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**Electromagnetic compatibility
and Radio spectrum Matters (ERM);
Short Range Devices (SRD) using Ultra Wide Band (UWB);
Transmission characteristics
Part 2: UWB mitigation techniques**

Reference

DTR/ERM-TGUWB-007-2

Keywords

DAA, radar, radio, SRD, testing, UWB

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Contents

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Foreword

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

The present document is part 2 of a multi-part deliverable covering Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB); Transmission characteristics, as identified below:

Part 1: "Signal characteristics";

Part 2: "UWB mitigation techniques".

Modal verbs terminology

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

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Introduction

Ultra Wideband technology (UWB) provides a very flexible technology for many fields of applications, like sensors, radars, short range telecommunications, etc.

The main characteristic of an UWB transmission is its very high bandwidth (greater than 50 MHz in ECC countries), combined with the capability to generating signals with reduced power consumption at the transmitter. This enables a variety of new applications, such that low power is required with very high bandwidth.

Due to its very large bandwidth, an UWB application should limit emissions in other bands, which may interfere with other applications. Therefore trade-offs between the transmitter power levels required by the intended UWB application and the low level of emissions that may be received by potential victim applications, without jeopardizing them, needs to be carefully assessed.

A way for increasing flexibility in designing UWB application, allowing higher power level of transmitted power and preventing at the same time harmful interference on other bands, are the so called mitigation techniques.

A mitigation technique is a limitation imposed over specific transmissions characteristics (e.g. duty cycle, special rules for accessing the medium, limitation of the radiated pattern within specific angular sectors, etc.), under which adoption the transmission may be enabled or the transmitted power levels may be increased.

There are two different kinds of usage of mitigation techniques in EU standards: a mitigation may be imposed as a mandatory requirement or it may be allowed as an optional requirement. When a mitigation is used as a mandatory requirement, a device is allowed to operate only if it adopts that mitigation; when a mitigation is used as an optional requirement, devices using the mitigation are allowed to increase the emitted power limits with respect to devices not using any mitigation. In UWB standards there are examples of both these usage.

In the present document a summary of the mitigation techniques allowed for UWB, classified by kinds of application and range of frequency, is presented.

The present document presents a summary of the different UWB applications covered by current ETSI standards. Then, starting from this summary, the different mitigation techniques are described and for each of the listed applications, the related technical parameters implemented in ETSI standards or EC and ECC regulations are reported.

1 Scope

The present document summarizes the requirements for different mitigation techniques adopted by Ultra Wide Band (UWB) applications.

Covered mitigation techniques are Listen Before Talk (LBT), Detect and Avoid (DAA), Transmitter Power Control (TPC), Low Duty Cycle (LDC), Radiation Power Limitation like Total Radiated Power limits (TRP), Exterior Limit, restrictions on e.i.r.p. over predefined angular sectors and shielding.

Additional information is given in the following annexes:

- Quantitative analysis for the technique of trading LDC against transmitted power (Annex A).
- Details on the mathematical models used for the evaluation of trading LDC against transmitted power (Annex B).

2 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.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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] EU Commission Decision 2009/343/EC 21 April 2009 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.

[i.2] EU 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 harmonized manner in the Community.

[i.3] ECC Decision of 24 March 2006 on the harmonized conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz, amended 9 December 2011 (ECC/DEC/(06)04).

[i.4] ECC Decision of 30 March 2007 on Building Material Analysis (BMA) devices using UWB technology (ECC/DEC/(07)01).

[i.5] ECC Report 064: "The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications", Helsinki, February 2005.

[i.6] ECC Report 120: "Technical requirements for UWB DAA (Detect and Avoid) devices to ensure the protection of radiolocation services in the bands 3.1 - 3.4 GHz and 8.5 - 9 GHz and BWA terminals in the band 3.4 - 4.2 GHz", Kristiansand, June 2008.

[i.7] ECC Report 123: "The impact of object discrimination and characterization (ODC) applications using ultra-wideband (UWB) technology on radio services", Vilnius, September 2008.

[i.8] ECC Report 170: "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.9] CEPT Report 010: Report from CEPT to the European Commission in response to the Mandate on UWB Specific Applications, Final Report on July 2006.

[i.10] CEPT Report 009: Report from CEPT to the European Commission in response to the Mandate on Harmonise radio spectrum use for Ultra-Wideband Systems in the European Union, Final Report on 28 October 2005.

[i.11] 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, Final Report on 28 October 2005.

[i.12] ETSI TS 102 883 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB); Measurement Techniques".

[i.13] ETSI TS 103 060 (V1.1.1): "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.14] ETSI TS 102 754 (V1.3.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics of Detect And Avoid (DAA) mitigation techniques for SRD equipment using Ultra Wideband (UWB) technology".

[i.15] ETSI TR 103 181-1 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB);Transmission characteristics Part 1: Signal characteristics".

[i.16] ETSI TR 103 086 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Conformance test procedure for the exterior limit tests in EN 302 065-3 UWB applications in the ground based vehicle environment".

[i.17] ETSI TR 102 495-1 (V1.1.1): "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 1: Building material analysis and classification applications operating in the frequency band from 2,2 GHz to 8 GHz".

[i.18] ETSI TR 102 495-2 (V1.2.1): "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 2: Object Discrimination and Characterization (ODC) applications for power tool devices operating in the frequency band of 2,2 GHz to 8,5 GHz".

[i.19] ETSI EN 302 435 (parts 1 and 2) (V.1.3.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra WideBand technology (UWB); Building Material Analysis and Classification equipment applications operating in the frequency band from 2,2 GHz to 8,5 GHz".

[i.20] ETSI EN 302 066 (parts 1 and 2) (V.1.3.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Ground- and Wall- Probing Radar applications (GPR/WPR) imaging systems".

[i.21] ETSI EN 302 498 (parts 1 and 2) (V.1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra WideBand technology (UWB); Object Discrimination and Characterization Applications for power tool devices operating in the requency band from 2,2 GHz to 8,5 GHz".

[i.22] ETSI EN 300 328 (V.1.8.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.23] ETSI EN 302 065-1 (V.1.3.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 1: Requirements for Generic UWB applications".

[i.24] ETSI EN 302 065-2 (V.1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 2: Requirements for UWB location tracking".

[i.25] ETSI EN 302 065-3 (V.1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 3: Requirements for UWB devices for road and rail vehicles".

[i.26] ETSI EN 302 729 (all parts) (V1.1.2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); 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".

[i.27] ETSI EN 302 372 (all parts) (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detection and Movement; Tanks Level Probing Radar (TLPR) operating in the frequency bands 5,8 GHz, 10 GHz, 25 GHz, 61 GHz and 77 GHz".

[i.28] Recommendation ITU-R P.526-10: "Propagation by diffraction".

[i.29] Recommendation ITU-R P 679-1: "Propagation data required for the design of broadcasting-satellite systems".

[i.30] Recommendation ITU-R RA 769-2: "Protection criteria used for radio astronomical measurements".

[i.31] ECC TG3#18-18R0: "Flexible DAA mechanism based on "isolation criteria" between victim service and UWB devices", ECC TG3 Meeting 18, Mainz, March 2007.

[i.32] "Report on Radio Frequency Compatibility Measurements between UWB LDC Devices and Mobile WiMAX (IEEE 802.16e-2005) BWA Systems", JRC, Ispra, July 26-27, 2010.

[i.33] "Mobile WiMAX - Part I: A Technical Overview and Performance Evaluation", August 2006, The WiMAX Forum.

[i.34] "Assessment of compatibility between Ultra WideBand devices and selected federal systems", NTIA special publication, L. K. Brunson et Alt., January 2001.

[i.35] "Propagation of Ultra Wideband Signals in Automotive Environment", Ching-Ping Wang and Wen-Jiao Liao, National Taiwan University of Science and Technology, Taiwan.

[i.36] "UWB screening attenuation measurements of cars", study by IPSC of JRC and ETSI TG31C on the measurements of the screening attenuation of cars in the frequency range between 0,85 GHz and 11 GHz, Joaquim Fortuny-Guasch, IPSC, October 2006.

[i.37] ETSI EN 302 500, Parts 1 and 2 (V.2.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra WideBand (UWB) technology; Location Tracking equipment operating in the frequency range from 6 GHz to 9 GHz.

[i.38] ECC Reports 094: "Technical requirements for UWB LDC devices to ensure the protection of FWA System", Nicosia, December 2006.

[i.39] ECC Reports 175: "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", March 2012.

[i.40] ECC Reports 139: "Impact of level probing radars using Ultra-Wideband technology on radiocommunications services", Rottach-Egern, February 2010.

[i.41] CEPT report 17: "Report from CEPT to the European Commission in response to the Mandate to: identify the conditions relating to the ha rmonised introduction in the European Union of radio applications based on ultra-wideband (UWB) technology", 30 March 2007.

[i.42] R&TTE Directive: Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity.

[i.43] ISO/IEC 7498-1: "Information technology -- Open Systems Interconnection -- Basic Reference Model: The Basic Model".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

absolute transmission availability ratio (Q_{aa})**:** for a victim link, this is the ratio between the sum of all time window where the aggregated interference level is below a predefined threshold, and a predefined observation time, irrespectively of the windows duration

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

equivalent isotropically radiated power (e.i.r.p.): product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain) (RR 1.161)

interferer or interfering link: link or service affected from interference coming from the device intended to be subjected to mitigation

jammer or jamming link: device intended to be subjected to mitigation, potentially affecting any victim link

linear trading (of e.i.r.p. levels versus LDC limits): passive mitigation technique consisting in limiting the product of duty cycle and e.i.r.p. power levels, provided that e.i.r.p. and LDC are within certain defined boundaries

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 %).

maximum mean e.i.r.p. spectral density: average power per unit bandwidth (centred on that frequency) radiated in the direction of the maximum level under the specified conditions of measurement

maximum peak e.i.r.p.: peak power specified as e.i.r.p. contained within a predefined bandwidth (typically 50MHz in UWB standards), at the frequency at which the highest mean radiated power occurs, radiated in the direction of the maximum level under the specified conditions of measurement

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

minimum guard distance: distance between a jammer and a victim link such that the signal to interference ratio is sufficiently high to guarantee a reliable quality of link for victim transmission

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

Quality of Service (QoS): objective indication of the quality of a communication link, based on the measurement of different parameters relevant to the connection performances

EXAMPLES: Service response time, signal-to-noise ratio, crosstalk, echo, interrupts, frequency response, loudness levels, packet error rate, etc.

quality of service management: adaptive policy implemented by a link management layer, having the goal to maximize the quality of service depending on the communication link status

EXAMPLES: Increasing coding and reducing throughput when transmission occurs in noisy channels, etc.

pulse: transmitted signal having the minimum duration (T_{pulse}) such to occupying the intended UWB bandwidth

NOTE: In case of non-pulsed UWB transmission, this definition does not apply.

pulse repetition time: for a pulsed transmission, this is the time interval between two consecutive pulses

relative transmission availability ratio (Q_{ar}): for a victim link, this is the ratio between the sum of all time window where the aggregated interference level is below a predefined threshold, and a predefined observation time, such that selected windows must have a duration not lower than a minimum required time equal to T_{guard}

signal to interferer ratio: ratio between the average power of a frame to be received by the victim link and the power of jamming transmission, computed at victim receiver side

transmitter power control: active mitigation technique consisting in determining, by means of some feedbacks from the environment where the device is operating, whether the application requires transmitting its maximum power or transmitter power may be reduced

trading linearl(ly) in dB (of e.i.r.p. levels versus LDC limits): See linear trading.

victim link (or service): See interferer link.

3.2 Symbols

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

D_U	the duty cycle due to the application
D_X	duty cycle due to the modulation
LDC_J	duty cycle of the jamming link
LDC_V	duty cycle of the victim link
PLPC	probability of losing a colliding packets

EXAMPLE: The probability that a single packet from a possible victim service, colliding against an interferer or jamming packet, gets lost at the victim receiver side.

PoC	Probability of Collision between signals of a victim service and signals of an interfering or jamming transmitter
P_{tx}	transmitter power by an intended device
T_{IFS}	inter-frame spacing between two consecutive frames of the victim communication service
T_{DD}	sum of Tframe and T_{IFS}: $T_{DD} = T_{frame} + T_{IFS}$

T_{frame} frame duration of the victim communication service

T_{guard} minimum interval seen by the victim receiver such that the interferer signal stay below Vguard, and a satisfactory quality of transmission for the victim service is guaranteed

T_{obs} any predefined observation time for an intended phenomenon

T_{off} silent period between two consecutive UWB Ton periods. In case of pulsed UWB devices, in general T_{off} >> PRT

T_{period} sum of T_{on} and T_{off} : $T_{period} = T_{on} + T_{off}$

T_{pulse} UWB pulse duration. For an UWB pulsed transmission, this is the duration of a single UWB pulse

NOTE: In case of non-pulsed UWB transmission, this parameter does not applyT_{on} duration of an UWB frame. In case of pulsed UWB devices, in general $T_{on} >> T_{pulse}$. For UWB applications other than communication links, T_{on} is the uninterrupted transmission time required by the UWB application to radiate into the air a meaningful uninterrupted information slot.

Q_a any parameter between Q_{aa} or Q_{ar}

Q_{aa} absolute transmission availability ratio

Q_{ar} relative transmission availability ratio

$V_{aggregate}$ aggregate level of many interferer signals

V_{guard} interferer signal level threshold at victim receiver to be complied in order to guarantee satisfactory quality of transmission for the victim service

3.3 Abbreviations

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

AF Activity Factor
APC Adaptive Power Control or Automatic Power Control
BER Bit Error Rate
BMA Building Material Analysis
BW BandWidth
BWA Broadband Wireless Access
CEPT European Conference of Postal and Telecommunications Administrations
CMS Cabin Management System
DAA Detect And Avoid
dc direct current
DC Duty Cycle
DCT Duty Cycle Template
DEC Decision of Electronics Comminications Committee
DUT Device Under Test
e.i.r.p. equivalent isotropically radiated power
ECC Electronic Communications Committee
FCC Federal Communications Commission
GPR Ground Probing Radar
ISM Industrial Scientific and Medical band
JRC Joint Research Centre
LAES Location tracking Application for Emergency and disaster Situations
LBT Listen Before Talk
LDC Low Duty Cycle
LoS Line of Sight
LPR Level Probing Radar
LT1 Location Tracking type 1
LT2 Location Tracking type 2
LTT Location Tracking for automotive & Transportation environment
MSS Mobile Satellite Services
MU Medium Utilization
NIM Non Interference Mode
NTIA National Telecommunications and Information Administration
ODC Object Discrimination and Characterization
OIS Object Identification and Surveillance
PER Performance
PHY Physical Layer, as described in Open Systems Interconnection (OSI) model

NOTE: ISO/IEC 7498-1 [i.43].

PLPC	probability of losing a colliding packets
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PRT	Pulse Repetition Time
PSD	Power Spectral Density
QoS	Quality of Service
R&TTE	Radio and Telecommunications Terminal Equipment
RAM	Random Access Memory
RAS	Radio Astronomy Service
RF	Radio Frequency
RSSI	Received Signal Strength Indication
Rx	Receiver or received
SIR	Signal to Interfere Ratio
SRD	Short Range Device
TCP	Transmission Control Protocol
TGUWB	Task Grooup Ultra-WideBand
TLPR	Tank Level Probing Radar
TPC	Transmit Power Control or Total Power Control
TPR	Tanks Probing Radars
TRP	Total Radiated Power
Tx	Transmitter or Transmitted
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UWB	Ultra WideBand
WPR	Wall Probing Radar
WRC	World Radiocommunication Conference

4 Overview of UWB Applications and Regulation in ECC/EC

4.1 Summary of UWB application defined in Europe

Ultra-wideBand 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 1.

Table 1: 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 analyzed, such to absorb the majority of the signal transmitted by the sensor
Material sensing devices, fixed or mobile	• Devices enabling radio determination application 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 constructions 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 RF strongly attenuating 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 2.

Table 2: 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	EN 302 065-1 [i.23]	Approval 03-2013		TG UWB
Location & Tracking	Location Tracking Type 1 (LT1)	• 6 to 9	EN 302 500 [i.37] EN 302 065-2 [i.24]	Published 10-2010 Approval 03-2013	EN 302 500 [i.37] to be transferred to EN 302 065-2 [i.24]	TG UWB
	Location Tracking Type 2 (LT2)	• 3,1 to 4,8	EN 302 501 EN 302 065-2 [i.24]	Stopped Approval 03-2013	Work Item EN 302 501 was stopped and transferred to EN 302 065-2 [i.24]	TG UWB
	Location Application for emergency Services (LAES)	• 3,1 to 4,8	EN 302 711 EN 302 065-2 [i.24]	Stopped Approval 03-2013	Work Item EN 302 711 was stopped and transferred to EN 302 065-2 [i.24]	TG UWB
Automotive & railway	Automotive and railway	• 3,1 to 4,8 • 6 to 9	EN 302 065-3 [i.25]	Approval 03-2013		TG UWB
	Location Tracking for automotive & transportation environment (LTT)	• 3,1 to 4,8 • 6 to 8,5	EN 302 882 EN 302 065-3 [i.25]	Stopped Approval 03-2013	Work Item EN 302 882 was stopped and transferred to EN 302 065-3 [i.25]	TG UWB
Concrete inspections & imaging	Professional Ground and Wall Probing Radars (GPR-WPR)	• 0,030 to 12,4	EN 302 066 [i.20]	Published 02-2008		
Material sensing devices	Building Material Analysis (BMA)	• 2,2 to 8,5	EN 302 435 [i.19]	Published 12-2009		
	Object Discrimination and Characterization (ODC)	• 2,2 to 8,5	EN 302 498 [i.21]	Published 06-2010		
	Object Identification for Surveillance Applications (OIS)	• 2,2 to 8	EN 302 499	Stopped		
Level probing radars	Tank Level Probing Radar (TLPR)	• 4,5 to 7 • 8,5 to 10,6 • 24,05 to 26,5 • 57 to 64 • 75 to 85	EN 302 372 [i.27]	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	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 TR 103 181-1 [i.15].

4.2 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 3. This table lists only those applications and related bands where mitigations are allowed. The tables does not include bands/application 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 4.

Table 3: 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)

Applications	Frequency Range [GHz]	Applicable mitigation
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.
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 amended 26 June 2009, Annex 1, [i.4]). NOTE 2: The restriction on angular sector of radiation to be complied above 0° in EN 302 065-3 [i.25] is therein called "Exterior Limit".		

Table 4: Main compatibility studies for different UWB applications

	LDC	DAA	TPC	TRP	LBT	Restricted Angular Sectors	Shielding
Non specific	ECC Report 094 [i.38]	ECC Report 120 [i.6]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 1	*NO*	ECC Report 120 [i.6]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 2	ECC Report 170 [i.8]	ECC Report 120 [i.6]	*NO*	*NO*	*NO*	*NO*	*NO*
Location Tracking Type 2 fixed outdoor	ECC Report 170 [i.8]	ECC Report 120 [i.6]	*NO*	NO	NO	ECC Report 170 [i.8]	*NO*
Location Application for emergency Services	ECC Report 170 [i.8]	ECC Report 120 [i.6]	*NO*	*NO*	*NO*	*NO*	*NO*
Material sensing devices, non fixed installations	ECC Report 123 [i.7] ECC Report 094	*NO*	*NO*	ECC Report 123 [i.7]	TG3 Meeting#15_ 09R0	*NO*	*NO*
Material sensing devices, fixed installations	ECC Report 094 [i.38]	*NO*	ECC Report 123 [i.7]	NO	TG3 Meeting#15_ 09R0	ECC Report 123 [i.7]	*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.8]	ECC Report 120 [i.6]	CEPT Report 17 [i.41]	*NO*	*NO*	ECC Report 170 [i.8]	*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.41]
Level Probing Radars	ECC Report 139 [i.40]	*NO*		*NO*	*NO*	*NO*	*NO*
Aircraft	ECC Report 175 [i.39]	*NO*	*NO*	*NO*	*NO*	ECC Report 175 [i.39]	ECC Report 175 [i.39]

5 Active Mitigation Techniques

An active mitigation technique is based on measurement/feedback from the environment (i.e. the transmitting device measures the channel, link or operating environment, and then decides the level of transmitted power based upon that measurement).

