8 GHz and 6,0 GHz to 9,0 GHz.

7.7.3 Technical description

Enclosed environments, completely surrounded by outer walls but without a roof. Examples: sport stadium, farm yards, certain logistics and industrial sites.

Having the ability to transmit from the fixed anchors would allow two major changes:

- **Increase of capacity** of the system, in a kind of GPS like system, where the fixed anchor nodes transmit time stamps which allow the mobile tags to self-locate. Currently, guidance systems to take visitors in the stadium to their seat would require TDOA where every visitor's device has to send blinks to anchors, which will calculate the position and send it back via a non-UWB link. With the change, the use of the spectrum can be much more efficient. UWB blinks of the anchor nodes allow every device within range to locate itself with 3 to 4 blinks.
- **Increased accuracy of the location**: the TDOA system can be converted to a two-way ranging based TOA system, increasing the accuracy of the localization of the nodes.

**Figure 13: Deployment scenario for enclosed environment applications:
Camp Randall Stadium (by Jim Bauer, Flickr) https://www.flickr.com/photos/lens-cap/15197731619/in/photolist-p9Ym8v-q9VnNX-TtkUXv-fVdJaU-of1icz-3hFdRo-p2JoXG-aR5HWM-aFNr5T-6g1on8-6d849Z-7GS5Lo-7GRWPQ-c77uVs-7GRS53-btTXBb-mwcn4K-dd42id-7GMVTV-7GRQwC-7GRMxC-6oBDuP-TNFSYU-Uap8aM-87pjGh-cLv4EW-cPfAVm-pACCbE-nr21vh-9L1pSg-7GRYoy-7GRQhW-acjMac-7GS17Q-f3t6V1-i5Sqpz-7PsKmL-7GRZb7-7GRXXm-fFGHoB-7GRVqG-8gM5sU-7YLdJC-7GMWBH-bGNTf4-8gM5qs-f1gXuB-4CoiEM-o2YfKL-nsnU1u**

7.7.4 Mitigation factors

For the present application and use case the following mitigation factors can be taken into account:

- Specific shielding factors surrounded by outer walls.
- Operation conditions directional antennas minimizing outside radiation.
- Environmental mitigation factors.

7.7.5 Applications specific market information

Real Time analytics is a growing market in sports. Solutions were initially based on GPS to collect data about professional athletes. The NFL has already deployed UWB based systems from Zebra leveraging the benefits of more accurate location information. Likewise in Europe, manufacturers of analytics equipment are investigating the use of UWB for soccer, rugby, etc.

The market is also changing form a purely professional market to a more open market with universities and schools looking at implementing UWB based solutions.

The worldwide market is estimated to be around 10 to 20 thousand sport pitches (e.g. soccer field) representing a value of > 1 Billion $.

7.8 Self-configuring outdoor TDOA localization system

7.8.1 Introduction

Current location systems operating outdoors have to comply with the ban on fixed outdoor transmitters. They achieve this by operating a Time-Difference-Of-Arrival system (TDOA), whereby fixed anchor nodes located at known positions each determine the time-of-arrival of a blink message from a tag. The network can then determine the position of the tag from the differences in the time-of-arrival at the anchors.

However, in order for this system to operate, the location of the anchor nodes needs to be known precisely. Ultra-wideband happens to be a technology well suited to determine locations but given that the nodes are fixed and outdoors, it is currently forbidden to use this capability. A limited number of transmissions from fixed outdoor nodes will help with automatic anchor node positioning and allow the localization system to become self-configuring, greatly reducing cost and complexity of deployment.

To be able to compare the time when the tag blinks arrive at the anchors, the anchors need precise time synchronization. In indoor applications, ease of deployment has been improved by replacing the synchronization cables with wireless synchronization methods. Eliminating the cables removes a potential health and safety hazard and increases uptake of the TDOA technology. Two typical environments for such tracking device operations are given in figures 14 and 15.

7.8.2 System requirements

The main technical requirements relevant to the application for coexistence investigations are given:

- Bandwidth 500 MHz.
- Data rate 6,8 Mbps.
- Location precision in general as precise as possible, below 10 cm.
- Spectrum band general UWB frequency ranges (3,1 GHz to 4,8 GHz, 6 GHz to 9 GHz).
- Wireless synchronization packets once per 150 ms.
- Antenna techniques: down tilt antenna with an antenna heights of < 3 m.
- Limitation of TX power and TRP are possible.

7.8.3 Technical description

Each anchor would do two-way ranging exchanges with a limited number of its nearest neighbours. Every two-way ranging exchange requires less than 10 frames of typically less than 1 millisecond duration.

Wired synchronization requires cables to connect all the anchors to the clock master. This increases installation costs. The attenuation of the cables and impedance matching also limit the maximum distance between the anchors and the clock master. Using the UWB PHY, accurate distribution of the wireless clock is possible and requires only a single packet from the master every 150 ms.

Figure 14: Behavioural monitoring of cattle on a farm (Cattle by LHOON, Flickr)
https://www.flickr.com/photos/lhoon/3586626009/in/photolist-6sWoXt-56ASH5-bSBzcc-pjE86B-6Kfte9-ceiRG7-5Py16h-SDyBws-UwspvA-fnwkfY-cW6gEQ-bssV5Y-sgMMkf-dMsM3P-j3y7i5-5VvXED-cYz2NN-Uv2cMr-dasULp-2vekHp-6t2reG-fmbWA6-6sW7YR-56ASvf-rzDRUv-UyuPEG-TQMi1x-5v9Umh-8Rk5n4-TUwEBz-6F9NGa-Sip7Qf-TFjztw-6F9NHB-8zTj6C-UuiWKe-R8iB4J-pDbxGp-SECqvd-bzZJRp-6uw5D8-qtqGyc-RWTuDN-ofYqMx-f52QL8-6uAfV9-aqug4z-6nQ6sU-4d3Dp9-rcMkrX

Figure 15: Tracking of personnel and equipment in building sites (Campbelltown Sports Stadium Redevelopment 2010 by Campbelltown City Council, Flickr) https://www.flickr.com/photos/campbelltowncitycouncil/7025375051/in/photolist-btTXBb-bGNTf4-bGNTfc-bGNiFZ-bGNiFT-bGNTeX-btTXB9-btTXBm-btU6SY

7.8.4 Mitigation factors

For the present application and use case the following mitigation factors can be taken into account:

- Very low duty cycle of below 1 %.
- Very low activity factor.