The three most common active mitigation techniques applicable to UWB devices are: Listen Before Talk (LBT), Detect And Avoid (DAA), Transmitter (or Total) Power Control (TPC).

5.1 Listen Before Talk (LBT)

5.1.1 General description

The technical basis behind 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.

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).

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

5.1.2 Technical parameters and implementation in ECC/EC regulation

LBT mitigation is actually used for following UWB applications:

1) Building Material Analysis (BMA), as described in TR 102 495-1 [i.17].

2) Material Sensing Devices: this incudes ODC and in general any device enabling radio determination application designed to detect the location of objects within a structure or to determine the physical properties of a material, as stated by ECC/DEC/(07)01 [i.4].

Both these UWB applications have been defined in ECC/DEC/(07)01 [i.4], with their relevant mitigations.

5.1.2.1 Building material analysis (BMA)

The studies for the LBT technique used for BMA were made during the preparation of ECC/DEC/(07)01 [i.4] and CEPT Report 010 [i.9].

This mitigation for BMA is regulated as defined in ECC/DEC/(07)01 [i.4] and in EN 302 435-1 [i.19].

The implementation of these mitigation techniques in BMA equipment allows increased transmission levels for to attain the maximum mean e.i.r.p. spectral density in some defined ranges. Technical parameters are shown in Table 5.

Table 5: Technical parameters for LBT for BMA devices

Frequency range (GHz)	Limit values - without LBT [dBm/MHz]	Limit values - with LBT [dBm/MHz]
1,215 ≤ f < 1,73	-90	-75
2,5 ≤ f < 2,69	-70	-55
2,7 ≤ f < 3,4	-75	-55

Application of LBT for BMA outside of these ranges does not give any benefit to the intended UWB application.

The detailed functional procedure is specified in [i.17] and is shown in Figure 1.

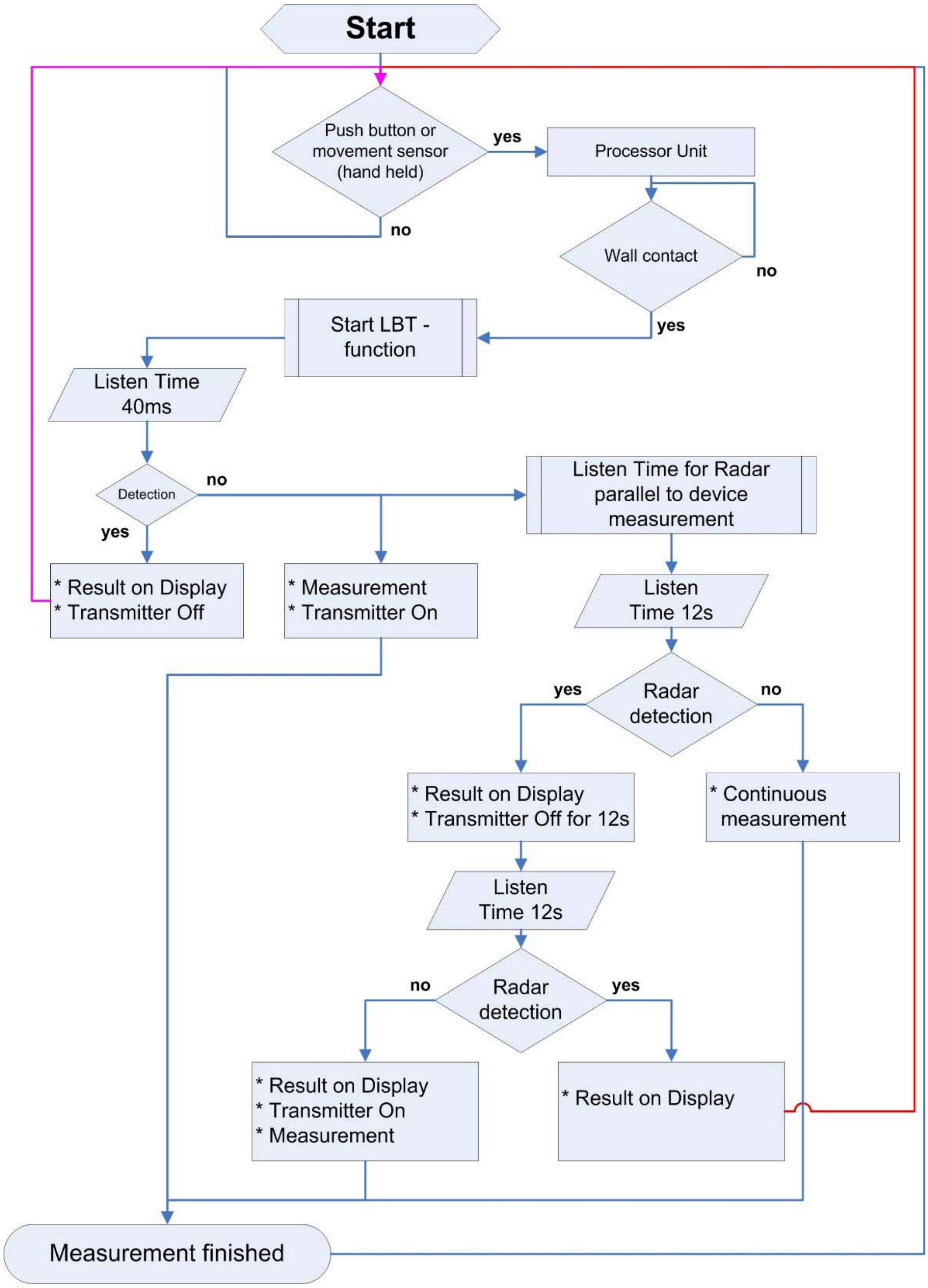


Figure 1: LBT implementation for BMA

It should be noted that, in addition to pure LBT, other kinds of mitigation should be implemented. Specifically TX operations, as defined by ECC/DEC/(07)01 [i.4], require that the transmitter may only be switched "ON" if manually operated with a non-locking switch (e.g. it may be a sensor for the presence of the operators hand), in addition to being in contact or close proximity to the investigated material. Additionally, the emissions should be directed into the direction of the object (e.g. measured by a proximity sensor or imposed by the mechanical design).

Technical listening requirements of the LBT mechanism for BMA devices which are defined as a peak power threshold value to ensure the protection of the listed services are defined within Table 6.

Table 6: Technical requirements of the "Listen Before Talk" mechanism for BMA

Frequency range	Threshold value (dBm)	Reaction time
Radar L-Band 1,215 GHz to 1,35 GHz	+8	Continuous listening of 12 s is required and automatic switch-off feasible each 10 ms if the threshold value is exceeded. In the case of detecting and switching off the transmitter, a silent time of at least 12 seconds while listening continuously is necessary.
MSS 1,55 GHz to 1,66 GHz	-43	Minimum continuous listening time of 40 ms before initial transmission of the device.
UMTS 2,5 GHz to 2,69 GHz	-44 -50	Minimum continuous listening time of 40 ms before initial transmission of the device. Remark: -44 dBm: for receiver BW ≤ 3,84 MHz -50 dBm: for receiver BW > 3,84 MHz
Radar S-Band 2,7 GHz to 3,4 GHz	-7	Continuous listening of 12 seconds is required and automatic switch-off feasible each 10 ms if the threshold value is exceeded. In the case of detecting and switching off the transmitter, a silent time of at least 12 seconds while listening continuously is necessary.

The test procedure for BMA equipment is described in EN 302 435 [i.19]. It requires the LBT effectiveness to be tested using specific predefined test signals, simulating potential victim services, as reported below:

Radar test signal:

- Pulse length: 0,4 µs to 90 µs.
- Pulse repetition time: 0,8 ms to 1,5 ms (670 Hz to 1 300 Hz).
- Pulse power: see Table 7.

Table 7: Radar test signals

	L-Band	S-Band
f/GHz	1,30	2,70
Power flux density at the BMA (W/m^2)	7,56E+00	1,03E+00
Power flux density at the BMA (dBm/m^2)	15,00	0,00
Received power at the BMA (dBm)	8	-7

UMTS test signal:

- Signal power: see Table 8.

Table 8: UMTS test signal

f/GHz (CW-Signal)	2,6
Power flux density at the BMA (W/m^2)	4,11E-05
Power flux density at the BMA (dBm/m^2)	-13,86
Received power at the BMA (dBm)	-44/-50

MSS test signal:

- Signal power: see Table 9

Table 9: MSS test signal

f/GHz (CW-Signal)	1,64
Power flux density at the BMA (W/m^2)	2,15E-05
Power flux density at the BMA (dBm/m^2)	-16,67
Received power at the BMA (dBm)	-43

5.1.2.2 Material Sensing devices other than BMA (e.g. ODC)

The LBT mitigation for Material Sensing Devices is specified in ECC/DEC/(07)01 [i.4] and EN 302 498-1 [i.21].

The studies for the mitigation parameters are summarized in ECC report 123 [i.7]. Such studies were performed for the preparation of the amendment of ECC/DEC/(07)01.

It should be noted that ECC report 123 [i.7] basically covers ODC, that are only a subset of Material Sensing Devices; moreover, in EN 302 498 [i.21] the related LBT procedure is specified only for ODC. Therefore no ETSI standard, nor any compatibility study describes LBT parameters for Material Sensing Devices different than ODC and BMA. This omission in the standards has been resolved by ECC/DEC/(07)01, that extends the LBT procedure defined by EN 302 498 [i.21] for ODC to any other type of Material Sensing device different than BMA.

In ECC/DEC/(07)01 [i.4] and ECC Report 123 [i.7] two different kinds of BMA applications are identified:

1) Applications of category A: fixed or quasi-fixed installations (e.g. table top saw)

2) Applications of category B: non fixed installations (e.g. drilling / break through protection)

as they are described in detail in the ETSI System Reference document TR 102 495-2 [i.18] and the ECC report 123 [i.7].

The implementation of LBT into a Material Sensing device allows increasing the transmitter levels for the maximum mean e.i.r.p. spectral density in some defined power ranges; however, for fixed applications, directions outside the angular sector -20° / +30° cannot benefit from the application of LBT in some frequencies. The situation is shown in Table 10.

Table 10: Technical parameters for LBT for Material Sensing Devices non BMA

Frequency range [GHz]	**Fixed installations (Application A) Maximum mean e.i.r.p. spectral density [dBm/MHz]**		**Non fixed installations (Application B) Maximum mean e.i.r.p. spectral density [dBm/MHz]**	
	Only outside of sector -20° / +30°		All directions	
	Without LBT	With LBT	Without LBT	With LBT
2.5 < f < 2.69	-65 (see note 1)	-50 (see note 1)	-65 (see note 2)	-50 (see note 2)
2.9 < f < 3.4	-50 (see note 1)		-70	-50
NOTE 1: In addition, TPC mitigation applies with 10dB dynamic range (see clause 5.3.2.1). NOTE 2: In addition, TRP mitigation applies (see clause 6.2.1.2.1).				

The functional procedures of the LBT mitigation for Material Sensing devices are different for applications of category A and B. They are defined in EN 302 498-1 [i.21] and they are shown in Figure 2 and Figure 3.

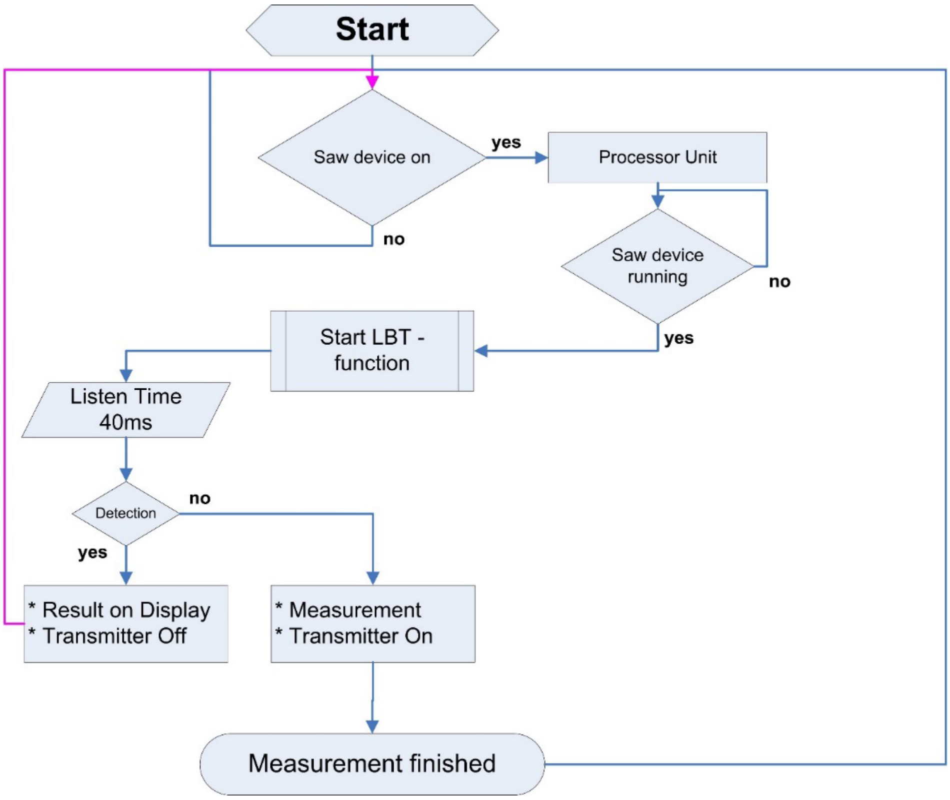


Figure 2: Flow diagram of LBT mechanism for non-BMA Material Sensing Device, Category A

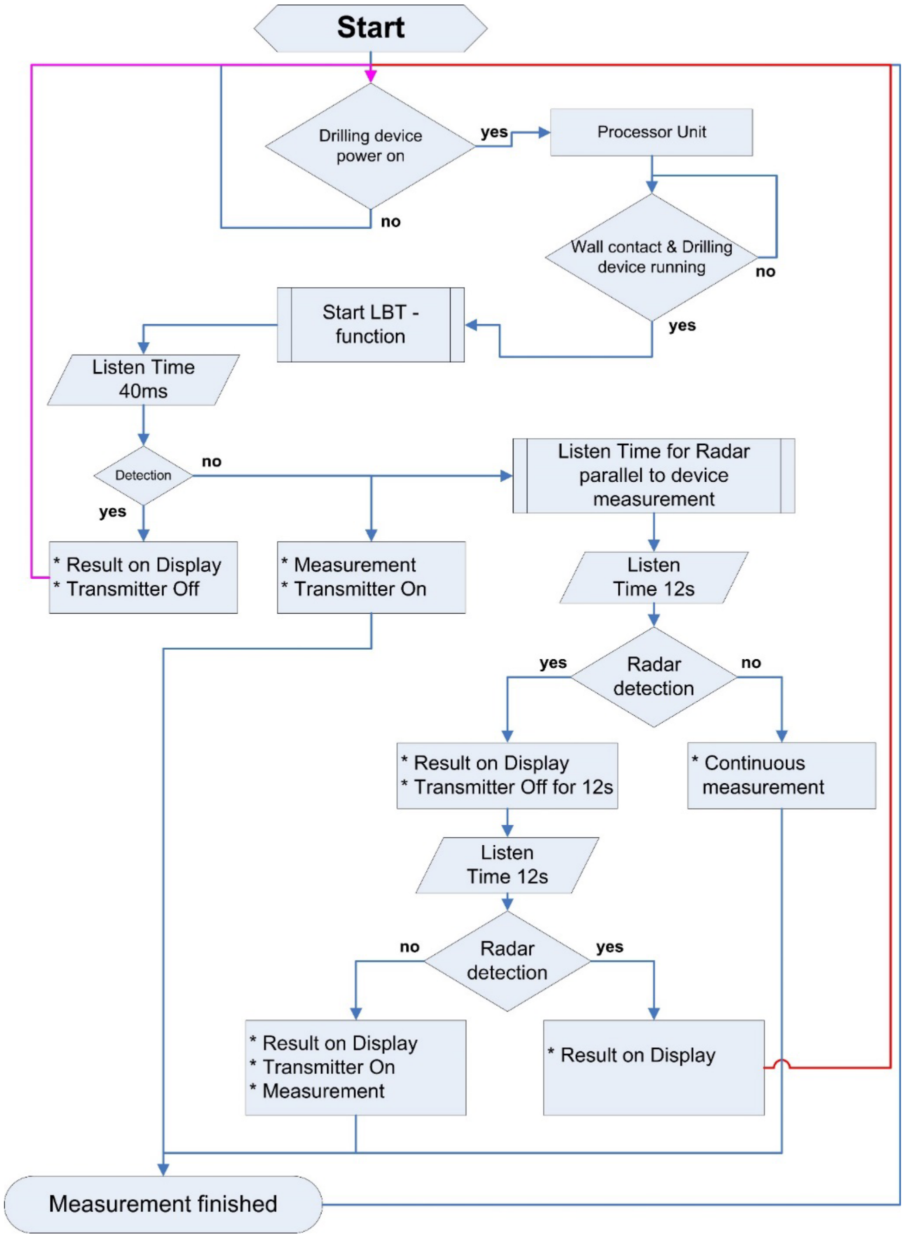


Figure 3: Flow diagram of LBT mechanism for non-BMA Material Sensing Device, Category B

Technical requirements (Listen requirements) of the "Listen Before Talk" mechanism for BMA devices are defined in Table 11.

Table 11: LBT threshold limits for Material Sensing devices different than BMA (e.g. ODC)

Frequency range	Threshold value [dBm]	Reaction time
UMTS 2,5 GHz to 2,69 GHz Both Categories	-44 -50	Minimum continuous listening time of 40 ms before initial transmission of the device. Remark: -44 dBm: for receiver BW ≤ 3,84 MHz -50 dBm: for receiver BW > 3,84 MHz
Radar S-Band 2,9 GHz to 3,4 GHz Only Category B	-7	Continuous listening of 12 s is required and automatic switch-off feasible each 10 ms if the threshold value is exceeded. In the case of detecting and switching off the transmitter, a silent time of at least 12 s while listening continuously is necessary.
NOTE: If the UE in the respective band are lower than the limit as defined in tables 3 and 4, the threshold value can be decreased by the difference. If the transmitter of the BMA device is only active in one or more parts of the frequency range of the external service, the LBT receiver of the BMA device has to be sensitive only in these parts. In this case the test signal frequency has to be adjusted accordingly.		

The test procedure required for Material Sensing devices is described in EN 30 498-1 [i.21], including the necessary test signals. The test signals and the procedure are shown below:

Radar test signal:

- Pulse length: 0,4 µs to 90 µs.
- Pulse repetition time: 0,8 ms to 1,5 ms (670 Hz to 1 300 Hz).
- Pulse power: see Table 12.

Table 12: Radar test signals

	S-Band
f/GHz	2,90
Power flux density at the BMA [W/m^2]	1,03E+00
Power flux density at the BMA [dBm/m^2]	0,00
Received power at the BMA [dBm]	-7

UMTS test signal:

- Signal power: see Table 13.

Table 13: UMTS test signal

f/GHz (CW-Signal)	2,6
Power flux density at the BMA (W/m^2)	4,11E-05
Power flux density at the BMA (dBm/m^2)	-13,86
Received power at the BMA (dBm)	-44/-50

5.2 Detect and Avoid (DAA)

5.2.1 General 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 indoor reception of other systems. Fixed broadband wireless access (including WiMAX) and mobile services (e.g. UMTS)) 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.

The DAA mitigation technique was initially studied in CEPT Report 009 [i.10]:

1) To protect indoor services operating between 3,1 GHz and 4,95 GHz.

2) To consider the technical and regulatory feasibility of a phased approach by removing DAA requirement in the band 4,2 GHz to 4,8 GHz until 2010 considering potential identification of spectrum for systems beyond IMT-2000 under WRC-07 agenda item 1.4.

3) To define maximum emission levels to protect outdoor services between 3,1 GHz and 4,95 GHz considering indoor deployment limitation for UWB devices: (-41,3 dBm/MHz).

4) To define emission levels for "avoid operation" mode to protect indoor services, considering achievable solutions (e.g. for MB-OFDM, -65 / -70 dBm/MHz) as stated by the industry and protection limits objectives (-70 / -85 dBm/MHz).

5) To define generic parameters of the indoor services to be protected in order to enable industry to propose DAA solutions. These parameters included but were not limited to the following parameters:

   - Minimum output power
   - Sensitivity
   - Activity ratio in idle mode
   - Typical session duration for defining time between consecutive detection operations

In ECC Report 120 [i.6] these studies where further investigated to ensure protection of Radiolocation Services in the bands 3,1 GHz to 3,4 GHz; 8,5 GHz to 9 GHz; and BWA terminals in the band 3,4 GHz to 4,2 GHz.

This report resulted in the following regulatory requirements for DAA mitigation as provided in EC Decision 2009/343/EC [i.1] for generic UWB usage:

A maximum mean e.i.r.p. density of - 41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm measured in 50 MHz should be allowed in the 3,1 GHz - 4,8 GHz and 8,5 GHz - 9,0 GHz bands provided that a detect and avoid (DAA) mitigation technique as described in the relevant harmonised standards adopted under Directive 1999/5/EC [i.42] is used.

Relevant harmonised standards on UWB describing DAA are EN 302 065-1, -2 and -3 [i.23], [i.24] and [i.25] in combination with TS 102 754 [i.14]. The DAA concept was further defined for generic UWB devices in TS 102 754 [i.14].

This mitigation technique is founded on defining different zones for which an appropriate UWB emission power level is authorized. Each zone corresponds to a distance between the UWB device and the potential victim service: in each zone a minimum isolation between the potential victim system and the UWB device should be guaranteed. This concept is embodied in the so called "zone model".

The "zone model" is based on the idea that it is possible to estimate the distance between the UWB device and the victim service by sensing the victim channel. This distance is calculated from the level of power detected in the band where the victim application is operating.

Therefore, the region of space around the victim receiver is segmented into discrete zones. In the first zone, zone 1 (the nearest), the UWB device should operate in the so-called "non-interference mode" (NIM), as defined in the non DAA regulatory framework using the parameters given in Table 14. This means that the transmitted power should be kept at minimum level. In the last zone, zone *N* (the most far), the UWB device can operate without restrictions up to the maximum permitted power level or as defined in a future DAA regulation for the corresponding operational frequency range. Between the zone 1 and zone *N* an arbitrary number of transition zones, 2 to *N*-1, may be defined, provided that equivalent protection can be assured. Based on the result of the detection process the UWB device has to determine the corresponding zone it occupies.

Table 14: Non-interference mode parameters in the band 3,1 GHz to 9,0 GHz

Operational Frequency	NIM Power levels (e.i.r.p.)	NIM Power levels (e.i.r.p.) with LDC implemented
3,1 GHz to 3,4 GHz	-70 dBm/MHz average. -36 dBm peak (see notes 2 and 3)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
3,4 GHz to 3,8 GHz	-80 dBm/MHz average. - 40 dBm peak (see notes 2 and 3)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
3,8 GHz to 4,2 GHz	-70 dBm/MHz average. -30 dBm peak (see notes 2 and 3)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
4,2 GHz to 4,8 GHz	-70 dBm/MHz average. -30 dBm peak (see notes 2 and 3)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
6,0 GHz to 8,5 GHz	-41,3 dBm/MHz average. 0 dBm peak (see note 2)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
8,5 GHz to 9,0 GHz	-65 dBm/MHz average. -25 dBm peak (see notes 2 and 3)	-41,3 dBm/MHz average. 0 dBm peak Standard LDC parameters (note 4)
NOTE 1: As defined in the scope of the present document, the DAA mitigation only affects the frequency bands 3,1 GHz to 3,4 GHz, 3,4 GHz to 3,8 GHz and 8,5 GHz to 9 GHz. NIM power levels for the other frequency bands are included in this table for informative purposes. NOTE 2: Devices installed in road or rail vehicle not using LDC need to implement TPC+DAA. NOTE 3: Devices fitted with DAA mitigation may operate to the maximum permissible limit of -41,3 dBm/MHz average and 0 dBm peak. NOTE 4: Standard LDC parameters are defined in ECC/DEC/(06)/04 [i.3].		

As existing systems are subject to technological change and other systems may be deployed or developed in the future e.g. IMT-Advanced, it should be noted that different zone parameters and transmission levels may be required.

The zone model is illustrated in Figure 4 for N = 4. This example has been taken from the CEPT ECC TG3 regulatory discussion [i.31]. The transition zones in this example are defined based on a 10 dB pathloss step size.

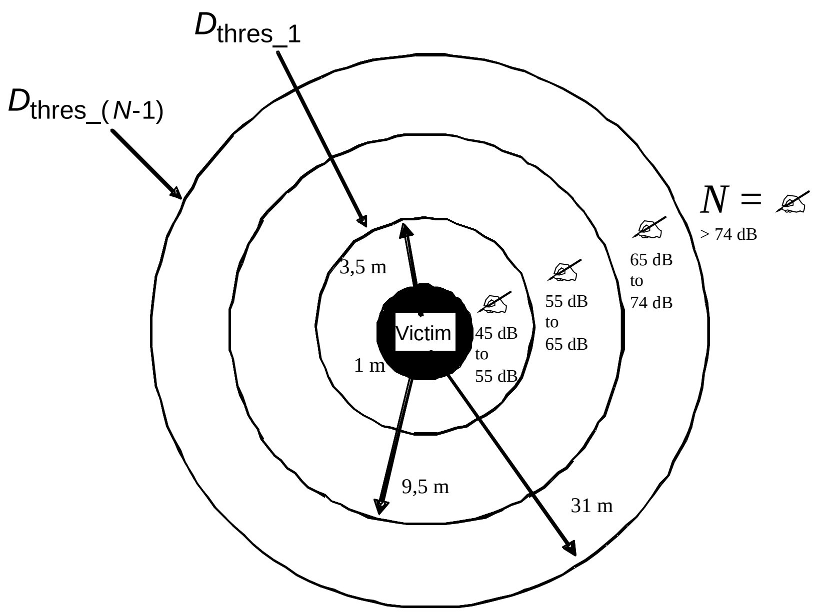


Figure 4: Zone model segmentation and corresponding path loss with LoS distance in meters for *N* = 4

The defined zone model is incorporated into the overall detect and avoid operational flow. This flow is shown in Figure 5.

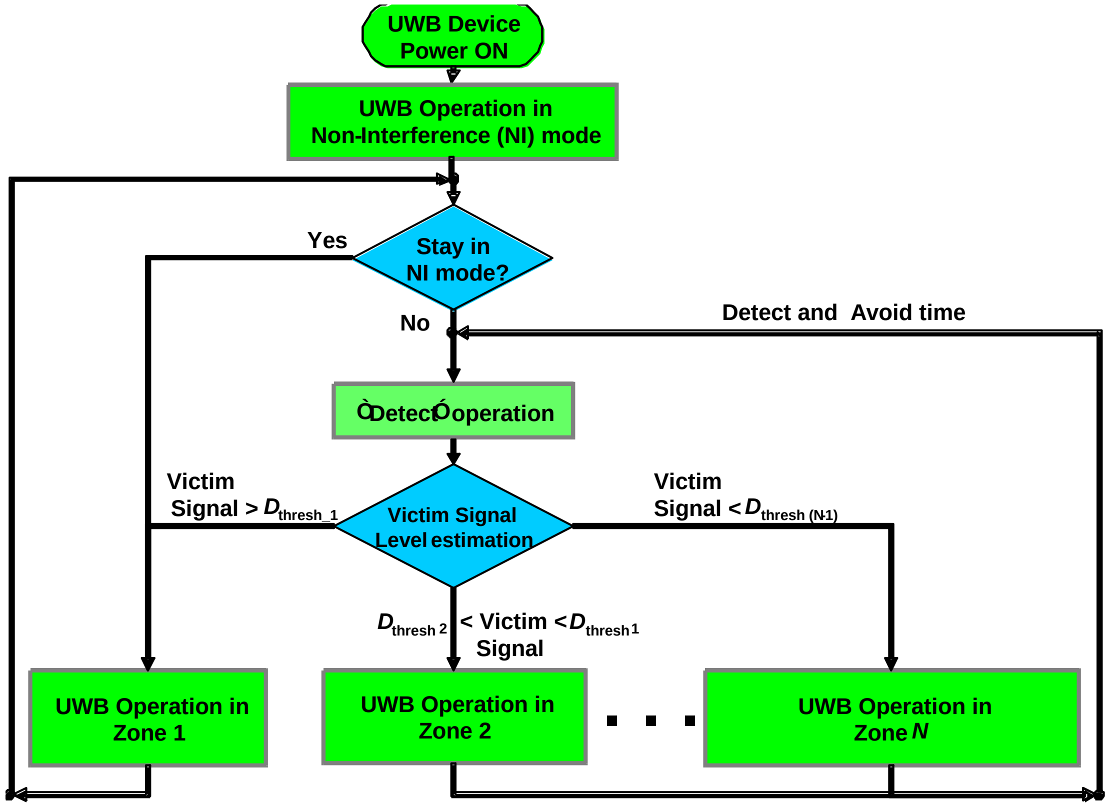


Figure 5: Detect and Avoid overview, including *N* zones

All UWB devices enter the non-interference mode (NIM) at start-up. This non-interference mode can only be changed after a signal detect, estimation, and decision process has been performed. Estimations are done against threshold levels D_{thres_n}, n = 1…N-1.

The non-interference mode operational zone can be subdivided into zones of equivalent protection where appropriate avoidance techniques are implemented. This gives rise to additional operational zones between the non-interference and free mode operational zones based on technical considerations. This multi zone concept is illustrated in Figure 6 taking into account the reduction of the UWB transmit power after the application of the appropriate avoidance technique.

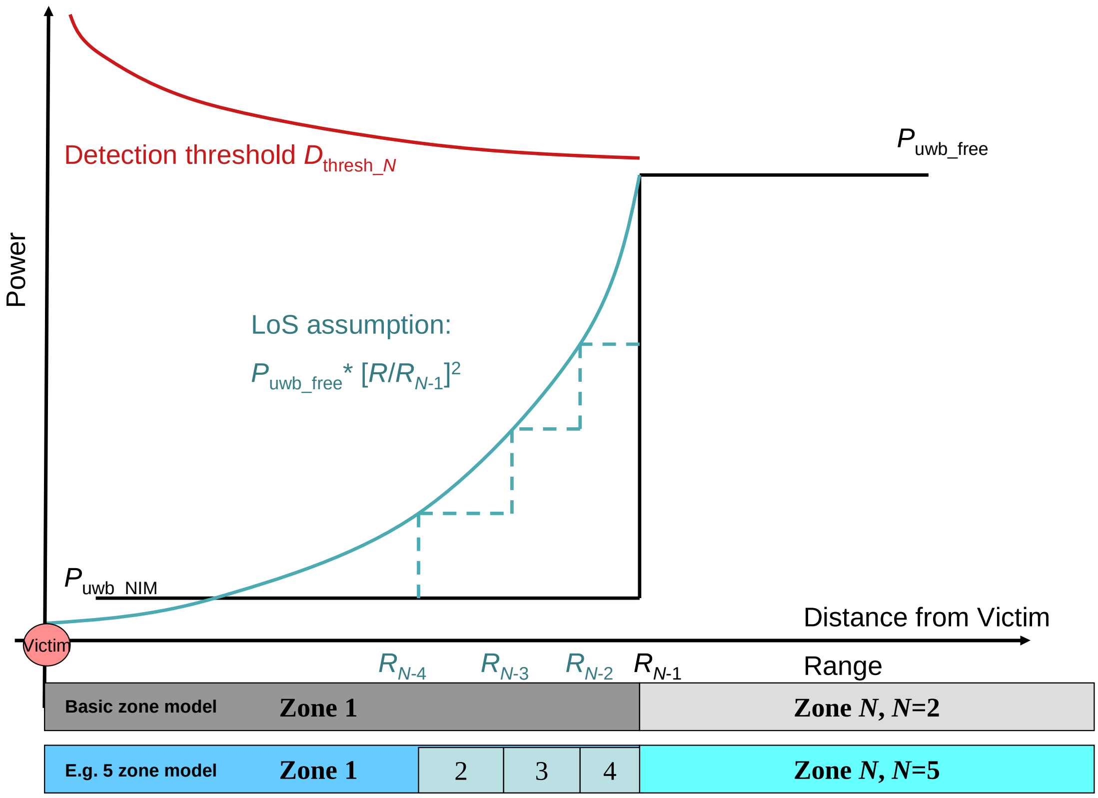


Figure 6: Illustration of multi zone concept based on equivalent protection levels

This basic zone model consists of two zones, the non-interference mode operational zone, zone 1, and the free mode operational zone, zone N, $N = 2$. The basic threshold level $D_{thresh\_(N-1)}$, separating free mode operational zone and the non-interference mode operational zone, is defined by two key parameters:

- Minimum needed isolation I, including margins for interference free operation of the victim receiver when in the presence of a UWB device operating in zone N.
- The transmit power of the victim device P_{TX_vic}.

Then $D_{thresh\_(N-1)}$ is given as:

$$D_{thresh\_(N-1)} = P_{TX\_vic} - I$$

During the detection and estimation process performed by the UWB device, a received victim signal level will be compared to the threshold level $D_{thresh\_(N-1)}$. If the received victim signal level exceeds the threshold level $D_{thresh\_(N-1)}$ the UWB device should operate in the non-interference mode. This signal level estimation is periodically updated in order to accommodate the potential for a change in the RF environmental conditions. When changes in the RF conditions are detected, the operational mode of the UWB device should be adapted accordingly.

The required UWB operational frequencies are defined by the victim services.

The frequency bands of the potential victim services required for analysis are given in Table 15. The UWB system bandwidth is defined by the -10 dBc points, and it should at least partly include the victim service. Where the frequency span of the UWB radio device is insufficient to cover the victim service's bandwidth, the frequency range should be split into two bands and tests repeated for the higher and lower frequency ranges.

Table 15: UWB System bandwidth for test

Victim Service	Bandwidth	Comments
S-band Radiolocation	3,1 GHz to 3,4 GHz	NIM power level: - -70 dBm/MHz mean - -36 dBm peak in 50 MHz
BWA	3,4 GHz to 3,8 GHz	NIM power level: - -80 dBm/MHz mean - -40 dBm in 50 MHz peak
X-Band Radiolocation	8,5 GHz to 9 GHz	NIM power level: - -65 dBm/MHz mean - -25 dBm in 50 MHz peak

For further details about the related test procedure, one can refer to TS 102 754 [i.14], Annex D.

For related limits, see TS 102 754 [i.14], Annexes A to C.

For measurement tolerance, see TS 102 754 [i.14], Annexes A to C.

5.2.2 Technical parameters and implementation in ECC/EC regulation

5.2.2.1 Non-specific applications

Technical parameters for for DAA, non-specific devices, are given in EN 302 065-1 [i.23].

For non-specific applications, maximum values of e.i.r.p. allowed with and without DAA are listed in Table 16.

Table 16: Maximum value of power spectral density limit for non-specific applications using DAA [i.15]

Frequency (GHz)	Maximum value of mean power spectral density (dBm/MHz)		Maximum peak power limit (dBm in 50MHz)	
	Without DAA	**With DAA**	**Without DAA**	**With DAA**
2,7 < f ≤ 3,4	-70	-41,3	-36	0
3,4 < f ≤ 3,8	-80	-41,3	-40	0
3,8 < f ≤ 4,2	-70	-41,3	-30	0
4,2 < f ≤ 4,8	-70	-41,3	-30	0
8,5 < f ≤ 9	-65	-41,3	-25	0

5.2.2.2 Location tracking type 1 (LT1)

Technical parameters for for DAA, LT1 devices are given in EN 302 065-2 [i.24].

For LT1 systems, maximum values of e.i.r.p. allowed with and without DAA are listed in Table 17.

Table 17: Maximum value of power spectral density limit for LT1 using DAA [i.15]

Frequency (GHz)	Maximum value of mean power spectral density (dBm/MHz)		Maximum peak power limit (dBm in 50MHz)	
	Without DAA	**With DAA**	**Without DAA**	**With DAA**
8,5 < f ≤ 9	-65	-41,3	-25	0

5.2.2.3 Location tracking type 2 (LT2)

Technical parameters for DAA, LT2 devices are given in EN 302 065-2 [i.24].

For LT2 systems, maximum values of e.i.r.p. allowed with and without DAA are listed in Table 18.

Table 18: Maximum value of mean power spectral density limit for LT2 using DAA

Frequency (GHz)	Maximum value of mean power spectral density (dBm/MHz)			
	Fixed outdoor LT2 transmitters		Mobile and fixed indoor LT2 transmitters	
	Without DAA	With DAA	Without DAA	With DAA
3,1 < f ≤ 3,4	-70	-41,3 (see note)	-70	-41,3 (see note)
NOTE: A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms also apply.				

Table 19: Maximum peak power limit for LT2 using DAA

Frequency (GHz)	Maximum peak power limit (dBm in 50MHz)			
	Fixed outdoor LT2 transmitters		Mobile and fixed indoor LT2 transmitters	
	Without DAA	With DAA	Without DAA	With DAA
3,1 < f ≤ 3,4	-36	0 (see note)	-36	0 (see note)
NOTE: A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms also apply.				

5.2.2.4 Location Application for emergency Services (LAES)

For LAES systems, maximum values of e.i.r.p. allowed with and without DAA are listed in Table 20.

Table 20: Maximum value of power spectral density limit for LAES using DAA

Frequency (GHz)	Maximum value of mean power spectral density (dBm/MHz)		Maximum peak power limit (dBm in 50MHz)	
	Without DAA	With DAA	Without DAA	With DAA
3,1 < f ≤ 3,4	-70	-41,3 (see note)	-36	0 (see note)
NOTE: A maximum duty cycle of 5 % per transmitter per second also applies.				

5.2.2.5 Automotive and Railway

For the operation of UWB devices installed in road and rail vehicles using DAA, the technical requirements below are applicable, as defined in ECC/DEC/(06)/04 [i.3] amended in 2009.

Table 21: Maximum value of power spectral density limits for automotive and railway using DAA

Frequency range	Maximum mean e.i.r.p. spectral density [dBm/MHz]		Maximum peak e.i.r.p. (dBm in 50 MHz)	
	Without DAA	With DAA	Without DAA	With DAA
3,1 to 3,4 GHz	-70	-41,3 (see note 1)	-36	0 (see note 1)
3,4 to 3,8 GHz	-80	-41,3 (see note 1)	-40	0 (see note 1)
3,8 to 4,8 GHz	-70	-41,3 (see note 1)	-36	0 (see note 1)
8,5 to 9,0 GHz	-65	-41,3 (see note 2)	-25	0 (see note 2)
NOTE 1: Operation is in addition subject to the implementation of Transmit Power Control (TPC) mitigation technique (see clause 5.3.2.3) and an exterior limit of -53,3 dBm/MHz (see clause 6.2.1.2.1). NOTE 2: Operation is in addition subject to the implementation of an exterior limit of -53,3 dBm/MHz (see clause 6.2.1.2.1).				