7.8.5 Application specific market information

The Real Time Location Market is estimated between $5 B and $15 B according to market analysts such as Frost&Sullivan, Markets&Markets and ABI. While a lot of the applications are indoor based, the need for accurate outdoor location is also important such as in the farming industry to locate cattle or in the manufacturing & logistics industry to locate workers for safety and locate goods to optimize process flows.

The estimated portion of outdoor use is around 30% of the total potential market of 1,7 Billion $ to 5 Billion $.

7.9 Application vehicle access systems

7.9.1 Introduction

Currently available Keyless Access Systems are vulnerable to a so called relay attack. This issue can be solved by a UWB runtime measurement. The link budget to get a full coverage of the car's surrounding is tough. Therefore every dB counts to make the system reliable. On the other hand the communication takes place for a very short amount of time (usually only a few ms) leading to a very low activity factor and duty cycle.

7.9.2 System requirements

- Bandwidth > 500 MHz.
- Data rate 10 kBits/s to 200 kBits/s.
- Location precision 0,01 m to 0,5 m.
- Possible operational Band 3,1 GHz to 4,8 GHz and 6,0 GHz to 8,5 GHz.
- Very low activity factor: 5 to 10 activations per day for [100 ms].
- Very low duty cycle: < 1 %.
- Trigger-before-talk.

All the mentioned mitigation factors are well known and proven in the UWB based regulation. Here an extension of these mitigation factors and techniques to other frequency ranges and applications is proposed.

7.9.3 Technical description

The technical details of the application can be found in clause 6.4 (Trigger-before-talk).

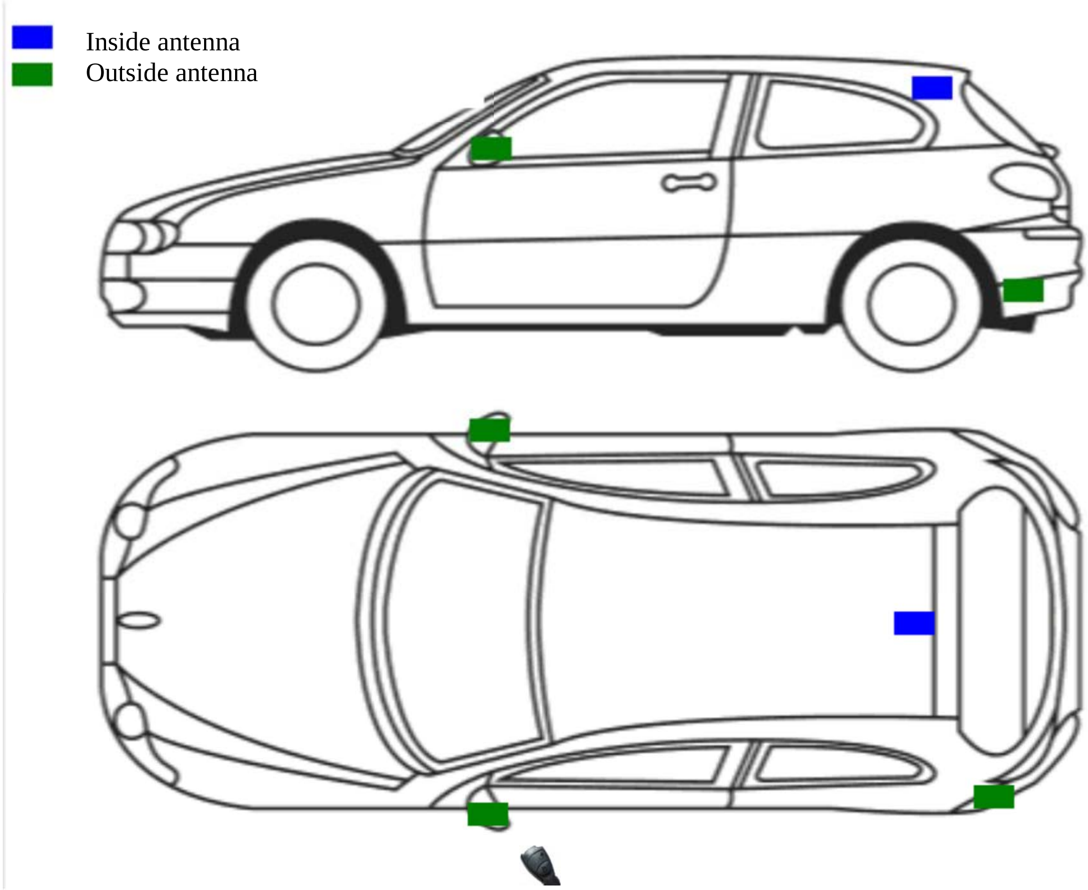


Figure 16: Typical antenna position for a UWB based key less entry system

7.9.4 Mitigation factors

For the present application and use case the following mitigation factors can be taken into account:

- Duty cycle restrictions:
  - Very low duty cycle and activity factor of below 1 % and 5 to 10 activations per day for [100 ms].
- Power restrictions.
- Specific absorption factors:
  - Only part of the devices are located at the outside of a car.
- Operation conditions:
  - Operation is manually triggered.
- Environmental mitigation factors:
  - Car location changes frequently thus no fixed location of the car.
  - Not used in moving traffic situations.

Proposal for the mitigation technique trigger before talk. There are several use cases, where a trigger before talk is limiting unnecessary UWB traffic, by only starting an action when the success is predictable. For more details related to this use case please refer to ETSI TR 103 416 [i.16].

7.9.5 Application specific market information

Every car equipped with a Keyless Access System will need to change to a secure ranging technology in the next few years. Therefore there will be a significant increase in demand for such devices deploying UWB technologies. The overall annual demand in the main regions is depicted in figure 17.

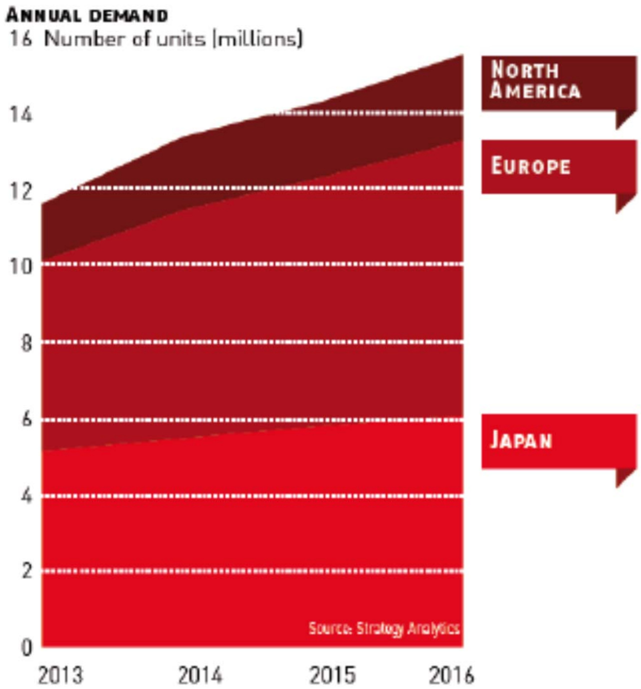


Figure 17: Annual keyless entry system market size in the main regions

7.10 High precision positioning in cooperative ITS

7.10.1 Introduction

In a future highly automated traffic system including communicating vehicles and other traffic participants (pedestrians) it will be required to have very precise positioning information for each of the participants. The participants can evaluate their position by different means like GPS, optical sensors or UWB ranging operations. This position information together with additional characteristics of the traffic participants are distributed using a cooperative ITS system. The receiving party can then build a detailed picture of its surroundings including all traffic participants.

A very high precision is especially required at dense traffic crossing situations, where precisions down to 10cm are required. In these urban scenarios the coverage with GNNS systems can be very limited and thus an additional system for a high precision positioning will be required.

A general overview of possible use cases in a cooperative ITS environment is given in [i.31] as a result of the EU Horizon2020 project HIGHTS (HIGH PRECISION POSITIONING FOR COOPERATIVE-ITS).

7.10.2 System requirements

The system requirements are based on the assumption that the system will provide positioning and communication services as an integrated part of an overall C-ITS system:

- Bandwidth > 500 MHz.
- Data rate 6 MBits/s - 12 MBits/s.
- TX power -41,3 dBm/MHz.
- Location precision 0,01 m to 0,5 m.
- Required range: 10 m to 50 m.
- Band 3,1 GHz to 4,8 GHz and 6,0 GHz to 8,5 GHz.
- Very low duty cycle: < 1 %.
- Trigger-before-talk for the mobile/portable usage by combining with 5,9 GHz C-ITS systems.
- Fixed antennas for UWB beacon transmission.
- Possible combination with data communication.
- Centralized DAA possible.
- Geolocation database possible.

All the mentioned mitigation factors are well known and proven in the UWB based regulations. Here an extension of these mitigation factors and techniques to other frequency ranges and applications is proposed.

7.10.3 Technical description

In the domain of intelligent transport systems (ITS), very high precision positioning is required in specific traffic situations like high density road crossings involving different traffic participants from cars to trucks to pedestrians. It can be assumed that an accuracy of 25 cm under dynamic behaviour is required to identify the used lane or the position of a pedestrian at the road side.

A solution for this issue can be the deployment of UWB based beacons at fixed roadside units as depicted in figure 18. The traffic participant's devices can then determine its position and can communicate this position using a cooperative ITS system like ETSI ITS-G5.

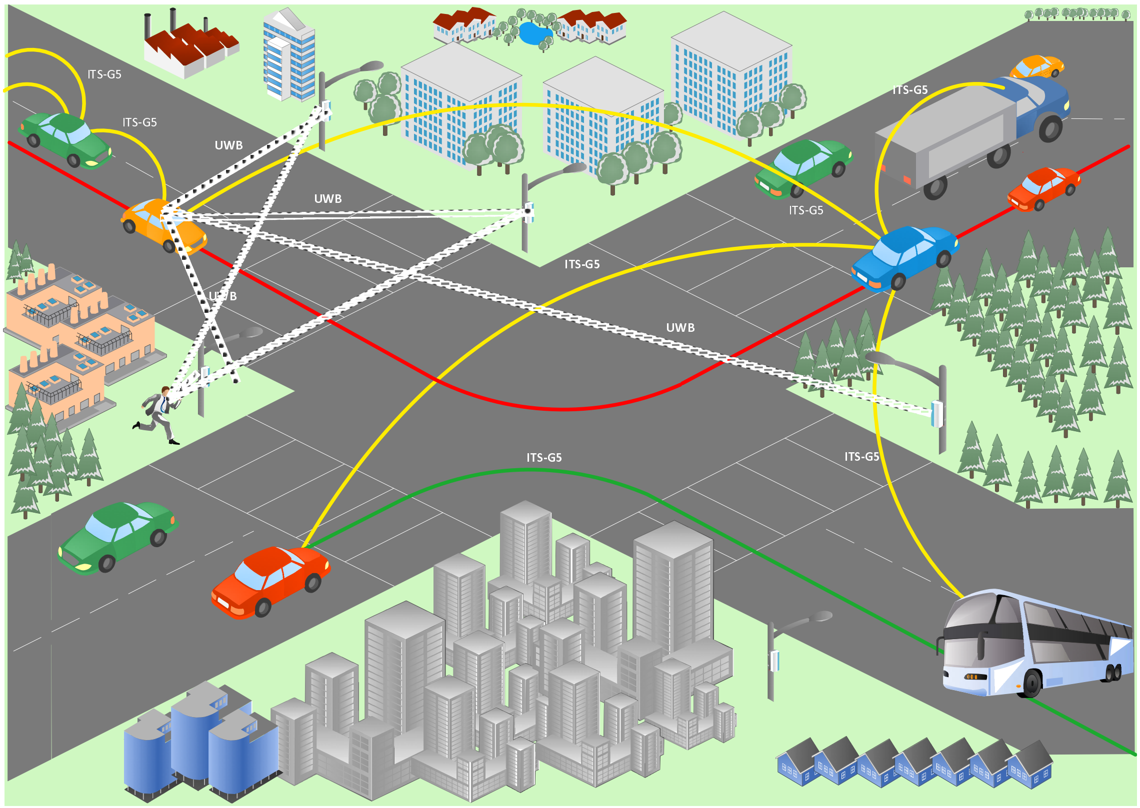


Figure 18: High precision positioning in cooperative ITS environments

7.10.4 Mitigation factors

The main mitigation factors in this application are:

- Duty cycle restrictions.
- Antenna patterns of the beacon stations with down tilt antennas.
- If higher TX powers than -41,3 dBm/MHz e.i.r.p. are required an additional DAA mechanism with a proper UWB channel selection can be deployed.
- Centralized DAA is possible.