5.3 Total (or Transmitter) Power Control (TPC)

5.3.1 General description

A TPC mitigation technique requires the transmitter to reduce the transmitted power by a fixed amount with respect to its normal operating conditions, until a specific need to transmit is detected, i.e. until the device itself detects the need to become fully operative. This fixed amount of power is called "TPC dynamic range".

The studies for these mitigation were made during the preparation of ECC/DEC/(07)01 [i.4] and the CEPT report 010 [i.9].

This mitigation technique is used for Material Sensing Devices, fixed installations only; level probing radars (LPR); and devices installed in automotive and railway vehicles.

An example control flow for TPC mitigation is provided in Figure 7. The flowchart is related to Material Sensing Devices, and specifically to ODC category A (quasi-fixed installation). However it is a good example, applicable in a general sense to devices required to implement TPC mitigation. The flow chart may be explained as follows:

- In its initial state, the device is "OFF" and the UWB sensor is not transmitting.
- When the device goes "ON", it starts transmitting the minimum allowed power, which is the maximum allowed power minus the defined TPC dynamic range.
- When the device senses the need to become fully operative (i.e. an object in the protection area, in the example of Figure 7), the device is allowed to increase the transmitted power up to the maximum allowed.
- When the device senses that there is no more need to be fully operative anymore, it goes "OFF", or it goes back to the reduced transmitted power status. In the example of Figure 7 the device goes "OFF" as soon as a critical condition is detected: Human tissue detected in the operating area. If no critical condition is detected, then the device goes in the reduced TX power status if no object is detected for a time interval longer than 3 seconds.

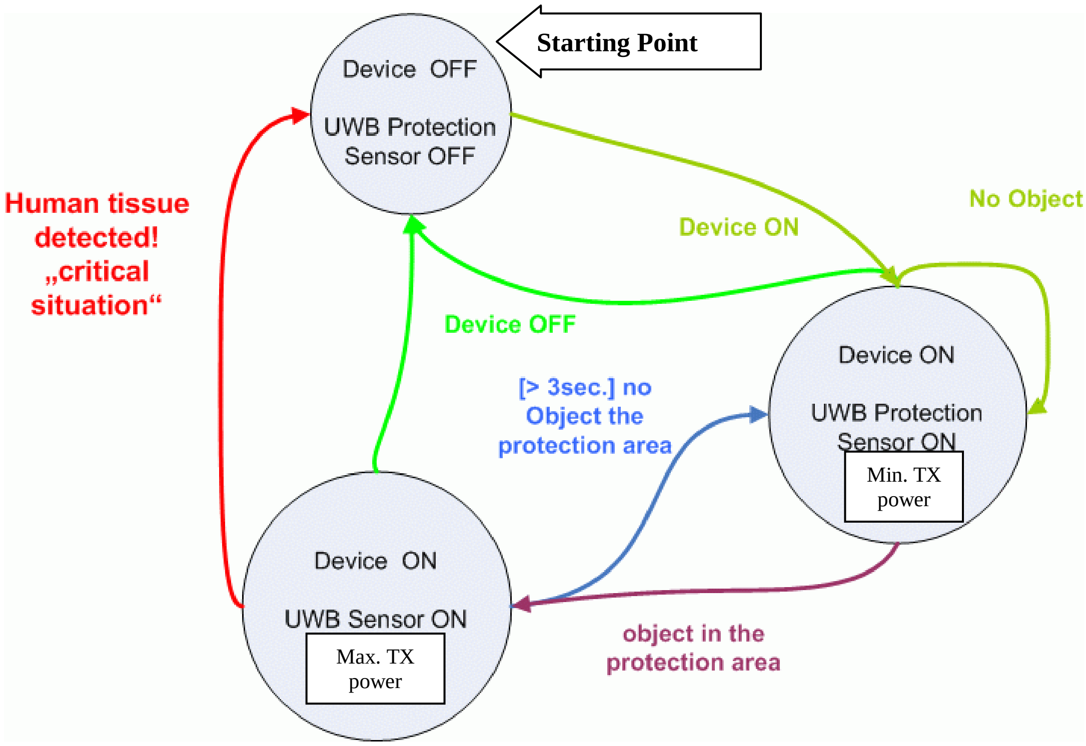


Figure 7: TPC - procedure (for Material Sensing device, fixed installations, from EN 302 498-1 [i.21])

It is seen that the device is allowed to transmit the maximum power when the need to be operating is detected (for ODC this means that an object is detected in the protection area), while it reduce its TX power whenever no need, or lower need, to be fully operative is detected for a specified amount of time (3 s for ODC). Finally, the device goes "OFF" as soon as a critical situation is detected and signalled, i.e. as soon as the device has successfully executed the task it is intended for.

5.3.2 Technical parameters and implementation in ECC/EC regulation

5.3.2.1 Material Sensing Devices other than BMA (fixed installations only)

For the Material Sensing devices different than BMA (e.g. ODC) fixed installations, the TPC mitigation is mandatory, and it is regulated as stated in ECC/DEC/(07)01 [i.4], in EC Decision 2009/343/EC [i.1] and EN 302 498 [i.21].

The transmitter should implement a TPC function with a dynamic range of 10 dB. This means:

- If the device (e.g. a saw) is working without TPC, than the generic UE limits included in Table 3 of EN 302 498-1 [i.21] should be complied.
- If the device is running with TPC, than the generic UE limits are 10 dB below the abovementioned Table 3 of EN 302 498-1 [i.21].

5.3.2.2 Level probing radars

The TPC mitigation for Level Probing Radar (LPR) is defined in EN 302 729-1 [i.26].

For LPR, TPC is referred to as "Automatic Power Control" or "Adaptive Power Control" (APC). However, the principle of operation is similar: the transmitted power is controlled on a need basis by the energy received within the total device receiver bandwidth.

Due to the fact that an LPR requires a certain amount of power in order to detect the reflected signal from the monitoring surface, this power may be adapted to the reflecting characteristics of the surface itself. The device senses the power of its echo (related to the distance between the transmitter and the monitoring surface), and increases the transmitter power as the echo decreases, so as to keep the echo level as constant as possible. Accordingly, the LPR device should reduce its transmitted power if more strength of signal is received by the radar.

The difference with classical TPC technique is that TPC generally means that there are only two power levels, a minimum and a maximum. On the other hand, APC is more flexible, with more than two power levels allowed.

TPC (or APC) for LPR devices can be implemented in the frequency ranges 6 GHz to 8,5 GHz, 24,05 GHz to 26,5 GHz, 57 GHz to 64 GHz or 75 GHz to 85 GHz.

The dynamic range for the APC, i.e. the ability to reduce the transmitted power with respect to maximum allowed limits, should be at least 20 dB from the condition of best case reflection (minimum transmitted power allowed) to worst case reflection (maximum transmitted power allowed); incremental steps should be 5 dB or less.

5.3.2.3 Automotive and railway

Devices mounted in railway or road vehicles and implementing a TPC procedure within the bands 3,1 GHz to 4,8 GHz and 6,0 GHz to 9,0 GHz are allowed to transmit at increased e.i.r.p. limits, according to rules similar to those applied to devices using DAA mitigation.

In this case, TPC dynamic range is 12 dB (see ECC/DEC/(06)/04, Annex 4, [i.3].

At the time of publication of the present document, a specific TPC procedure for automotive and railway is not defined, as in the case of ODC. Some examples of possible implementations may be found in clause 5.4.

Table 22 applies for such devices, when they are using TPC.

Table 22: Maximum value of power spectral density limit for automotive and railway using TPC

Frequency range	Maximum mean e.i.r.p. spectral density [dBm/MHz]		Maximum peak e.i.r.p. (dBm in 50 MHz)	
	Without TPC	With TPC	Without TPC	With TPC
3,1 to 3,4 GHz	-70	-41,3 (see note 1)	-36	0 (see note 1)
3,4 to 8,8 GHz	-80	-41,3 (see note 1)	-40	0 (see note 1)
3,8 to 4,8 GHz	-70	-41,3 (see note 1)	-36	0 (see note 1)
6,0 to 8,5 GHz	-53,3	-41,3 (see note 2)	-13,3	0 (see note 2)
8,5 to 9,0 GHz	-65	-41,3 (see note 1)	-25	0 (see note 1)

NOTE 1: Operation is in addition subject to the implementation of Detect And Avoid (DAA) mitigation technique (see clause 5.2.2.5) and an exterior limit (see clause 6.2.1.2.1) of -53,3 dBm/MHz.
NOTE 2: Operation is in addition subject to the implementation of an exterior limit (see clause 6.2.1.2.1) of -53,3 dBm/MHz.

5.4 Difference between DAA and TPC

At first sight, DAA and TPC may seem similar, in that they use some kind of feedback from the operating environment in order to decide to adapt the TX power at lower levels.

However a specific difference exists between these two mitigations:

- In DAA, the criterion to be checked in order to decide the level of transmitted power is "external" to the application: it is driven by potential victims. More specifically, if the UWB device detects a "defined" radio application signal, then the UWB emission should be:
    - reduced (based on the received level to fulfil the protection distance); or
    - the UWB transmission should be shifted into another frequency range.

DAA allows reducing the single interference between UWB device and other radio applications.

- In TPC, the criterion to be checked in order to decide the level of transmitted power is "internal" to the application: it is driven by the UWB application or link itself: the UWB device should use the minimal power necessary for guaranteeing correct operations (e.g. communication, sensing, etc.).

TPC allows reducing the aggregation interference between other UWB devices or other radio applications.

In clause 5.3.1 a TPC implementation adopted for Material Sensing Devices is described: in that case the feedback came from the operating environment itself, i.e. the detection of objects in the application area. For an UWB communication application, the criterion internal to the application itself is different; it may be the status and the quality of the communication link.

In Figure 8 the difference between DAA and TPC is described: the device applying DAA mitigation is driven by a possible victim radio application in the area where the UWB device is operating; the application of TPC is driven by, e.g. the link quality established between two UWB devices communicating with each other.

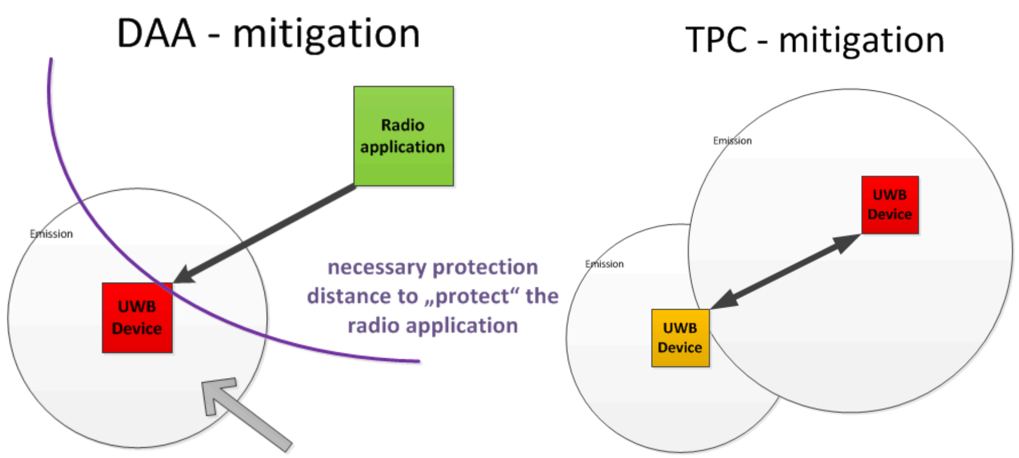


Figure 8: TPC/DAA - Difference between TPC and DAA

In Figure 9 two options are shown for the implementation of the TPC in an UWB communication link: a simple UWB device may start transmitting using either the maximum or the minim allowed level of power. Then, based upon whether it receives an answer or not, it may increase or decrease the power level, until sufficient power is transmitted to receive a response from another device. A timeout guarantees that the device does not occupy the channel for an undetermined time.

In Figure 10 a more sophisticated option for a Master/Slave communication is presented: the Master initiates the communication, then the Slave answers. At this point, the Master may use any useful link quality indication in order to compute the necessary power level to be transmitted. Criteria for determination of the required power level may be RSSI, QoS, or any other equivalent criteria.

Once the TX power level is determined, the Master may communicate this information to the Slave, and the Slave should adapt the transmitted power to the level imposed by the Master.

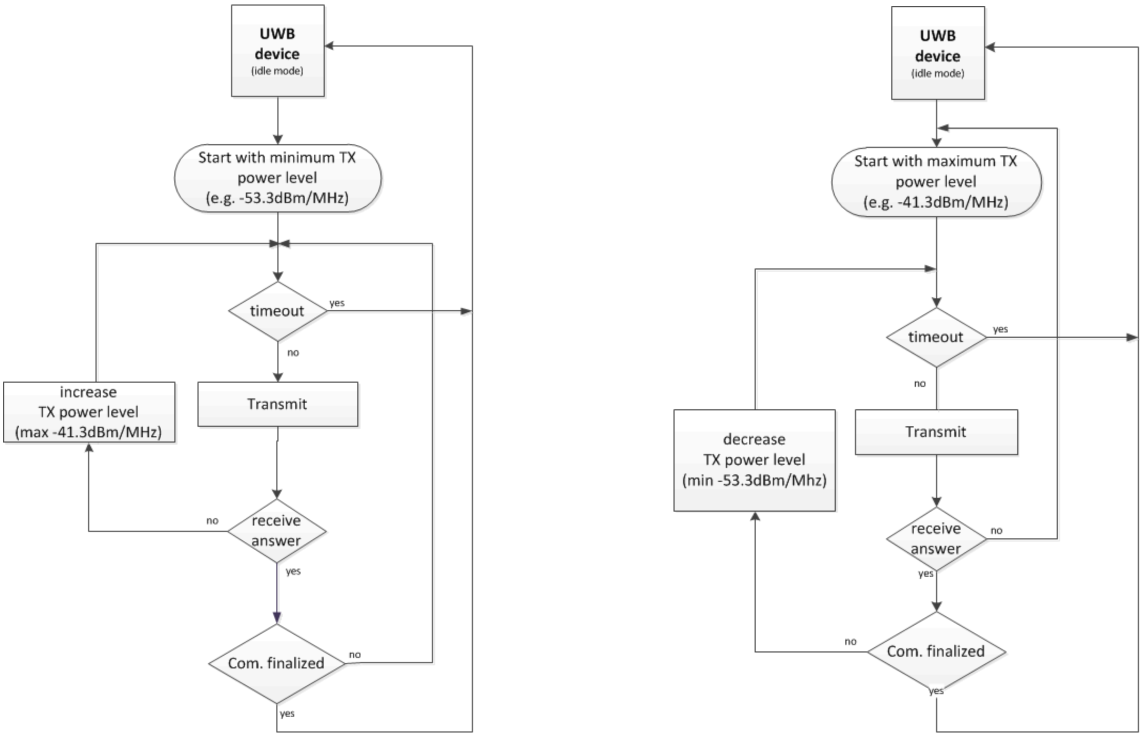


Figure 9: Two options for a simple application using TPC: start at minimum TX power and start at maximum TX power, then adapt the power to the level required to finalize the communication

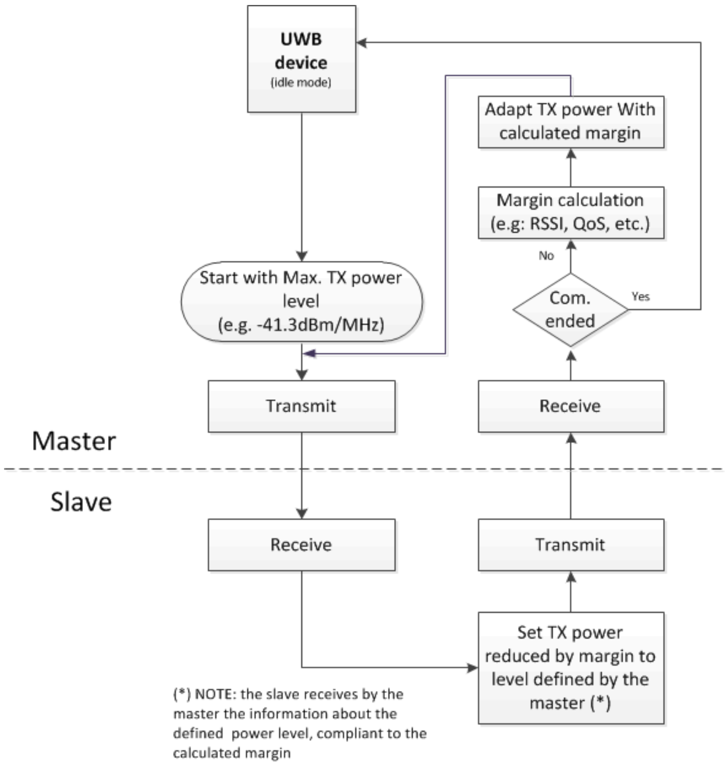


Figure 10: Option for a master slave application using TPC: the master determines the level of TX power basing on quality of link (e.g. RSSI, QoS, or other link quality indications)

6 Passive Mitigation Techniques

Passive mitigation techniques differ from active mitigation techniques in that they do not make usage of any channel measurement nor any feedback from the operating environment. A passive mitigation technique is a technique assuming "a priori" knowledge of its effects.

6.1 Low Duty Cycle (LDC)

6.1.1 General description

Duty Cycle (DC) is a passive mitigation technique often used in radio regulation and harmonized 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, TS 103 060 [i.13], having the goal to harmonize different DC definitions existing in different standards. According to [i.13], 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 the TS 103 060 [i.13] 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 a 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.

A clear example of DC usage in this sense may be found in EN 300 328 (V.1.8.1) [i.22], related to wideband communication in the 2,4 GHz. In this standard a Medium Utilization factor (MU) is defined as the product of duty cycle and the RF power levels (see clauses 4.3.1.5 and 4.3.2.4). Radiation limits are then imposed over this factor, allowing increased DC with decreased transmission power, or vice versa.

In Figure 11 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.