Other mitigation factors can be evaluated.

7.11 Living object protection (LOP) systems for wireless electrical vehicle (EV) charging (WEVC)

7.11.1 Introduction

Currently electric cars are charged through cables adding some extra effort when parking the car overnight or at work. To make charging more seamless, several vendors are now considering wireless/inductive charging as an alternative. Inductive power transfer is highly effective, compact, easy and safe to use, and economic for volume car production. Limited and specialized deployments, such as in bus fleets, have served as excellent proof-of-concept test beds for vehicle charging; but the circular coil technologies upon which these implementations are based have been developed about as far as possible. Due to the high energy transfer, safety is an important matter.

Wireless EV charging using inductive power transfer presents two types of safety hazards:

- Excessive heating of stray objects which are energized by the inductive power transfer magnetic field between base and vehicle pads with the risk of skin burns or fire.

- Direct exposure of humans, animals and implantable medical devices to magnetic and electrical fields which may cause potentially adverse health effects, or erratic operation of IMDs.

While other technologies may be used to detect foreign stray objects, UWB radar sensors are very well suited to detect humans and other living objects and thus contribute to safe and low cost EV charging systems.

7.11.2 System requirements

The main technical requirements relevant to the application for coexistence investigations are given:

- Bandwidth up to 2,5 GHz.
- Pulse based Sensor: 16 MHz PRF.
- Location precision: < 0,1 m.
- Range: < 1 m.
- Spectrum band: 6,0 GHz - 8,5 GHz.

7.11.3 Technical description

Wireless EV charging systems can produce electromagnetic fields which exceed the regulated levels for humans and implantable medical devices such as heart pacemakers. Between and around the pads, these emissions may cause potentially adverse health effects to humans and other vertebrates including pets, or erratic operation of IMDs could occur. The human exposure hazards are greatest when somebody lies on the ground by the side of the car and reaches into the gap between the pads with their arm.

EMF radiation should comply with the international safety regulations. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines have been established to limit human exposure to time-varying EMF with the aim of preventing adverse health effects. The guidelines provide reference safety restrictions of both electric field and magnetic field for occupational exposure and general public exposure. Regulators refer to the ICNIRP guidelines in their development of safety regulations. IMD immunity regulations are set by the American National Standards Institute and the Association for the Advancement of Medical Instrumentation. Automotive OEMs impose more stringent limits in various places around the car (e.g. by the sills) than those in ICNIRP guidelines, in some cases.

Effective LOP systems should ensure that WEVC is immediately shut down when parts of the human body (e.g. a hand, arm or foot) and animals approach the Z-gap zone where field strengths exceed safety limits. Safety regulations are set for humans, including those with IMDs. However, systems should also protect various animals including household pets.

Some LOP systems have also suffered from various limitations. These include a tendency to false trigger due to incidental movements around the vehicle or vehicle vibrations, and missed detections: for example, no provisions for sleeping animals (i.e. not moving). Some systems have been located on the vehicle: OEMs now specify that LOP systems should be located off vehicles.

Extensive development of radar technology-based LOP systems significantly improve system operation by eliminating or significantly reducing false triggers. Sensing and signal processing electronics is conveniently contained in the base pad and provides information on object speed and distance from the base pad. The coverage includes a defined area around the perimeter of the base pad and directly above the base pad surface. The coverage will vary depending on the properties of the WEVC system and the vehicle model being charged. Vehicle-specific coverage areas can be defined and then programmed into the LOP system. The LOP system sensitivity is configurable and limits for the minimum size of living objects to be detected can be defined. This balances risks of missed detections with risks of false triggers.

Figure 19: Wireless electric vehicle charging system (with permission of Qualcomm)

7.11.4 Mitigation factors

Possible mitigation factors are:

- Duty cycle restrictions:
    - Optional like in 3,1 GHz - 4,8 GHz band.
    - Duty cycle below 1 %.
- Power restriction:
    - Power restriction possible to -51,3 dBm/MHz for systems with up tilt antennas.
- Antenna techniques:
    - Radiation shielded by car.

All proposed mitigation techniques are already in use and qualified for different applications and frequency bands (e.g. ETSI EN 302 065-3 [i.4]).

7.11.5 Application specific market information

The Technavio report "Global Electric Vehicle Charger Market 2016-2020" [i.39] analyzes the global EV charging system market forecasts.

EXAMPLE: Wireless Charging Ready for Burgeoning Mass Market in EVs, 18th August 2015 http://www.wiseharbor.com/pdfs/WiseHarbor%20Spotlight%20Report%201%20Efficacy%202015Aug18.pdf [i.40].

7.12 Industrial Asset tracking

7.12.1 Introduction

Industrial manufacturers have a need to accurately location track several kinds of assets.

EXAMPLE: High value instrumentation, hazardous materials, and personnel working in hazardous areas. In many cases these assets are located outdoors but in areas that have significant amounts of infrastructure like tanks or pipes that highly attenuate other wireless tracking systems like GPS or Wi-Fi tracking techniques.

The primary objective of an UWB industrial asset tracking device is to maintain the same level of tracking accuracy in outdoor industrial environments as can be done indoors. Many of these assets are mobile and move between "indoor" and "outdoor" environments as part of a daily process. The mobile asset tag can be easily affixed to the asset but cannot be tracked when it moves "outdoors". This high accuracy location information is transmitted to a remote location. This information can be used not only to track assets in a daily bases but in emergency situations will aid in the rescue of personnel or providing information as to hazardous material locations.

This application is similar to the "Self configuring outdoor TDOA localization system" application in clause 7.8.

7.12.2 System requirements

Here the main technical requirements relevant of the application for coexistence investigations are given:

- Bandwidth 500 MHz.
- Data rate 6,8 Mbps.
- TX power: -41,3 dBm/MHz e.i.r.p.
- Location precision in general as precise as possible, below 10 cm.
- Spectrum band general UWB frequency ranges (3,1 GHz to 4,8 GHz, 6 GHz - 9 GHz).
- Wireless synchronization packets once per 150 ms.
- Antenna techniques: down tilt antenna with an antenna heights of < 5 m.
- Fixed outdoor is required.

7.12.3 Technical description

The UWB Industrial Asset Tracking System consists of a mobile tag and a fixed device that accurately measures the location of the mobile tag using the time of flight of the transmitted signal. The range/location data is then transferred to another industrial communication device like Wireless Hart for display on a digital site map or other such device.

The Industrial Asset Tracking System uses a radio transceiver compliant with the IEEE 802.15.4-2011 [i.41] Ultra Wide Band Standard to track high value assets. A time of flight ranging scheme is used to determine real time location of these assets. The LIAT system can be configured over a range of data rates and RF bands to best accommodate the type of environment it is deployed.

A typical operational environment for LIAT systems using UWB is depicted in figure 20.

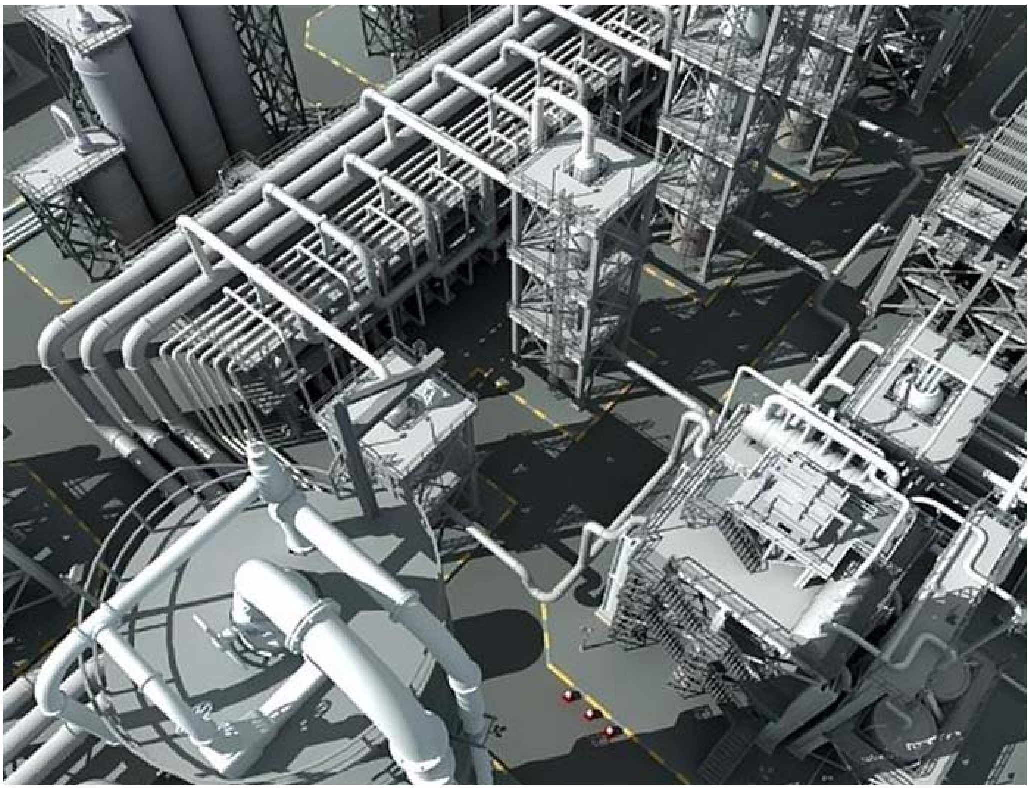


Figure 20: Typical industrial environment for LIAT systems

7.12.4 Mitigation factors

The primary application for these devices are industrial sites. As such, the devices are not commercially available. This provides for several mitigation advantages:

1) The devices would be contained within the property boundaries of the industrial operator.

2) The devices are professionally installed and maintained providing for a high level of accuracy with regard to signal attenuation at prescribed outdoor boundaries.

3) Industrial locations typically have a high level of infrastructure that provides high signal attenuation.

4) Industrial sites are typically remote from highly populated areas and due to the low output power and longer distances, potential victims are minimal.

5) Fixed UWB antennas would use downward facing directional antennas further controlling the proliferation unwanted interference signals.

7.13 Summary

The depicted applications in clause 7 represent a set of use cases which are either not possible today or only possible with limitations. Especially the UWB band between 6,0 GHz to 9,0 GHz would benefit from some regulatory updates including the implementation of additional existing and new mitigation techniques in order to allow especially a fixed outdoor usage and an increased TX power for indoor usage scenario. The increased indoor TX power could be limited to fixed indoor systems with an centralized DAA approach or industrial/professional use cases.

8 Current regulations and standards

8.1 Summary of UWB application defined in Europe

Ultra-wide-Band technology is mainly related to sensor applications, specifically functions such as radars, ranging and location tracking devices, and/or their related communications. Applications using UWB in Europe, described in ETSI and ECC documents, are summarized in table 3.

Table 3: Overview of UWB applications, as resulting from ETSI standards and current EU regulations