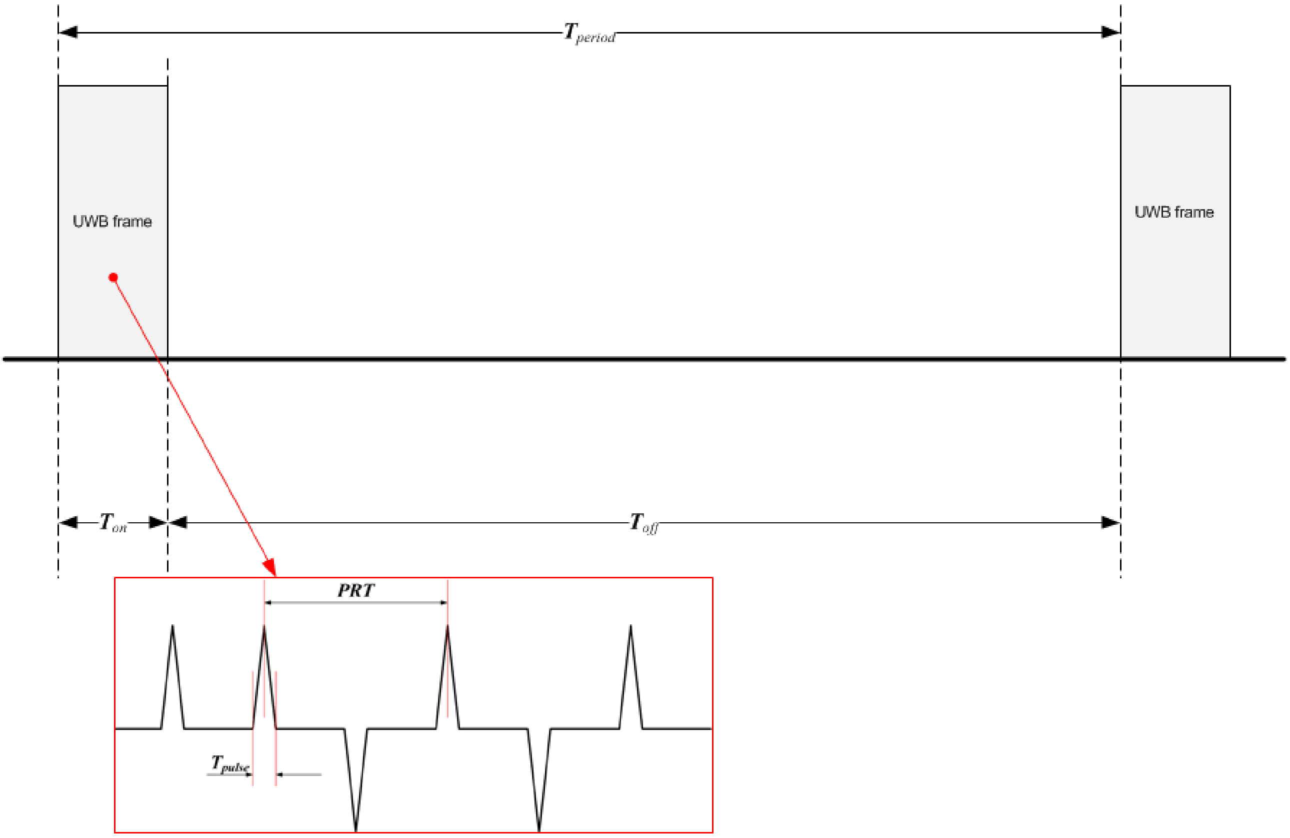


Figure 11: Duty Cycle parameters definition

6.1.2 Technical parameters and implementation in ECC/EC regulation

The LDC limits for Ultra-wideband technology have been defined in ECC/DEC/(06)/04 [i.3], in EC DEC 2007/131/EC [i.2] and EC DEC 2009/343/EC [i.1]. Devices are allowed to operate, or to increasing their emission limit, by adopting DC mitigations.

The limits for duty cycle mitigation are stated in [i.3] as follows:

Table 23: Duty cycle limits stated in ECC/DEC/(06)/04

Parameter		Limit
Maximum transmitter on time	Ton max	5 ms
Mean transmitter off time	Toff mean	≥ 38 ms (averaged over 1 s)
Sum transmitter off time	∑ Toff	> 950 ms per second
Sum transmitter on time	∑ Ton	< 18 s per hour

A list of UWB selected applications and related emitted power level when operating at these LDC limits are described in the following paragraphs.

6.1.2.1 Generic UWB usage

For generic UWB usage, LDC is an optional mitigation technique. Its applicability is described in EN 302 065-1 [i.23].

For devices not using any mitigation technique:

- in the 3,1 GHz - 3,8 GHz bands, a maximum mean e.i.r.p. density of -70 dBm/MHz and a maximum peak e.i.r.p. of -36 dBm measured in 50 MHz are allowed;
- in the 3,8 GHz - 4,8 GHz bands, a maximum mean e.i.r.p. density of -80 dBm/MHz and a maximum peak e.i.r.p. of -30 dBm measured in 50 MHz are allowed.

On the other hand, for devices adopting LDC according to limits described in Table 23, a maximum mean e.i.r.p. density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm measured in 50 MHz are allowed in the whole 3,1 GHz - 4,8 GHz bands.

6.1.2.2 Location tracking equipment

For LAES devices, LDC is a mandatory requirement: in the 3,4 GHz - 4,8 GHz band an LAES devices apply a 5 % duty cycle.

For all LT2 devices, LDC is a mandatory requirement: a maximum duty cycle of 5 % per transmitter per second and a maximum T_{on} = 25 ms also applies in the band 3,8 GHz - 4,8 GHz.

Moreover, fixed indoor LT2 devices, in the band 3,8 GHz - 4,8 GHz, should apply an additional limit of 1,5 % per minute, or equipment should implement an alternative mitigation technique that provides at least equivalent protection.

No duty cycle mitigations are considered for LT1 devices.

6.1.2.3 Automotive and railway vehicles

For the operation of equipment using ultra-wideband technology in automotive and railway vehicles, LDC is an optional requirement: in the bands 3,1 GHz to 4,8 GHz and 6,0 GHz to 8,5 GHz, the same limits than generic UWB usage apply. On the other hand, in case such devices would adopt LDC mitigation technique as described in Table 23, these limits are increased up to -41,3 dBm/MHz and 0 dBm over 50 MHz (as in case of generic UWB usage). However, devices emitting along directions higher than 0° are subjected to an additional radiation limits (exterior limit, see clause 6.2.1.2.1).

Moreover, in cases in which the vehicle is running at speeds higher than 20 Km/h, the LDC limit over 1 hour of period, i.e. 18 s per hour, may be increased, linearly with its speed, up to 180 s per hour at 40 Km/h. This last limit is described in Figure 12.

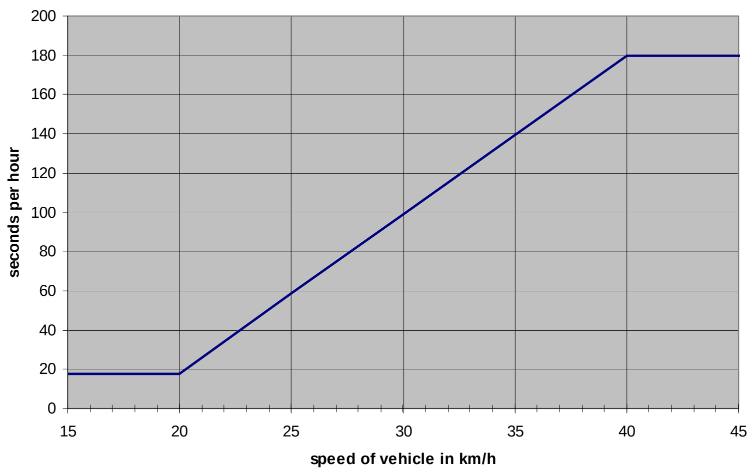


Figure 12: Trading LDC with vehicle speed in EN 302 065-3 [i.25]

6.1.2.4 Material Sensing Devices other than BMA

For Material Sensing Devices other than BMA (e.g. ODC), non-fixed installation (category B), in EN 302 498-1 [i.21] a cumulative duty cycle not higher than 10 % over 1 second is required In the following bands:

- 2,69 GHz ≤ f < 2,7 GHz
- 3,4 GHz ≤ f < 3,8 GHz
- 4,8 GHz ≤ f < 5,0 GHz

6.1.2.5 Tank level probing radar

Duty cycle technical parameters for TLPR are described in EN 302 372-1 [i.27];

For TLPR two contributions are considered to calculate duty cycle: the duty cycle due to the application, D_U, and the duty cycle due to the modulation, D_X.

The duty cycle D_U is under control of the user, determined by the users' transmission time, and it is normally declared by the user or applicant. The level of the duty cycle D_U determines the DC category of the device. The provider should declare the duty cycle D_U and the respective duty cycle category for the TLPR device, as indicated in g Table 24. There are no restrictions on D_X.

Table 24: TLPR Duty Cycle, D_U

Duty cycle Category	Duty cycle ratio
1	≤ 0,1 %
2	≤ 1,0 %
3	≤ 10 %
4	Up to 100 %

The duty cycle due to modulation, D_X, is determined by the transmitters modulation. The duty cycle D_X is important when the radiated power is measured and the modulation cannot be switched off. This is specifically the case when the equipment is using a pulsed type of modulation.

Limits for D_X are reported in Table 25.

Table 25: Duty Cycle, D_X

Duty cycle Categories	Duty cycle ratio
1	≤ 0,1 %
2	≤ 1,0 %
3	≤ 10 %
4	Up to 100 %

The duty cycle D_X should be measured over any one-hour period.

A limitation on D_X exists for pulsed systems: they should only be category 1 or 2, i.e. D_X should not exceed 1 % per hour.

6.1.2.6 Level Probing Radars

For Level Probing Radars, duty cycle is an optional mitigation technique.

Two different kinds of duty cycle are defined in EN 302 729 [i.26]:

- A "Duty Cycle resulting from the user, or "Activity Factor", defined as follows:
    - Activity Factor (AF) - is the ratio of an active measurement periods (bursts, sweeps, scans) within the overall repetitive measurement cycle, i.e. T_{meas}/T_{meas_cycle}.
    - The AF can be used as additional mitigation technique: an AF of 10 % represents an interference mitigation of 10 dB.
- A "Duty Cycle resulting from modulation", defined as follows:
    - For pulse modulation devices, the Tx amplitude is periodically switched on for a short time (i.e. the pulse duration) and switched off during the subsequent reception period. A typical example is shown in Figure 13.

- The time between the rising edges of the pulsed output power is called the Pulse Repetition Interval (PRI). The PRI may vary between subsequent pulses, in which case the modulation is called staggered PRI.
- The Pulse Repetition Frequency (PRF) is the inverse of the PRI averaged over a time sufficiently long to cover all PRI variations.
- The "duty cycle resulting from modulation" is the product of the PRF and the pulse duration.

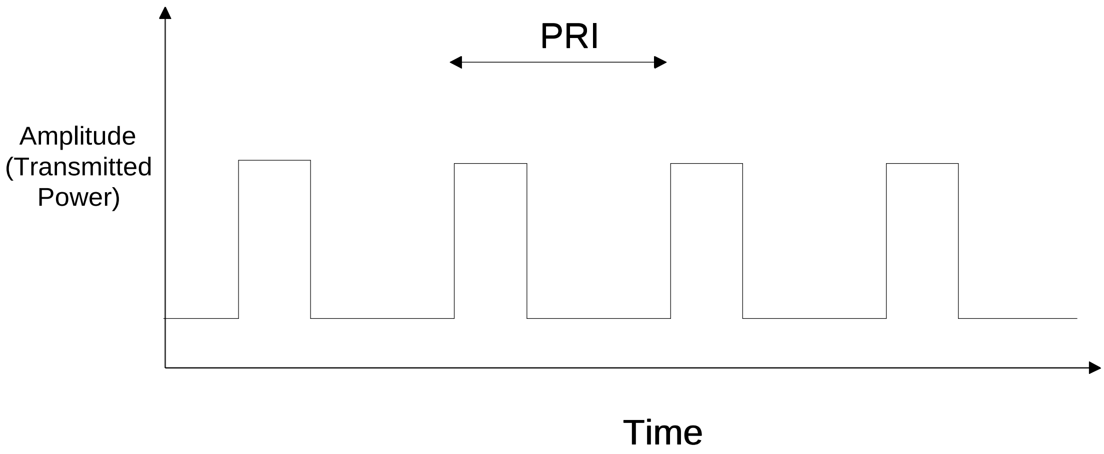


Figure 13: Typical pulse modulation scheme

There are no specific restrictions on duty cycle for LPR, and it may be used as additional mitigation. In this case the manufacturer should provide sufficient information for determining compliance with the LPR emission limits (defined in clauses 7.2.3 and 7.3.3 of [i.26].

6.1.2.7 Trading LDC against transmitted power

It may be noted that for many duty cycle limits defined for UWB no gradual trading of duty cycle against transmitted power is foreseen. In certain cases there is only a *fixed* amount of DC allowed in order to increase the emission power limits. As an example, a device in the band 3,1 GHz - 4,8 GHz utilized in automotive applications is only allowed to operate at -70 dBm/MHz or -80 dBm/MHz with a 100 % duty cycle, or at -41,3 dBm/MHz with a 5 % duty cycle. Therefore, in this case, a hard gap of 28,7 dBm/MHz exists between UWB devices using LDC and UWB devices not using LDC.

Hence a question arises, as to whether this gap may be smoothed by adopting some kind of gradual trading of LDC against transmitted power.

This point has been raised in the ECC, and the resulting CEPT Report 45 [i.11] concluded that, under some predefined conditions, a trading of transmitted power and duty cycle is admissible and may be considered a mitigation technique that achieves equivalent effects to LDC mitigation, as defined in Table 23.

This gradual trading of LDC against transmitted power is specified in EN 302 065-3 [i.25], and is under deeper analysis in the CEPT SE24 working group. Parameters for this mitigation are included in EN 302 065-3 [i.25] and are shown in Table 26. The grey row represents current limits stated by EC DEC(06)04 [i.3], the other rows represent other traded limits, considered as equivalent mitigation.

Table 26: Trading PSD against LDC in current UWB standard (EN 302 065-3 [i.25]):

Mean PSD Limit	External limit Elevation > 0°	Long Term Duty Cycle see note 2	Short Term Duty Cycle see note 1	Max Ton	Mean Toff	Max ∑Ton see note 1	Min ∑Toff
dBm/MHz	dBm/MHz	Seconds within 1 hour	% in 1 second	ms	ms	ms	ms
-41,3	**-53,3**	**18-180**	**5**	**5**	**38**	**50**	**950**
-44,3	-56,3	36-360	10	10	38	100	900
-47,3	-59,3	72-720	20	20	38	200	800
-50,3	-62,3	144-1 440	40	40	38	400	600
-51,3	-63,3	180-1 800	50	50	38	500	500

The main justifications underlying the applicability of this exchange have been outlined in CEPT Report 45 (see [i.11], Annex 2). They will also be shown again and analyzed in greater details in Annexes A and B of the present document.

6.2 Radiation pattern mitigations

In this clause, a set of passive mitigation techniques are grouped as related to limitations of the characteristic radiation pattern emitted by the regulated device.

These limits impose the far field radiation to be bounded; locally (e.g. along certain predefined directions or angular sectors, as in the case of automotive Exterior Limit), or globally (e.g. integrating the whole far field over a sphere, as in the case of TRP).

6.2.1 Total Radiated Power (TRP)

6.2.1.1 General 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 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 14.

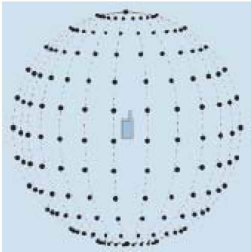


Figure 14: Measurement points across the spherical surface

To calculate the TRP from the measured e.i.r.p. values at the discrete measurement point, the following formula can be used:

$$TRP = \sum_{\Theta}\sum_{\Phi}\frac{e.i.r.p.(\Theta,\Phi)}{4\pi}\cdot\Delta A(\Theta,\Phi)$$

with $\Delta A(\Theta,\Phi) = \int\limits_{\Theta-\Delta\Theta/2}^{\Theta+\Delta\Theta/2}\int\limits_{\Phi-\Delta\Phi/2}^{\Phi+\Delta\Phi/2}\sin(\Theta)\,d\Theta\,d\Phi = \Delta\Phi\cdot\left|-\cos(\Theta+\Delta\Theta/2)+\cos(\Theta-\Delta\Theta/2)\right|$

being the surface element for which the measured e.i.r.p. value is valid and $\Delta\Theta$ respectively $\Delta\Phi$ the discrete step in angle.

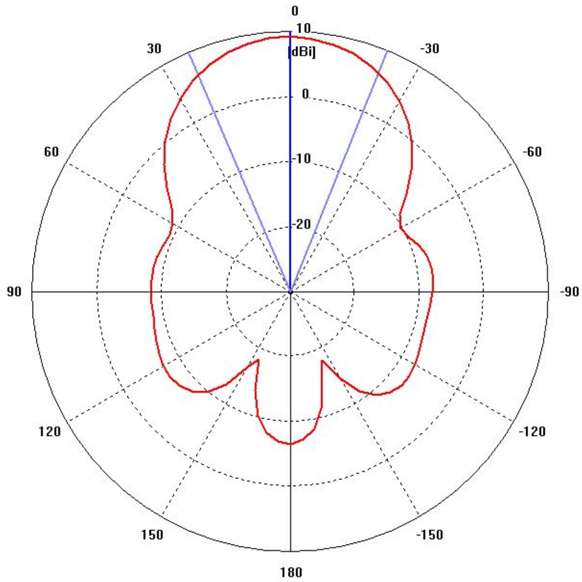


Figure 15*:* Example radiation pattern of an antenna in free-space with a directivity of D = 9,3 dBi

In case the directivity D of the transmit antenna including all surrounding parts is known, the TRP derives from the e.i.r.p. the following way:

$$TRP = \frac{e.i.r.p.}{D}$$

In Figure 15 the directivity is 9,3 dBi and the 0 dBi circle represents the TRP. As an example for an e.i.r.p. of -55,7 dBm/MHz the TRP derives to -65 dBm/MHz. For a lossless antenna the gain G equals the directivity D. For real antennas the gain equals

$$G = \eta\cdot D$$

where η is the efficiency of the antenna.

This mitigation applies to the following Material Sensing Devices:

- Non-BMA, non fixed installations, as described in the ETSI System Reference Document [i.17] and ECC/DEC/(07)/01 [i.4], in the following bands:
  - 2,5 GHz to 2,69 GHz
  - 3,4 GHz to 3,8 GHz
  - 4,5 GHz to 5,0 GHz
- Building Material Analysis, in all allowed bands, as described in the ETSI System Reference Document [i.17] and ECC/DEC/(07)/01 [i.4].

6.2.1.2 Technical parameters and implementation in ECC/EC regulation

6.2.1.2.1 Material Sensing Devices other than BMA, non-fixed installations

The TRP mitigation for non BMA equipment, is regulated in ECC/DEC/(07)01 [i.4].

The studies for the mitigation parameters were done in ECC report 123 [i.7] for the preparation of the amendment of ECC/DEC/(07)01 [i.4].

The implementation of the TRP mitigation technique in a non BMA Material Sensing Device applies only to non-fixed installation, and it is allowed in the following frequency ranges, according to the limits shown in Table 27.

Table 27: TRP technical parameters for non BMA Material Sensing Devices, non-fixed installations

Frequency range [GHz]	Maximum mean e.i.r.p. limit [dBm/MHz]	TRP limit [dBm/MHz]
2,5 ≤ f < 2,69	-65	-75 (in combination with LBT)
3,4 ≤ f < 3,8	-50	-55 (in combination with 10 % LDC)
4,8 ≤ f < 5,0	-55	-65 (in combination with 10 % LDC)

The test procedure necessary for BMA equipment is described in the ETSI harmonized standard EN 302 435. [i.19].

6.2.1.2.2 Building Material Analysis

For the Building Material Application the mitigation is regulated as defined in ECC/DEC/(07)01 [i.4].

The studies for these mitigation were performed during the preparation of ECC/DEC/(07)01 [i.4] and the CEPT report 010 [i.9].

The TRP requirements for BMA devices consist of a generic requirement for all bands plus additional requirements in some specific bands:

- The generic requirement imposes that the Total Radiated Power spectral density (as defined in clause 6.2.1) has to be 5 dB below the maximum mean e.i.r.p. spectral density limits allowed for BMA and defined in Table 3 of ECC/DEC/(07)/01 [i.4].
- The specific requirement is stated specifically to protect the usage of the RAS frequency ranges in the ranges 2,69 GHz to 2,7 GHz and 4,8 GHz to 5 GHz, where the maximum allowed mean e.i.r.p. spectral density is -55 dBm/MHz, and the TPC limit should fulfil the limitation included in Table 28.

Table 28: Specific TPC requirements for BMA, to protect RAS

Frequency range (GHz)	Maximum mean e.i.r.p. limit [dBm/MHz]	TRP limit [dBm/MHz]
2,69 ≤ f < 2,7	-55	< -65
4,8 ≤ f < 5	-55	< -65

The test procedure necessary for Material Sensing Devices is described in the ETSI harmonized standard EN 302 435 [i.19].

6.2.2 Restrictions on angular sectors of radiation

6.2.2.1 General description

Radiation pattern 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 sidelobes. 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 are applications that implement this category of mitigation.