Type of application	Description
Generic	• Non-specific, generic consumer applications.
Location & Tracking	• Localization of object in a range gate. • Tracking of target movements within the detection range. • Sensor tracking technology for mass market applications. • Indoor tracking applications covered by FCC regulation and ECC UWB decision. • Localization of persons and objects in emergency areas.
Automotive & railway	• Sensing or communication application, intended for usage related to road and rail vehicles, and namely: o stand-alone radio equipment with or without its own control provisions, mounted in road or rail vehicles. o plug-in radio devices intended for use with, or within, a variety of host systems, e.g. personal computers, etc. o plug-in radio devices intended for use within combined equipment, e.g. modems, access points, etc. o equipment for the communication inside and outside of road and rail vehicles. o equipment for the localization of devices inside and outside of road and rail vehicles, e.g. hand-held devices.
Concrete inspections & imaging	• Imaging systems based on field disturbance sensors, designed to operate only in close proximity or even in contact with the ground or wall or other concrete structures, for the purpose of detecting or obtaining images of buried objects or determining the physical properties within the structure. The energy from these sensors is intentionally directed into the material to be analysed, as such the majority of the signal transmitted by the sensor is absorbed.
Material sensing devices, fixed or mobile	• Devices enabling radio determination applications designed to detect the location of objects within a structure or to determine the physical properties of a material. This may include localization of hidden targets in construction e.g. pipes, holes, wires for increased safety while e.g. drilling, construction testing, or characterization of material, e.g. metal or plastic or humidity, sensors which could be attached/integrated in tooling equipment and, and namely: o Building Material Analysis (BMA), i.e. devices designed to detect the location of objects within a building structure or to determine the physical properties of a building material. o Object Discrimination and Characterization (ODC) devices, allowing the identification and classification of objects (including human tissue) in addition to detecting their presence and position. The operation is contactless and works over a short distance of less than 40 cm, even if the object is hidden by an obstacle. o Ground Probing Radars (GPR) radiating directly downwards into the ground, such that any horizontal radiation from this equipment is considered as undesired emission. o Wall Probing Radars (WPR) radiating directly into a "wall", where the "wall" is a building material structure, the side of a bridge, the wall of a mine or another physical structure that absorbs a significant part of the signal transmitted by the radar.
Level probing radars	• Level probing sensors, that may radiate in free space (LPR), concerned with process control, to measure the amount of various substances (mostly liquids or granulates) having the main purposes of: o to increase reliability by preventing accidents; o to increase industrial efficiency, quality and process control; o to improve environmental conditions in production processes. • Level probing sensors installed in closed tanks made of strong attenuating RF material (TLPR), holding a substance, liquid or powder, that cannot radiate outside of their container.
Airborne applications	• Cabin Management System (CMS) application field. • Passenger communication and in-flight entertainment. • Mobile devices (also by passengers) which will become part of the future cabin equipment. • Communication headsets for pilots in the cockpit and for the flight crew.

These applications are defined in official documents delivered by ETSI and CEPT. A more detailed overview of UWB standards applications, as well as related ETSI framework and status in the standards process, are listed in table 4.

Table 4: Overview ETSI Standards

Type	Application	Frequency Ranges [GHz]	ETSI Standard	Status	Remark	Responsible ETSI TC ERM
Generic	Non-specific consumer or professional applications	3,1 to 4,8 6 to 9	ETSI EN 302 065-1 [i.2]	ETSI Published 11-2016	RED compliant	TG UWB
Location & Tracking	Location Tracking Type 1 (LT1)	6 to 9	ETSI EN 302 065-2 [i.3]	ETSI Published 11-2016	RED compliant	TG UWB
	Location Tracking Type 2 (LT2)	3,1 to 4,8	ETSI EN 302 065-2 [i.3]	ETSI Published 11-2016	RED compliant	TG UWB
	Location Application for emergency Services (LAES)	3,1 to 4,8	ETSI EN 302 065-2 [i.3]	ETSI Published 11-2016	RED compliant	TG UWB
Automotive & railway	Automotive and railway	3,1 to 4,8 6 to 9	ETSI EN 302 065-3 [i.4]	ETSI Published 11-2016	RED compliant	TG UWB
	Location Tracking for automotive & transportation environment (LTT)	3,1 to 4,8 6 to 8,5	ETSI EN 302 065-3 [i.4]	ETSI Published 11-2016	RED compliant	TG UWB
Concrete inspections & imaging	Professional Ground and Wall Probing Radars (GPR-WPR)	0,030 to 12,4	ETSI EN 302 066 [i.24]	Published 02-2008		
Material sensing devices	Building Material Analysis (BMA)	2,2 to 8,5	ETSI EN 302 065-4 [i.5]	ETSI published 11-2016		
	Object Discrimination and Characterization (ODC)	2,2 to 8,5	ETSI EN 302 065-4 [i.5]	Published 06-2010		
	Object Identification for Surveillance Applications (OIS)	2,2 to 8	ETSI TR 102 495-3 [i.42]	Stopped		
Level probing radars	Tank Level Probing Radar (TLPR)	4,5 to 7 8,5 to 10,6 24,05 to 27 57 to 64 75 to 85	ETSI EN 302 372 [i.25]	Published 02-2009		Former TG TLPR Now TG UWB
	Level Probing Radars (LPR)	6,0 to 8,5 24,05 to 26,5 57 to 64 75 to 85	ETSI EN 302 729 [i.26]	Published 05-2011		Former TG TLPR Now TG UWB
Airborne applications	Aircraft	Under study			Under study	

These applications are described in greater detail in ETSI TR 103 181-1 [i.19].

8.2 Summary of mitigation techniques allowed for UWB applications

Due to the different usage profiles required for the previously described UWB applications, numerous mitigation techniques have been developed. These various mitigation techniques have been studied in ETSI and ECC/CEPT reports. A summary is shown in table 6. This table lists only those applications and related bands where mitigations are allowed. The table does not include bands/applications where no mitigation is defined or allowed.

The main compatibility studies that have been performed by ECC for the listed applications are shown in table 5.

Table 5: Overview of applicable mitigation techniques to UWB applications

Applications	Frequency Range [GHz]	Applicable mitigation
Non-specific applications	3,1 to 4,8	LDC or DAA
Non-specific applications	8,5 to 9,0	DAA
Location Tracking Type 1 (LT1)	8,5 to 9,0	DAA
Location Tracking Type 2 (LT2)	3,1 to 3,4	LDC and DAA
Location Tracking Type 2 (LT2)	3,4 to 3,8	LDC
Location Tracking Type 2 (LT2)	3,8 to 4,8	LDC
Location Tracking Type 2 (LT2), fixed outdoor	3,8 to 4,8	LDC and restricted angular sector radiation (above 30°)
Location Application for emergency Services (LAES)	3,1 to 3,4	LDC and DAA
Location Application for emergency Services (LAES)	3,4 to 4,2	LDC
Location Application for emergency Services (LAES)	4,2 to 4,8	LDC
Automotive and railway LTT	3,1 to 4,8	LDC and restricted angular sector radiation (above 0°, note 2) or DAA and TPC and restricted angular sector radiation (above 0°, note 2)
Automotive and railway LTT	3,4 to 3,8	LDC and restricted angular sector radiation (above 0°, note 2) or DAA and TPC and restricted angular sector radiation (above 0°, note 2)
Automotive and railway LTT	3,8 to 4,8	LDC and restricted angular sector radiation (above 0°, Note 2) or DAA and TPC and restricted angular sector radiation (above 0°, note 2)
Automotive and railway LTT	6,0 to 8,5	LDC and restricted angular sector radiation (above 0°, note 2) or TPC and restricted angular sector radiation above 0°, note 2)
Automotive and railway LTT	8,5 to 9,0	DAA and TPC and restricted angular sector radiation limit (above 0°, note 2)
Concrete inspections & imaging (GPR/WPR)	All bands	Limited TX operations (note 1)
Material sensing devices: non fixed installations, all	All bands	Limited TX operations (note 1)
Material sensing devices: non fixed installations, all	2,50 to 2,69	Limited TX operations (note 1) and LBT and TRP
Material sensing devices: non fixed installations, all	2,69 to 2,70	Limited TX operations (note 1) and LDC
Material sensing devices: non fixed installations, all	2,9 to 3,40	Limited TX operations (note 1) and LBT
Material sensing devices: non fixed installations, all	3,4 to 3,80	Limited TX operations (note 1) and TRP and LDC
Material sensing devices: non fixed installations, all	4,8 to 5,00	Limited TX operations (note 1) and TRP and LDC
Material sensing devices: fixed installations, all	All bands	TPC
Material sensing devices: fixed installations, all	1.73 to 2.20 2,50 to 3,80 4,80 to 5,00 5,25 to 5,35 5,60 to 5,725	TPC and restricted angular sector radiation within elevation angles -20°/+30°
Material sensing devices: fixed installations, all	2,5 to 2,69	Usage of LBT, in addition to TPC and restricted angular sector radiation, allows further increasing of maximum permitted e.i.r.p.
Material sensing devices: BMA only	All bands	Limited TX operations (note 1) and TRP
Material sensing devices: BMA only	1,215 to 1,73 2,5 to 2,69 2,7 to 3,40	Usage of LBT, in addition to Limited TX operations and TRP, allows further increasing of maximum permitted e.i.r.p.

Applications	Frequency Range [GHz]	Applicable mitigation
Tank Level Probing Radar (TLPR)	All bands	LDC
Level Probing Radars (LPR)	All bands	LDC or TPC, and other radiation pattern limitation (shielding, thermal radiation)
Aircraft	Under study	Under study
NOTE 1: "Limited TX Operations" means that the transmitter can be switched "on" only if manually operated with a non-locking switch (e.g. it may be a sensor for the presence of the operators hand) and, moreover, only if being in contact or close proximity to the investigated material and the emissions being directed into the direction of the object (e.g. measured by a proximity sensor or imposed by the mechanical design). Additional requirements may be imposed to switching on and off the transmitter (see ECC/DEC/(07)01 [i.10] amended 26 June 2009, Annex 1). NOTE 2: The restriction on angular sector of radiation to be complied above 0° in ETSI EN 302 065-3 [i.4] is therein called "Exterior Limit".		

Table 6: Main compatibility studies for different UWB applications

	LDC	DAA	TPC	TRP	LBT	Restricted Angular Sectors	Shielding
Non specific	ECC Report 094 [i.14]	ECC Report 120 [i.7]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 1	*NO*	ECC Report 120 [i.7]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 2	ECC Report 170 [i.11]	ECC Report 120 [i.7]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 2 fixed outdoor	ECC Report 170 [i.11]	ECC Report 120 [i.7]	*NO*	NO	NO	ECC Report 170 [i.11]	*NO*
Location Application for emergency Services	ECC Report 170 [i.11]	ECC Report 120 [i.7]	*NO*	*NO*	*NO*	*NO*	*NO*
Material sensing devices, non fixed installations	ECC Report 123 [i.23] ECC Report 094 [i.14]	*NO*	*NO*	ECC Report 123 [i.23]	TG3 Meeting#15_09R0	*NO*	*NO*
Material sensing devices, fixed installations	ECC Report 094 [i.14]	*NO*	ECC Report 123 [i.23]	NO	TG3 Meeting#15_09R0	ECC Report 123 [i.23]	*NO*
Material sensing devices: BMA	TG3 Meeting#15_09R0	*NO*	TG3 Meeting#15_09R0	TG3 Meeting#15_09R0	TG3 Meeting#15_09R0	*NO*	*NO*
Automotive and railway	ECC Report 170 [i.11]	ECC Report 120 [i.7]	CEPT Report 17 [i.21]	*NO*	*NO*	ECC Report 170 [i.11]	*NO*
Concrete Inspections (GPR/WPR)	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*
Tank Level Probing Radars		*NO*	*NO*	*NO*	*NO*	*NO*	CEPT Report 17 [i.21]
Level Probing Radars	ECC Report 139 [i.22]	*NO*		*NO*	*NO*	*NO*	*NO*
Aircraft	ECC Report 175 [i.20]	*NO*	*NO*	*NO*	*NO*	ECC Report 175 [i.20]	ECC Report 175 [i.20]

9 Proposed changes to regulations

9.1 Introduction

During the UWB regulation process a set of mitigation techniques have been developed for the protection of incumbent services and applications. These techniques have been evaluated in a specific application domain and corresponding scenarios. Most of these techniques could be used in other application domains and environments thus extending the possible use cases of UWB devices to include other frequency bands or scenarios.

Examples:

- Deployment of DAA process to protect fixed links in the band 6 GHz to 8,5 GHz for fixed outdoor usage and increase of the allowed TX power for indoor usage.
- Low Duty cycle to protect FSS uplink in the band above 6 GHz.
- Antenna techniques in the band 6 GHz to 9 GHz.
- Deploy exterior limits to band 6 GHz to 9 GHz to increase TX power.
- Attenuation indoor-to-outdoor update to simplify coexistence with incumbent services.