6.2.2.2 Technical parameters and implementation in ECC/EC regulation

6.2.2.2.1 Automotive and railway

ECC Report 170 [i.8] provides detailed compatibility studies in the bands 3,4 GHz - 4,8 GHz and 6 GHz - 8,5 GHz on the impact of LDC UWB devices installed inside road and rail vehicles. It assumes a penetration rate of 50 %, 10 devices per vehicle (6 in 3,1 GHz - 4,8 GHz and 4 devices per vehicle in 6 GHz - 8,5 GHz) and their intended emissions directed towards the inside. The report concludes that a maximum mean e.i.r.p. spectral density limit of -53,3 dBm/MHz for emissions directed outside road and rail vehicles would provide a high level of confidence for the protection of most potentially affected radio services.

According to this study a difference is made between interior and exterior limits of radiations in vehicular applications provided that the emission inside the vehicle should fulfil the same limitations as generic UWB usage, and the transmission emitted outside the vehicle from sidelobes or scattered radiation is suitably attenuated. Thus devices attempting to restrict their radiations to inside the car are generally subjected to less limitations in comparison to devices radiating outside the surface of the car.

On the other hand, emissions directed outside of the vehicle are subjected to an increased limit when the elevation angle is greater than 0°. This specific restriction on the angular sector radiation is called Exterior Limit (EN 30 065-3 [i.25], clause 4.5. The exterior limit for automotive applications is defined in CEPT ECC/DEC/(06)04 [i.3]:

- outside the vehicle at elevation angle < 0°, and inside the car, for each UWB device installed in a road or rail vehicle, a maximum peak e.i.r.p. spectral density of 0 dBm/50 MHz and a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz is required if other mitigation technique are applied (TPC, LDC, DAA, etc.);
- for the emissions outside the vehicle at elevation angles higher than 0° (reference plane the ground plane), the Exterior Limit consists in a maximum mean e.i.r.p. spectral density limit of -53,3 dBm/MHz. This should be combined with other mitigation (LDC, TPC, DAA, etc.).

Figure 16 illustrates this mitigation requirement.

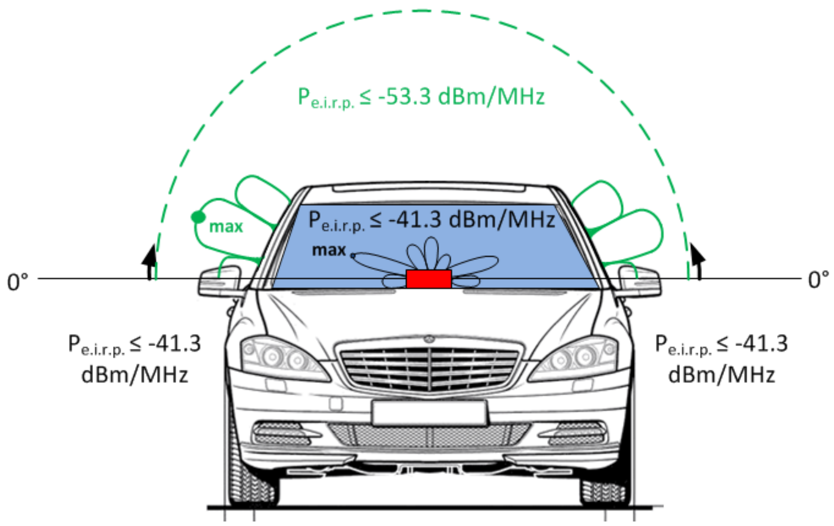


Figure 16: Principle of the regulations [i.25]

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

The frequency bands where this mitigation applies are 3,1 GHz to 4,8 GHz, 6 GHz to 8,5 GHz and 8,5 GHz to 9 GHz.

Technical parameters related to this regulation are summarized in Table 29 and Table 30.

Table 29: Mean PSD and exterior limit

Frequency (GHz)	Maximum value of mean power spectral density (dBm/MHz)		
	Devices with additional mitigation (e.g. DAA, LDC, TPC)		Devices without additional mitigations
	Vehicle exterior at elevation angle < 0°, Vehicle interior	Vehicle exterior at elevation angle > 0°	All elevation angles, vehicle interior and exterior
3,1 < f ≤ 3,4 (see notes 1 and 2)	≤ -41,3	≤ -53,3	-70,0
3,4 < f ≤ 3,8 (see notes 1 and 2)	≤ -41,3	≤ -53,3	-80,0
3,8 < f ≤ 4,8 (see notes 1 and 2)	≤ -41,3	≤ -53,3	-70.,0
6 < f ≤ 8,5 (see notes 1 and 3)	≤ -41,3	≤ -53,3	-53,3
8,5 < f ≤ 9 (see notes 2)	≤ -41,3	≤ -53,3	-65,0

NOTE 1: Low Duty Cycle (LDC) also applies (in alternative to DAA and TPC).
NOTE 2: Detect And Avoid (DAA) and Transmit Power Control (TPC) also applies (in alternative to LDC).
NOTE 3: TPC also applies (in alternative to LDC).

Table 30: Peak power for automotive and railway application

Frequency (GHz)	Maximum value of peak power limit (dBm measured in 50 MHz)	
	Devices with additional mitigation (e.g. DAA, LDC, TPC)	**Devices without additional mitigations**
	All elevaton angles, vehicle interior and exterior	
3,1 < f ≤ 3,4	**≤ 0 (see notes 1 and 2)**	**-36,0**
3,4 < f ≤ 3,8	**≤ 0 (see notes 1 and 2)**	**-40,0**
3,8 < f ≤ 4,8	≤ 0 (see notes 1 and 2)	-30,0
6 < f ≤ 8,5	≤ 0 (see notes 1 and 3)	-13,3
8,5 < f ≤ 9	≤ 0 (see notes 2)	-25,0
NOTE 1: Low Duty Cycle (LDC) also applies. NOTE 2: Detect And Avoid (DAA) or Transmit Power Control (TPC) also applies (in alternative to LDC). NOTE 3: TPC also applies (in alternative to LDC).		

6.2.2.2.2 Location Tracking Type 2 (LT2, fixed outdoor installation only)

Location Tracking Type 2, fixed outdoor installations in the band 4,2 GHz to 4,4 GHz are subjected to a restriction in the azimuth angular sector higher than 30°.

This restriction is defined in EN 302 065-2 [i.24]. The related compatibility studies have been done in ECC Report 170 [i.8].

The maximum mean e.i.r.p. spectral density in the band 4,2 GHz to 4,4 GHz for emissions that appear 30° below the horizontal plane should be less than -41,3 dBm/MHz, see clause 4.1.1. [i.24].

The maximum mean e.i.r.p. spectral density in the band 4,2 GHz to 4,4 GHz for emissions that appear 30° or greater above the horizontal plane should be less than -47,3 dBm/MHz, see clause 4.1.1.4 [i.24].

In both cases, a maximum duty cycle of 5 % per transmitter per second and a maximum $T_{on} \leq 25$ ms also applies.

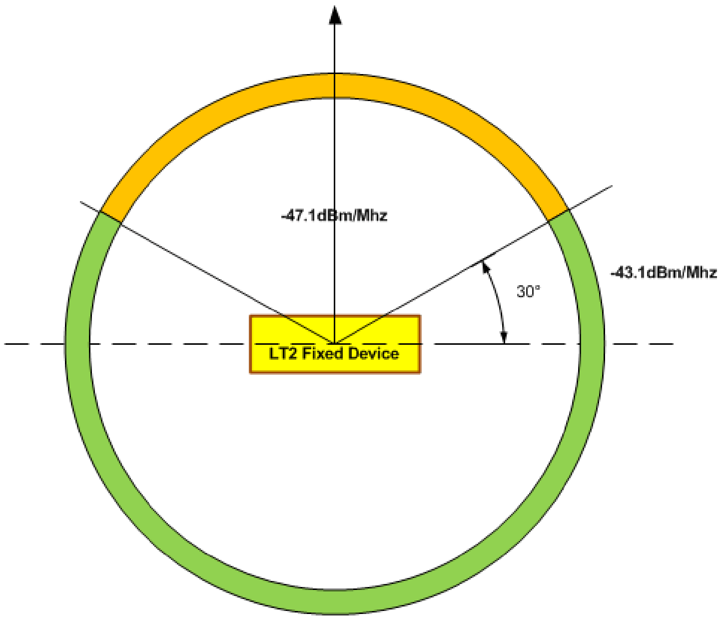


Figure 17: Emitted power limits for angular sectors for LT2 devices, fixed outdoor

6.2.2.2.3 Material Sensing Devices (fixed installations only)

For Material Sensing Devices other than Building Material Analysis (e.g. Object Discrimination and Characterization), fixed installations, a restriction is stated on angular sector radiation higher than -20° and lower than +30°, being 0° the plane parallel to the ground.

The situation is shown in Figure 18.

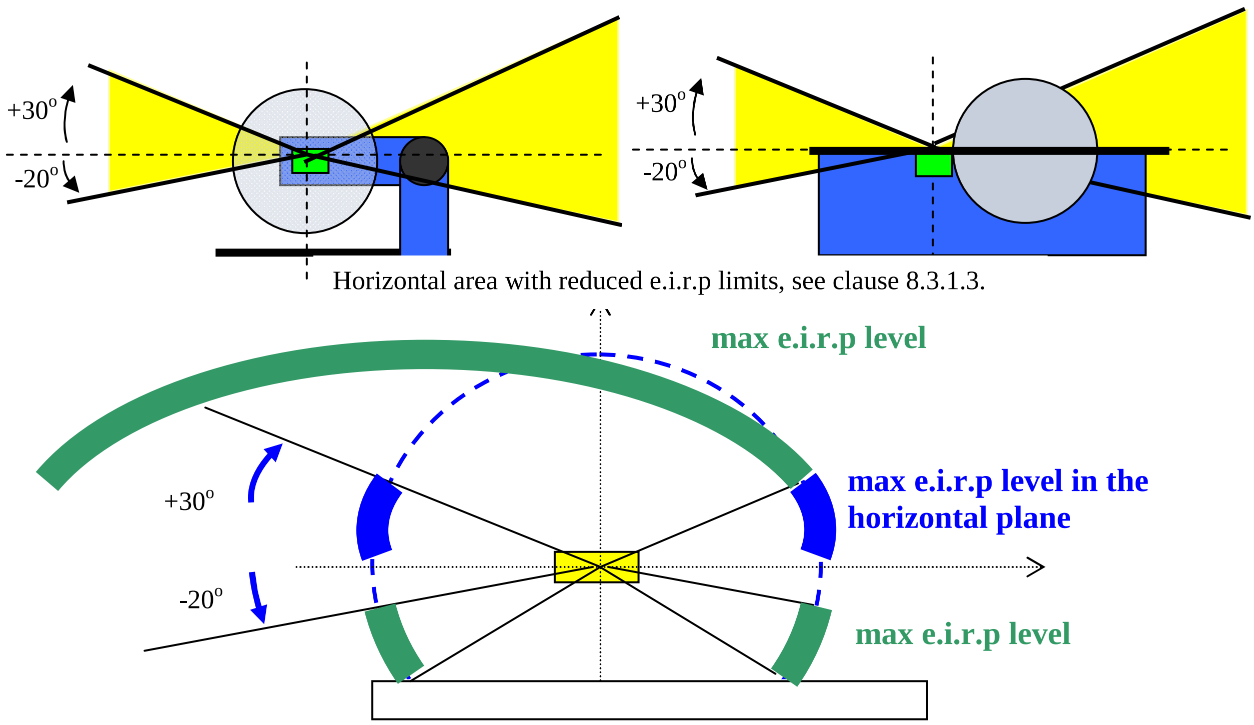


Figure 18: Restriction on angular sector for material sensing devices

This mitigation is stated in ECC/DEC/(07)/01 [i.4] and EN 302 498-1, clause 8.3.1.3 [i.21]. Details of frequency bands and limits are reported in Table 31.

Table 31: PSD restriction in function of angular sensor for material sensing device

Frequency range	Material Sensing Devices other than BMA (e.g. ODC) Fixed installations (Application A)	
	Maximum mean e.i.r.p spectral density: elevation < -20° or > +30°	**Maximum mean e.i.r.p spectral density: elevation from -20° to +30°**
1,73 to 2,2 GHz	-65 dBm/MHz	-70 dBm /MHz
2,5 to 2,69 GHz	-65 dBm/MHz (see note)	-70dBm/MHz
2,69 to 2,7 GHz	-55 dBm/MHz	-75 dBm/MHz
2,7 to 2,9 GHz	-50 dBm/MHz	-70 dBm/MHz
2,9 to 3,4 GHz	-50 dBm/MHz	-70 dBm/MHz
3,4 to 3,8 GHz	-50 dBm/MHz	-70 dBm/MHz
4,8 to 5 GHz	-55 dBm/MHz	- 75 dBm/MHz
5,25 to 5,35 GHz	-50 dBm/MHz	- 60 dBm/MHz
5,6 to 5,65 GHz	-50 dBm/MHz	-65 dBm/MHz
5,65 to 5,725 GHz	-50 dBm/MHz	-60 dBm/MHz
NOTE: Devices using a Listen Before Talk (LBT) mechanism, as described in the harmonised standard EN 302 498-2 [i.21], which meet the technical requirements defined within Appendix 1 of EC/DEC/(07)/01 [i.4], are permitted to operate in the frequency ranges 2,5 GHz to 2,69 GHzand 2,9 GHz to 3,4 GHz with a maximum mean e.i.r.p. spectral density of -50 dBm/MHz.		

The $P_{e.i.r.p.}$ is the power density referenced location of the UWB sensor inside the bench top tool, taking the frequency depending free space attenuation and the measurement equipment into account.

6.2.3 Shielding

6.2.3.1 General description

Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials. Shielding is typically applied to enclosures to isolate electrical devices from the 'outside world', and to cables to isolate wires from the environment through which the cable runs. Electromagnetic shielding that blocks radio frequency electromagnetic radiation is also known as RF shielding.

Typical materials to be considered for electromagnetic shielding include sheet metal, metal screen, and metal foam. Any holes in the shield or mesh should be significantly smaller than the wavelength of the radiation that is being kept out, or the enclosure will not effectively approximate an unbroken conducting surface.

In ECC/DEC/(06)04 [i.4] and ECC Report 064 [i.5] it is shown the Table of the building attenuation, depending on the frequency range for the radio communications systems below 10,6 GHz from generic UWB applications. These results are in line with the CEPT Report 009 [i.10].

An environment where shielding needs to be carefully taken into account is the automotive environment, because of the metallic structure that greatly contributes radiation shielding and diffraction. In Recommendation ITU-R P 679-1 [i.29] some cases of shielding and additional attenuation for the car from the inside to the outside are described, e.g. high shielding is expected for metalized windows or another metallic parts in a car, like fender or metallic parts in a vehicle, and are described the method to measure the attenuation introduced by some car elements as the tyre. There exist a lot of papers describing the emission characteristics for UWB devices operating and an automotive environment (see e.g. [i.35] and [i.36].

All these works show that it is necessary a thorough study, analysis and measurement of the shielding or the attenuation of the UWB emission by different elements (like through metalized windows) around to the environment where the device is mounted.

6.2.3.2 Technical parameters and implementation in ECC/EC regulation

6.2.3.2.1 Tank Level Probing Radars (LPR)

Shielding is considered a mitigation factor for Tanks Probing Radars (TPR). This is due to the special collocation of such kind of devices, i.e. inside industrial tanks and huge containers provided with external floating roofs.

An external floating roof is made of metallic material such as aluminium. The roof acts as a shielding to prevent the scattering energy from the LPR. Furthermore, walls may make the emissions in the direction around the horizontal line quite small according to the calculations from Recommendation ITU-R P.526-10 [i.28]. No openings above the floating roof exist in practice. The reduction factor of the basin and floating roof shielding applicable for LPR applications is 30 dB according to Recommendation ITU-R P.526-10 [i.28]. This mitigation applies to all emissions above 3 GHz. LPR equipment installed in such a shielded environment may therefore use higher emission levels.

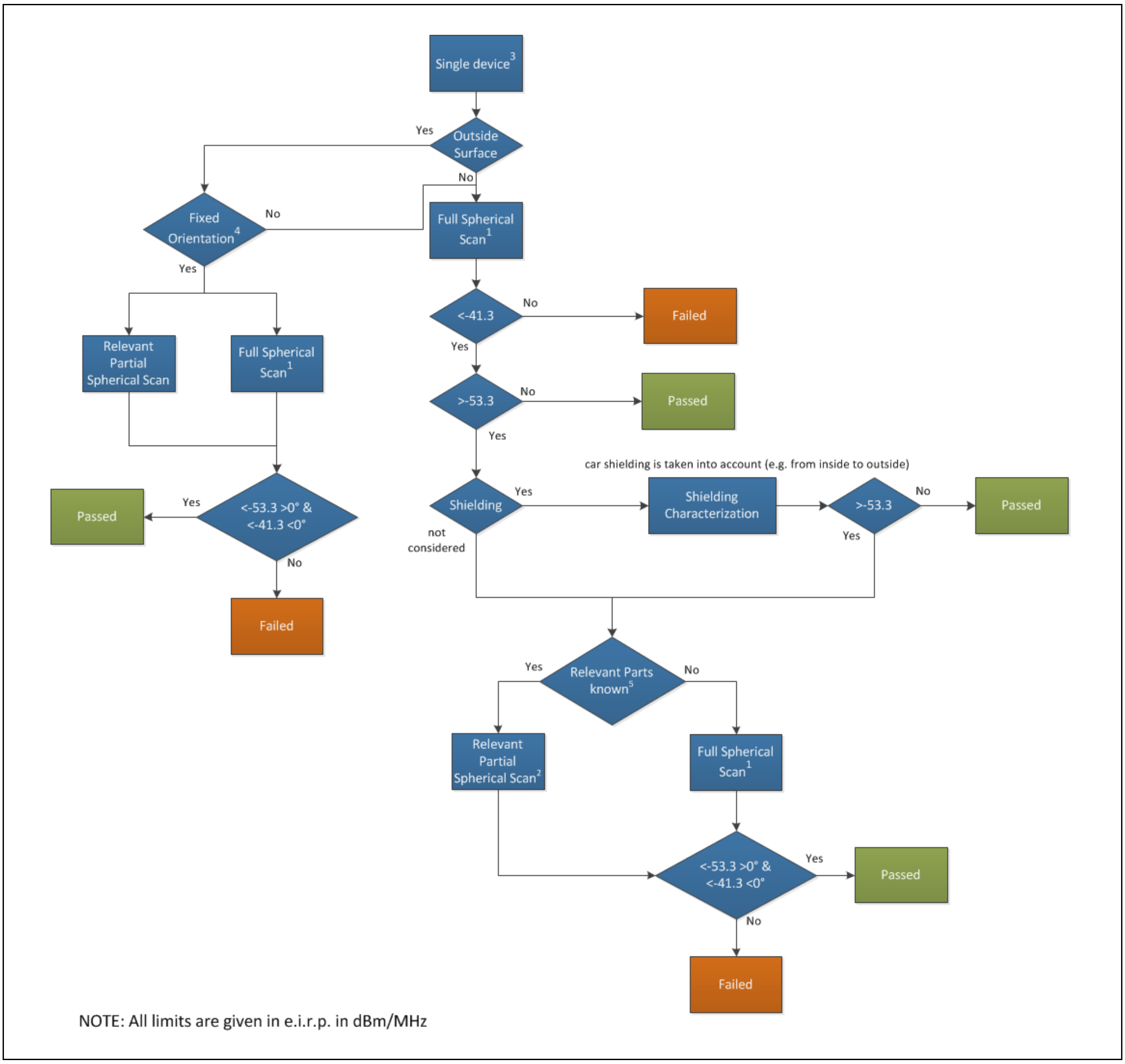
The manufacturer should provide sufficient information in the possible combination of emission levels and shielded installation environment.