9.2 Detailed Regulation proposal

Table 7: Overview proposed regulation

	ECC/DEC(06)04 [i.6], Annex 1	**ECC/DEC(06)04 [i.6], Annex 2**	**Proposal 1 from ETSI TR 103 314**	**Proposal 2 from ETSI TR 103 314**
Frequency range	**Maximum mean e.i.r.p. spectral density**	**Maximum mean e.i.r.p. spectral density**	**Fixed outdoor (generic)**	**Fixed or quasi-fixed indoor (generic)**
	Generic use; fixed outdoor and vehicular use excluded	Vehicular use	Possible mitigations: • Power restriction to -53,3 dBm/MHz • Antenna down tilt • DC restriction • Interference management • Height restriction • DAA	Possible mitigations: • DC restriction • Interference management • Indoor only • Fixed/quasi fixed • DAA
Below 1,6 GHz	-90 dBm/MHz	-90 dBm/MHz	-90 dBm/MHz	-90 dBm/MHz
1,6 to 2,7 GHz	-85 dBm/MHz	-85 dBm/MHz	-85 dBm/MHz	-85 dBm/MHz
2,7 to 3,1 GHz	-70 dBm/MHz	-70 dBm/MHz	-70 dBm/MHz	-70 dBm/MHz
3,1 to 3,4 GHz	-70 dBm/MHz (notes 1 and 2)	-70 dBm/MHz (notes 1* and 2*)	-70 dBm/MHz (notes 1 and 2)	-70 dBm/MHz (notes 1 and 2)
3,4 to 3,8 GHz	-80 dBm/MHz (notes 1 and 2)	-80 dBm/MHz (notes 1* and 2*)	-80 dBm/MHz (notes 1 and 2)	-80 dBm/MHz (notes 1 and 2)
3,8 to 4,8 GHz	-70 dBm/MHz (notes 1 and 2)	-70 dBm/MHz (notes 1* and 2*)	-70 dBm/MHz (notes 1 and 2)	-70 dBm/MHz (notes 1 and 2)
4,8 to 6 GHz	-70 dBm/MHz	-70 dBm/MHz	-70 dBm/MHz	- 70 dBm/MHz (note 5*)
6 to 8,5 GHz	-41,3 dBm/MHz	-53,3 dBm/MHz (notes 1* and 3)	[-47,3] dBm/MHz (note 4)	-41,3 dBm/MHz (note 5)
8,5 to 9 GHz	-65 dBm/MHz (note 2)	-65 dBm/MHz (note 2*)	-65 dBm/MHz (note 2)	-65 dBm/MHz (note 2**)
9 to 10,6 GHz	-65 dBm/MHz	-65 dBm/MHz	-65 dBm/MHz	-65 dBm/MHz
Above 10,6 GHz	-85 dBm/MHz	-85 dBm/MHz	-85 dBm/MHz	-85 dBm/MHz

	ECC/DEC(06)04 [i.6], Annex 1	ECC/DEC(06)04 [i.6], Annex 2	Proposal 1 from ETSI TR 103 314	Proposal 2 from ETSI TR 103 314
Frequency range	**Maximum mean e.i.r.p. spectral density**	**Maximum mean e.i.r.p. spectral density**	**Fixed outdoor (generic)**	**Fixed or quasi-fixed indoor (generic)**

NOTE 1: Within the band 3,1 - 4,8 GHz, devices implementing **Low Duty Cycle (LDC) mitigation technique** (see Annex 2, in [i.6]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 1*: Within the band 3,1 - 4,8 GHz and 6 - 8,5 GHz, devices implementing Low Duty Cycle (LDC) mitigation technique (see Annex 2, in [i.6]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz. Operation is in addition subject to the implementation of an exterior limit (see Annex 5, in [i.6]) of -53,3 dBm/MHz.

NOTE 2: Within the bands 3,1 - 4,8 GHz and 8,5 - 9 GHz, devices implementing **Detect And Avoid (DAA) mitigation technique** (see Annex 3, in [i.6]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 2*: Within the bands 3,1 - 4,8 GHz and 8,5 - 9 GHz, devices implementing Detect And Avoid (DAA) mitigation technique (see Annex 3, in [i.6]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz. Operation is in addition subject to the implementation of Transmit Power Control (TPC) mitigation technique (see Annex 4, in [i.6]) and an exterior limit (see Annex 5, in [i.6]) of -53,3 dBm/MHz.

NOTE 2**: Within the band 8,5 - 9 GHz, fixed or quasi fixed indoor devices implementing Detect And Avoid (DAA) mitigation technique (see Annex 3, in [i.6]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -31,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 3: Within the band 6 - 8,5 GHz devices implementing Transmit Power Control (TPC) mitigation technique (see Annex 4, in [i.6]) and an exterior limit (see Annex 5, in [i.6]) of -53,3 dBm/MHz are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 4: Within the band 6 - 8,5 GHz devices implementing "fixed outdoor" **TBD mitigation** techniques (to be developed) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 5: Within the band 6 - 8,5 GHz devices operated fixed or quasi-fixed indoor implementing **TBD mitigation (e.g. new DAA)** techniques are permitted to operate with a maximum mean e.i.r.p. spectral density of -31,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 5*: Within the band 4,8 - 6 GHz devices operated fixed or quasi-fixed indoor implementing **TBD mitigation** techniques are permitted to operate with a maximum mean e.i.r.p. spectral density of - 55 dBm/MHz and a maximum peak e.i.r.p. of -15 dBm defined in 50 MHz.

10 Conclusions

The present document provides information on existing and new mitigation techniques for the protection of incumbent services from harmful interference generated by devices deploying ultra-wide band technologies. It evaluates the applicability of existing and implemented application specific mitigation techniques to other application domains and incumbent services.

The inclusion of the proposed regulation update into the UWB regulatory framework will significantly extend the applicability of UWB based technologies.

Annex A:
Market information

All relevant information is included in the main body of the present document.

Annex B: Technical information

All technical information is included in the main text of the SRDoc.

Annex C: Expected compatibility issues

See table 6 in clause 8.

Annex D: Bibliography

- ETSI TR 103 086 (V1.1.1) (03-2013): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Conformance test procedure for the exterior limit tests in EN 302065-3 UWB applications in the ground based vehicle environment".
- ECC Report 167 (May, 2011): "The Practical Implementation of Registration/Coordination Mechanism for UWB LT2 (Location Tracking Type 2) Systems".
- CEPT/ECC Report 64: "The protection requirements of radiocommunications systems below 10,6GHz from generic UWB applications", Helsinki, February 2005.
- CEPT Report 34: "Report B from CEPT to European Commission in response to the Mandate 4 on Ultra-Wideband (UWB); Final Report on 30 October 2009 by the Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT)".
- Commission Decision 2007/131/EC of 21 February 2007 on allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonised manner in the Community (notified under document number C(2007) 522).
- ETSI TS 102 754 (V1.3.1) (03-2013): "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".
- ERC Recommendation 74-03 (2011): "Unwanted Emissions in the Spurious Domain", Cardiff.
- ECC Report 235 (May 2015): "Assessment of the feasibility of the possible joint use, on a long term basis, of the adjacent bands 5925-6425 MHz and 6425-7125 MHz for P-P links".
- 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".

History

Document history		
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