6.2.3.2.2 Automotive and Railway

Shielding in Automotive and Railway depends on the fact that the metallic structure of a car provides an intrinsic means to reduce radiation coming from devices mounted on a car.

Shielding may be used in Automotive and Railway application as an additional mitigation factor that may be taken into account when measuring compliance of the device to the Exterior Limits requirement: when measuring e.i.r.p. limits, shielding may be characterized and added to the total budget of e.i.r.p. radiation in order to understand whether or not the device is compliant to regulations.

The structure of the Exterior Limit measurement procedure stated in EN 302 065-3 [i.25] is shown in Figure 19, and it is seen that the shielding characterization is part of this flowchart.



NOTE 1: Full spherical scan to obtain transmission pattern or common measurement method according to TS 102 883 [i.12].

NOTE 2: The horizontal reference plane is the height of the sensor and all measurements have to be performed above 0° elevation to this plane.

NOTE 3: If the part of mounting has influence on the transmission pattern, then the manufacturer can declare the whole part as a device, e.g. door, mirror, bonnet, light, etc.

NOTE 4: If the fixed orientation of the surface and therefore the main transmission direction can be declared by the manufacturer.

NOTE 5: Are the relevant parts of the vehicle, which are expected to influence the transmission to the outside. The measurement setup can be reduced to the known relevant parts.

Figure 19: Concept for the measurement procedure of the exterior limit in Automotive and Railway application

The device under test (DUT) is specifically measured for different applications and different mounting locations.

If a device has a maximum mean power less or equal than -53,3 dBm/MHz (e.i.r.p.) including the transmission pattern, then it is only necessary to measure the device by itself. This can be done radiated or conducted according to TS 102 883 [i.12]. If the transmission pattern of the device is not known a full spherical scan according to Annex B of EN 302 065-3 [i.25] should be performed.

If the maximum mean power measured by the full spherical scan is greater than -53,3 dBm/MHz (e.i.r.p.), shielding may be considered: if shielding from the inside to the outside of the car occurs, it can be taken into account as additional mitigation if the manufacturer can characterize the lowest shielding in all direction to the outside. An example for a measurement procedure for the shielding characterization can be found in TR 103 086 [i.16]. If the transmit power (e.i.r.p.) minus the shielding is less than -53,3 dBm/MHz the device passes. In case the additional attenuation due to shielding is not sufficient to match the Exterior Limit, the device should be measured with the relevant parts of the car.

Figure 20 shows the measurement flow for devices mounted inside the tyre. The measurement methods are defined in clause 6.3.5 of EN 302 065-3 [i.25], due to the specific location of this device, i.e. inside a tyre, that is "belonging" to the vehicle but outside of the vehicle itself.

For the DUT the horizontal reference plane is the height of the sensor inside the tyre and all measurements have to be performed above 0° elevation with respect to this plane.

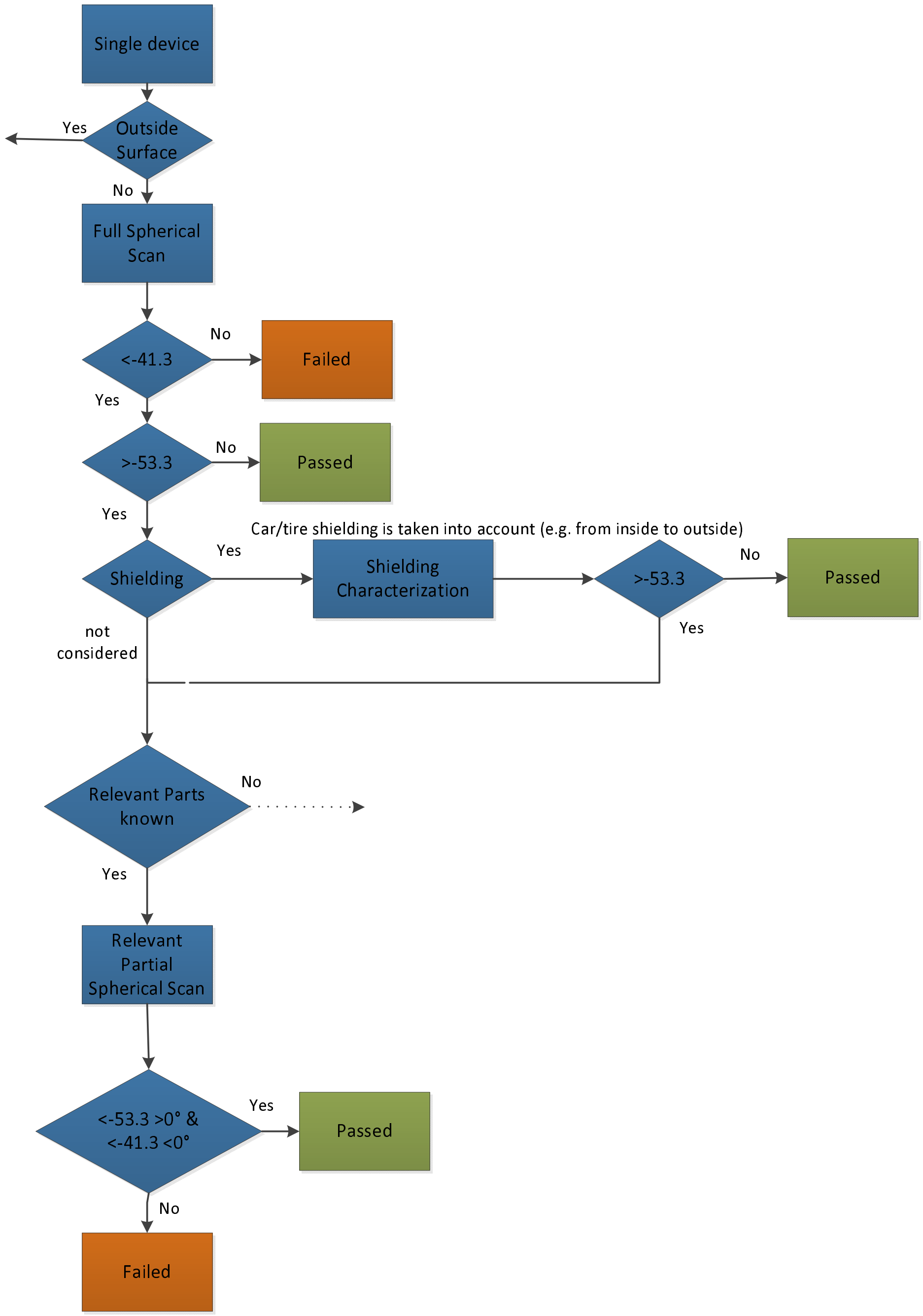


Figure 20: Measurement Flow for devices mounted inside a tyre

The device including the antenna is installed inside the tyre. Although it is mounted "outside" the vehicle, it cannot be considered outside of its surface. Therefore, the answer to the initial conditional block is negative.

Thus it is necessary to perform a total spherical scan around the device itself. In case the result of the measurement is between -53,3 dBm/MHz and -41,3 dBm/MHz, the shielding characterization of the tyre can be taken into account as additional mitigation factor: the device can be considered compliant if the previously measured PSD level (standalone device) subtracted by the attenuation due to shielding effects of the tyre is smaller than or equal to -53,3 dBm/MHz. The minimum attenuation of the appropriate tyre family as declared by the tyre manufacturer should be used in the calculation.

In previous flowchart, attenuation due to shielding effects of the tyre is related to the whole wheel including tyre with rim mounted on it. If the attenuation due to shielding effects of the tyre is not applicable or sufficient, a partial spherical scan on a realistic ground should be performed.

Annex A: Quantitative analysis for the technique of trading LDC against transmitted power

A.1 Executive summary

In this annex, data will be analyzed from JRC Report [i.32], ECC Report 170 [i.8] and Recommendation ITU RA 769-2 [i.30], in order to understand whether a linear trading of LDC against transmit power would provide a protection criteria equivalent to LDC as stated by ECC/DEC/(06)04 amended in 2011.

The analyses presented in this appendix are specifically focused on the trading law described in Table 26.

To the goal of performing the target analysis, mathematical models of LDC effects on a victim receiver are evaluated basing on data included in [i.32], [i.8] and [i.30].

Two different scenarios are considered, well known in compatibility studies performed in ECC, and namely:

- A **single interfere scenario:** where a single interferer is jamming a victim receiver, generally at short distance.
- An **aggregate scenario:** where a plurality of emitters, generally located at distances higher than in the previous case, produce a cumulative effects on a victim receiver.

Clear and short conclusions may be achieved from the arguments exposed in the next paragraphs and namely:

- **For single interferer scenario:** given the limits described in ECC/DEC/(06)04 [i.3], a linear trading of PSD against LDC as described in Table 26 may provide benefits in terms of reduction of PER and reduction of minimum safe distance.

  Moreover, benefits are even achieved by increasing both T_{on} and T_{off}, once LDC has been established.

  The main reason for this effect is underlied by the fact that PER decreases very sharply as the signal to interfere ratio increases (SIR), i.e. when the jammer e.i.r.p. is reduced and LDC is increased. This effect holds for almost any generic communication protocol, because of the fact that PER curves versus SIR exhibits in general a "quasi-threshold" behavior at very low SIR values, due to their exponential dependency on the raw bit error rate.

- **For an aggregate interferer scenario:** under the well consolidated hypothesis of uncorrelated emitters and long integration time at receiver, any LDC variation may be converted to same variation of PSD, in case a frequency domain analysis is adopted. This trading is already adopted within some regulatory bodies. See e.g. Recommendation ITU-R RA 769-2 [i.30] and ECC Report 170 [i.8]: in both cases LDC only transmit power is relevant, whilst in [i.8] LDC is transformed linearly in dB of equivalent attenuation.

  For aggregated scenarios, the effectiveness of this trading has been verified even in the time domain, by benchmarking the time such that the whole level of interfering signal stays below a certain threshold, for the traded and untraded protection criterion. It has been shown that for a high density of emitters the trading of PSD against LDC linearly in dB provides same margins than the untraded protection criterion, within experimental uncertainty. Moreover, in case of lower density of emitters, this time margin may even be increased: this is consistent with the fact that, as the emitters density decreases, the scenario approaches the limit of a single interferer scenario (i.e. the nearest to the victim receiver), where clear benefits in applying a linear trading of LDC against transmitted power are shown in clause A.4.

These conclusions provide evidence of the possibility to interpret the LDC rules stated in ECC/DEC/(06)04 [i.3] as a baseline of LDC regulations, without excluding the possibility to trade them with transmitted power limits in a more flexible way, such to increasing the capability of deployment of new industrial UWB applications.

A.2 Introduction: trading LDC against transmitted power

LDC mitigation in ETSI standards is used in different way: it is used either as a mandatory requirements or as an optional requirement. When used as a mandatory requirement, a device is allowed to operate only if it adopts a predefined duty cycle; when used as an optional mitigation, devices using LDC are allowed to increase the emitted power limits with respect to devices not using any LDC limitation. In this appendix this last case is called: trading of duty cycle against transmitter power.

Examples of these two different usage of LDC may be retrieved in ETSI UWB standards: e.g. for LAES and LT2 operating in the band 3,4 GHz to 4,8 GHz, adoption of 5 % LDC is mandatory; on the other hand, for automotive and railway in the band 3,1 GHz to 4,8 GHz, devices adopting 5 % LDC are allowed to operate up to -41,3 dBm/MHz, while devices not adopting any LDC limitation cannot exceed the e.i.r.p. limit of -70 dBm/MHz in the band 3,1 GHz to 3,4 GHz and 3,8 GHz to 4,8 GHz, and the limit of -80 dBm/MHz in the band 3,4 GHz to 3,8 GHz.

In this appendix a special case of trading, consisting in keeping constant the product of the e.i.r.p. limit by the LDC, is specifically analyzed. This kind of trading will be called thereinafter: "**linear in dB**" or "**linear trading**".

A clear example of this trading is given in EN 300 328 [i.22] for wideband communications in the 2,4 GHz ISM band: in EN 300 328 [i.22] a Medium Utilization factor (MU) is defined as the product of duty cycle and the RF power levels divided by a reference power level, namely 100 mW (see clauses 4.3.1. and 4.3.2.4 of EN 300 328 [i.22]).

EXAMPLE: MU = P_{tx}(e.i.r.p.)/100mW×0,1

EN 300 328 [i.22] imposes this parameter to comply the limit of 10 %, and, provided that MU would not exceed the value of 10 %, the EN allows different RF power level, either by increasing the RF power and decreasing the LDC, or decreasing the RF power and increasing the LDC (e.g. P_{tx}=50 mW at DC=20 %, or P_{tx}=200 mW at DC=5 %).

In UWB standards an example of duty cycle intended in this sense is provided by EN 302 729-1 [i.26], where a "duty cycle resulting from user", or "Activity Factor", is defined, and then it is stated that it can be used as additional mitigation technique, such that an AF of 10 % represents an interference mitigation of 10 dB.

Another example of this kind of trading, specifically proposed for UWB standardization process, is shown in Table 26, where allowed combinations of LDC limits and e.i.r.p. limits for automotive and railway UWB devices are listed.

Therefore, the concept of linear trading seems to be adopted and agreed in a lot of other cases. On the contrary a long discussion arises within CEPT and ETSI in order to understand whether this kind of trading could be adopted. At the time of publication of the present document a discussion is still ongoing in CEPT, within the scope of SE24 work item 37. Hence, although these concept seems accepted in many cases, it still needs a complete clarification in all contexts.

The strongest argument against the linear trading is that the way in which transmitted power and duty cycle "truly" combines their effect against a victim receiver in general is not linear in dB, with the exception of some special cases.

The strongest argument in favor of the linear trading is that, although being true that a linear combination (in dB) of effects against a victim receiver holds only in some special cases, this does not means that application of linear trading would provide worse effects than the "true" non-linear law of combination: **effects of linear trading may even provide better effects at victim receiver side, exactly for the reason that the true law may be not linear**. Some meaningful cases of this second kind will be examined in this annex.

A second important point analyzed in this annex is the effects of limits on the maximum period allowed for continuous transmitter operation. This interval is often indicated as T_{on} time. In EC Decisions [i.1] and [i.2], such T_{on} time is limited to 5 ms. This is also reaffirmed in ECC/DEC/(06)04 [i.3]. On the other hand, some compatibility studies, and precisely the ECC Report 170, [i.8], that was based on results of an experimental campaign conducted by the JRC Research Centre of ISPRA, [i.32], demonstrates that in some cases, e.g. a victim WiMAX link jammed by an UWB link, worst effects against the victim link are achieved at T_{on} values lower 5 ms, whilst the link degradation is less critical in case of higher T_{on} values, up to 50 ms. Hence it seems that current regulations states limits that are not optimal on $T_{on.}$ Therefore this kind of behavior needs to be investigated and clarified in more detail.

The aim of this annex is to analyze these points related to DC as a passive mitigation technique, in order to provide a better understanding of these matters, so as to be helpful in future processes of regulations or revision of currently approved harmonized standards.

The reference parameters adopted in in this annex are the LDC limits stated in EC DEC(06)04 [i.3] for Ultra Wideband: these limits and the analyzed trading are those reported in Table 26.

A.3 Basic assumptions

A.3.1 Definitions and terms

In this annex it is assumed that a main service and an UWB link are contemporaneously operating, interfering each other. The main service is intended as the *victim link*, while the UWB link is intended as the *jamming link*.

The situation of interest is shown in Figure A 1. For the purpose of this appendix, definitions and symbols listed in clause 3 apply. For clarifying these definitions and symbols, one can refer to Figure A 1.

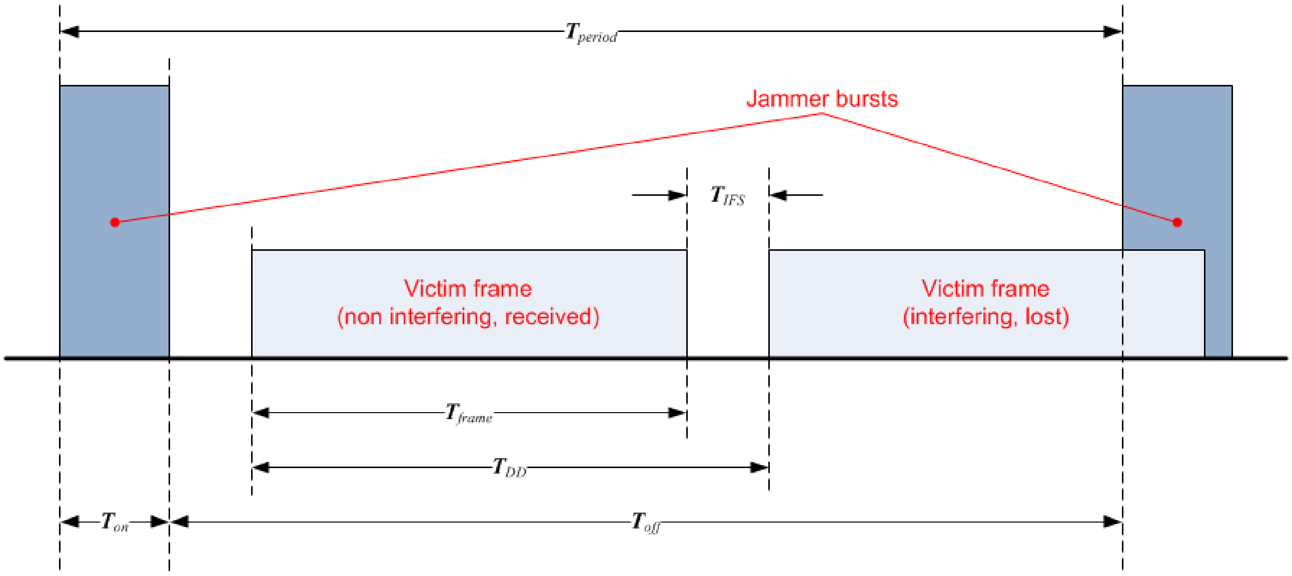


Figure A.1: Exemplary case of interference between a jamming service and a victim service

A.3.2 Analyzed scenarios

In order to achieve more insights about the trading of LDC against transmitted power, there is the need to summarizes two main points considered in official documents adopted in EC (and even outside EC), regarding the different scenarios where interferer effects should be taken into account: one may basically distinguish a scenario based on a single interferer, and a scenario where a lot of interferers affect the victim receiver. These may be described as follows:

- **Single interferer scenario:** in this case, a single jammer affects the victim receiver. Typically, the degradation of performance is estimated using parameters such as percent of packet lost (for services such as UDP), increasing of transfer data time (for services such as ftp), and degradation of audio or video quality (for video streaming or VoIP).

  Due to the fact that the victim services produce packets having a typical length (e.g. 5 ms for WiMAX), adopting duty cycle mitigation and consequently imposing the interferer a T_{off} time to be higher than a predefined minimum or average value, guarantees the victim radio service a safe transmission time allocation, lowering the probability that packets would collide with jammer packets.

- **Aggregated interferers scenario:** In this case, a set of interferers produces an aggregate field affecting a victim receiver. It is realistic and commonly adopted the hypothesis of uncorrelated interferers, thus the aggregated interfering field received by the victim is seen as increased noise floor level. Therefore, the parameter of interest in this case is mainly the interferer whole power to noise floor ratio, namely I/N, or the Signal to Interferer Ratio, namely SIR.

Due to the fact that the interfering field is seen as extra noise, adopting the criterion to limit the I/N ratio or the SIR ratio (in predefined typical scenarios) guarantees the victim receiver to achieve satisfactory packets error rates at predefined sensitivity levels.

In the following, general conclusions are provided for both cases, based on data available in official ECC documents. The assumptions are valid for UWB versus a narrower band victim (e.g. a WiMAX link).

A.4 Single interferer scenario analysis

A.4.1 Fundamental remarks: benefits implied by a linear trading of duty cycle against transmitted power

In this clause some results are analyzed reported in the JRC Report [i.32], "Report on Radio Frequency Compatibility Measurements between UWB LDC Devices and Mobile WiMAX (IEEE 802.16e-2005) BWA Systems", and included "as is" in ECC Report 170 [i.8]. Basing on these data only, one can demonstrate several benefits that may be achieved by linearly trading TX power against LDC, and by increasing T_{on} and T_{off}, given a predefined LDC.

In the following, there is consideration of Figures A.2 and A.3, taken from [i.32] (even replicated in [i.8]). These figures refer to PER degradation of a WiMAX link jammed by a single UWB transmitter in function of the Signal to Interferer Ratio (SIR), according to a test setting which details may be found in [i.32]. Specifically, the figures present different cases of T_{on} when LDC = 5 %. Moreover, the case at LDC=100 % also is presented, i.e. the highest dotted curve: it is clear that, for any other case having LDC < 100 % even not represented in the figure below, the related PER curve will be lying below the PER curve corresponding to 100 % duty cycle.

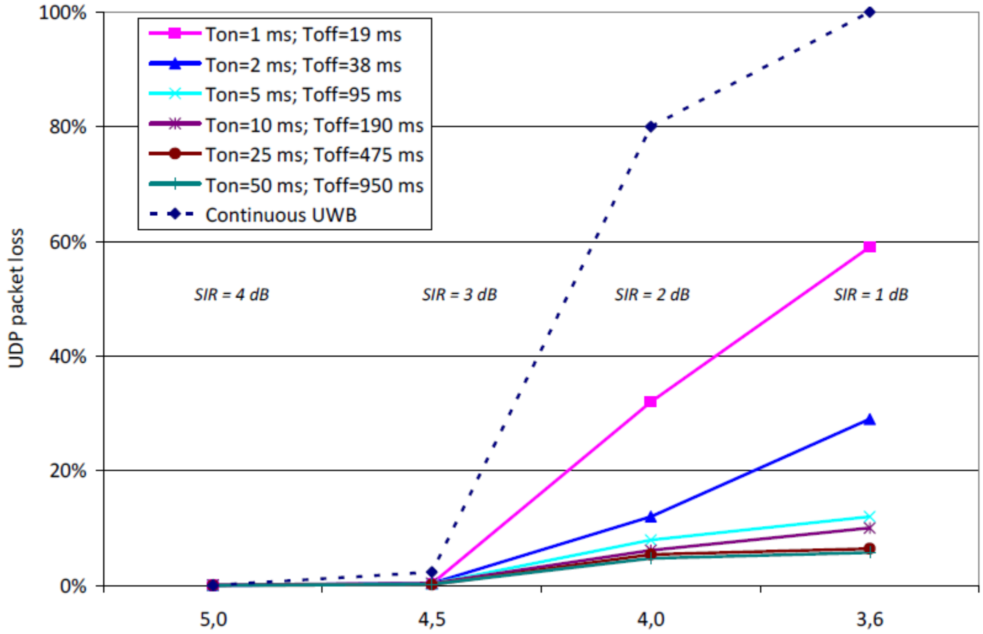


Figure A.2: UDP packet loss versus equivalent distance to interferer (LOS), victim RSSI = -84,6 dBm (from [i.32])

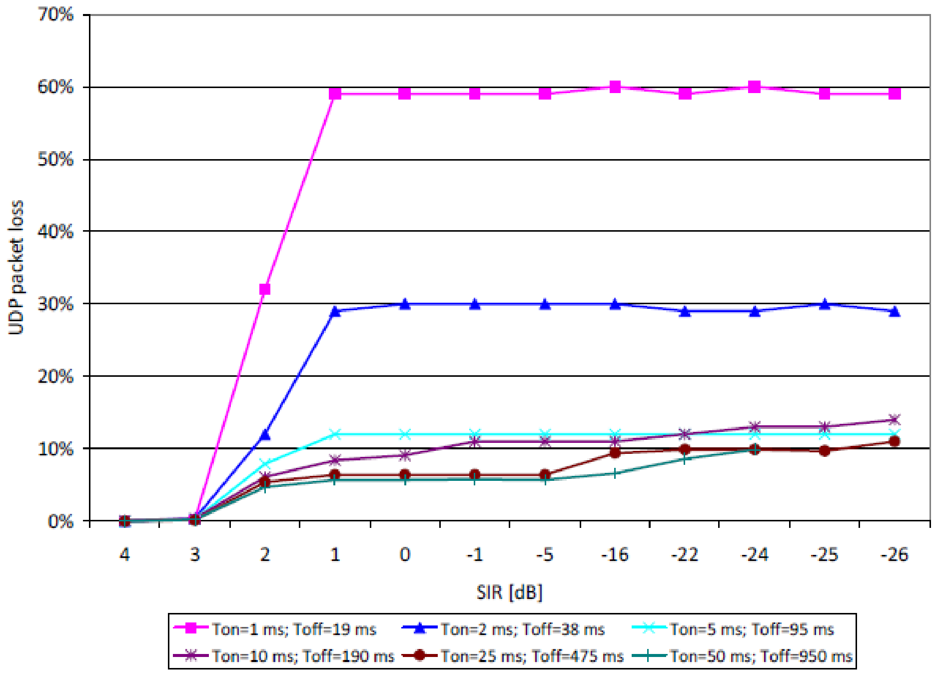


Figure A.3: UDP packet loss rates versus WiMAX Signal-to-Interference Ratio (SIR) for various pulses, RSSI = -84,6 dBm (from [i.32])

An analysis of these figures provides deep insight on LDC, discovering three kinds of benefits that may be achieved by linearly trading TX power against LDC:

Benefits of trading TX power against LDC linearly in dB: PER.

From both figures it may be observed that:

- When duty cycle is 5 % (all lines except the dotted one), for any value of T_{on} and T_{off}:
  - worst case PER is achieved at SIR ≤ 1,0 dB
  - PER < 5 % may be achieved when SIR > 3,0 dB
  - PER ≈ 0 % is achieved when SIR > 4,0 dB

  When duty cycle is ≤ 100 %, for any LDC value such that 5 % < LDC < 100 %, and for any value of T_{on} and T_{off}, the case LDC = 100 % represents an upper boundary. Hence:
  - worst case PER is 100 %, and it is achieved at SIR ≤ 1,0 dB when LDC=100 %
  - PER < 5 % may be achieved when SIR > 3,0 dB, for any value of LDC, T_{on} and T_{off}
  - PER ≈ 0,% is achieved when SIR > 4,0 dB, for any value of LDC, T_{on} and T_{off}

An immediate conclusion from these figures is that, under the tested conditions, **the percentage of lost packets by a WiMAX victim receiver decreases from its worst value down to 0 % as SIR increases by few dB, from 1 dB to 4 dB: as this gap in dB is very sharp, this means that one may achieve great benefits over PER at victim receiver side by reducing the transmitted power even by a few dB**.

As a matter of example demonstrating this last sentence, the following case may be considered: TX and RX at 3,6 m, LDC = 5 %, T_{on} = 25 ms, SIR = 2,0, such that PER ≈ 5 %. In case the LDC is doubled from 5 % to 10 % (equivalent to +3 dB) and the transmitted power is reduced by 3 dB, SIR is increased up to 5 dB: this means PER ≈ 0 %, whichever T_{on} and T_{off} would be used. This example confirms that benefits may be achieved by applying linear trading of LDC and PSD, even when TX and victim RX are within relatively short distances.

It may be noted that the described benefit underlies on the fact that the PER curve is very sharp and it decreases from best values (almost 0 %) to worst values (almost 100 %) within few dB. This is a general conclusion, common to almost all communications protocol, due to the fact that the PER curves vary exponentially with respect to BER, hence they are normally very sharp, exhibiting an "almost threshold effect", falling from lowest PER to highest PER within very few dB: **therefore the described kind of benefit on PER holds in general for all communication protocols and not only for WiMAX**.

Benefits of trading TX power against LDC linearly in dB: minimum safe distance.

Relate now the SIR to the distance between the jammer transmitter and the victim receiver. Due to the fact that SIR = 4,0 dB - i.e. the SIR such that PER ≈ 0 % - corresponds to a distance about 5 m (see Figures A.2 and A.3), first one may conclude that **the effect of a single UWB interferer is not meaningful against a WiMAX receiver when the UWB transmitter is located at distance greater than 5 m from the victim receiver**.

This does not mean that one may disregard "any" mitigation technique when the distance increases above 5 m. The correct interpretation is that the single interferer scenario does not apply when the distance between the UWB interferer and the WiMAX victim is greater than 5 m: hence, when such a distance increases above 5 m the correct mitigation scenario to be considered is related to the aggregate scenario, not the single interferer scenario. This scenario will be analyzed further in this annex.

This fact reflects a general principle, and namely the fact that the minimum distance such that the link is immune from interferer may be decreased according to a PSD reduction. The law of variation of this minimum distance may be computed by considering that the transmitted power decreases according to the square of distance. Hence, given an UWB node transmitting a certain power spectral density, say PSD_0, and given a minimum distance immune from interferer effect, say $L_{min}(PSD_0)$, should this transmitter change its power spectral density from PSD_0 to PSD_1, a new minimum distance immune from interference, say $L_{min}(PSD_1)$, would be given, which variation in dB is the same and opposite amount in dB. As a matter of example, let us consider that the performances shown in Figure A.2 have been computed at PSD_0 = -41,3 dBm/MHz, measured when transmitter is continuously on: by reducing this power spectral density e.g. at PSD_1 = -47,3 dBm/MHz, the minimum immune distance is halved from 5 m to 2,5 m.

This fact is reflected in Table A.1 where a safe distance of 4,5 m is assumed for PER < 5 % at PSD = -41,3 dBm/MHz: it is seen that this safe distance decreases as LDC is increased and the PSD is traded to LDC linearly in dB, such to keep SIR = 3,0 dB and consequently PER < 5 %.

Table A.1: Decreasing of safe distance for PER < 5 % when trading PSD against LDC linearly in dB

LDC	Variation of LDC (dB)	PSD dBm/MHz	Safe distance for PER < 5 %	Variation of safe distance for PER < 5 % (dB)
5 %	0	-41,3	4,50 m	0
10 %	+3	-44,3	3,18 m	-3
20 %	+6	-47,3	2,25 m	-6
40 %	+9	-50,3	1,59 m	-9
50 %	+10	-51,3	1,42 m	-10
100 %	+13	-54.3	1,01 m	-13

It should be noted that this means that **each time the duty cycle is doubled - and the PSD is reduced by 3 dB accordingly - the minimum safe distance is reduced by a factor** $\sqrt{2} = 1{,}414$ $\sqrt{2} = 1.41$.

Finally it may be noted that in this case also, for same reason addressed when discussing benefit over PER of linear trading, the described benefit on minimum safe distance holds in general for all communication protocols and not only for WiMAX.

Benefits of increasing Ton and Toff.

Another important conclusion coming out from Figures A.2 and A.3 is that, by increasing T_{on} and T_{off} and keeping same duty cycle, PER is reduced. Hence there is no need to limit T_{on} and T_{off} once LDC has been established: on the contrary, given a predefined LDC, better PER is achieved as T_{on} and T_{off} increase, as it may be seen straightforward either from Figures A.2 and A.3.

It is easy to explain this behaviour: with reference to Figure A.1: suppose a certain DC has been defined, let T_{period} be the repetition time for the interferer transmission, let T_{DD} be the repetition time for the victim transmission, and let T_{frame} be the duration of the victim frames; assume now $T_{on} >> T_{frame}$, and $T_{period} >> T_{DD}$: in this limit case it is clear that they will exist a lot of victim frames within T_{on}, colliding with jammer frames; on the other hand there will exist a lot of victim frames within T_{off}, and these will not collide against jamming frames: therefore colliding and not colliding frames will be distributed proportionally to T_{on} and T_{off} respectively, as long as T_{period} increases with respect T_{DD}. The situation is shown in Figure A.4.

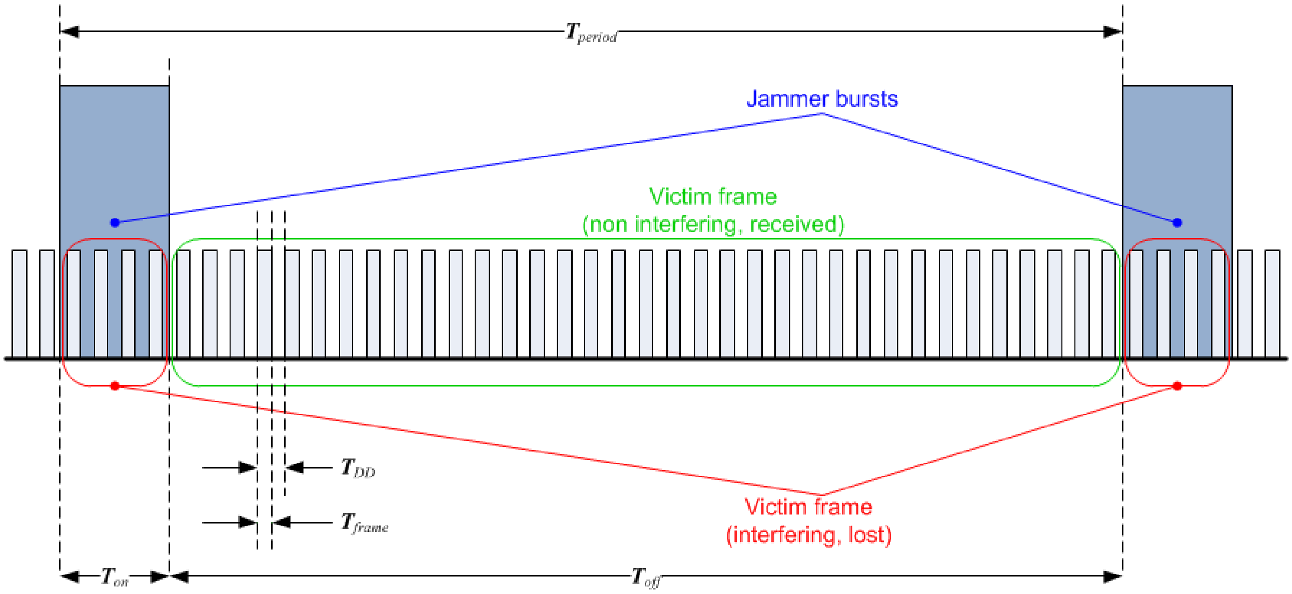


Figure A.4: Collisions when $T_{on} >> T_{frame}$, and $T_{period} >> T_{DD}$: PoC = T_{on}/T_{period}

On the other hand, as long as T_{period}, decreases with respect to T_{DD}, the probability of collision increases, and it becomes 100 % when $T_{period} << T_{DD}$ and $T_{on} << T_{frame}$ accordingly: this is the worst case, since no victim frame is free of collisions anymore. This is shown in Figure A.5.

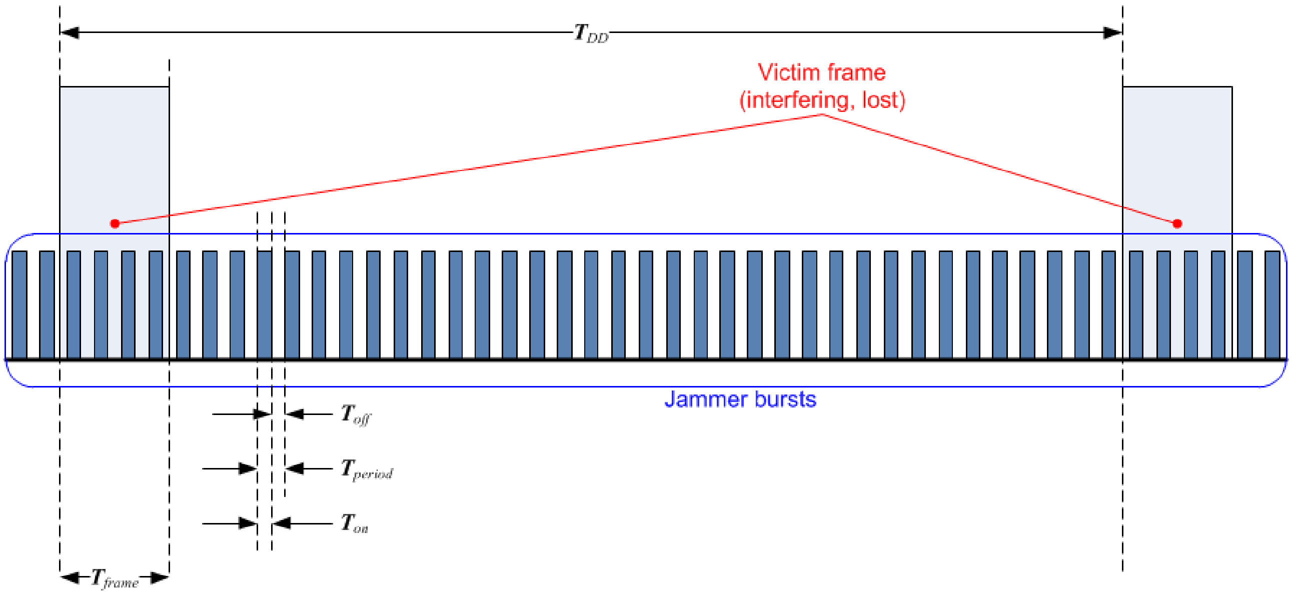


Figure A.5: Collisions when $T_{on} << T_{frame}$, and $T_{period} << T_{DD}$: PoC = 100 %

Hence, given a predefined duty cycle LDC for the jamming link, probability of collision tends from 100 % to LDC as T_{period} increases from values lower or comparable to T_{DD} to values much higher than T_{DD}. Finally, for the probability of collision, say PoC, the following equations hold:

$$\min\{PoC(T_{on}, T_{period}, T_{DD}, T_{frame})\} = 100\%, \qquad \frac{T_{DD}}{T_{period}} >> 1$$

$$\min\{PoC(T_{on}, T_{period}, T_{DD}, T_{frame})\} = \frac{T_{on}}{T_{period}} = LDC, \qquad \frac{T_{DD}}{T_{period}} << 1 \text{ and } \frac{T_{frame}}{T_{on}} << 1 \tag{A.1}$$

where the equality has to be intended in a convergence sense.

In general, once a collision occurs, the probability of losing the colliding victim packet is not 100 % but it is a function of SIR: hence the probability of losing a packet in presence of collisions is given by the probability of collision, PoC, multiplied by the PER in function of SIR when LDC=100 %, i.e. the values that may be achieved by the dotted curve in Figure A.2: this special PER value will be denoted as PLCP(SIR). Therefore, taking into account these two probabilities, and reminding equations (A.1), the following equations hold for PER, in function of SIR, T_{on}, T_{off}, T_{period} and T_{DD}:

$$\min(PER) = PLCP(SIR), \qquad \frac{T_{DD}}{T_{period}} >> 1$$

$$\min(PER) = \frac{T_{on}}{T_{period}} * PLCP(SIR) = LDC * PLCP(SIR), \qquad \frac{T_{DD}}{T_{period}} << 1 \text{ and } \frac{T_{frame}}{T_{on}} << 1 \tag{A.2}$$

It is needed to highlight here that, even in absence of collisions, the PER will not be null due to the thermal noise floor. Hence, in general, previous equations hold when the PER in function of SIR is significantly lower than the PER in function of the noise floor, i.e. when the jamming signal power within the victim frequency band is sufficiently higher than the thermal noise floor.

It is worth noting how the very simple arguments leading to (A.2) provide a very good qualitative explanation of the curves shown in Figure A.2: in fact, the more the T_{period} (i.e. $T_{on} + T_{off}$) decreases, the more the PER increases towards a maximum boundary, the dotted line, representing the PER versus SIR curve reached when LDC = 100 %, i.e. continuously tramsitting UWB; on the other hand, the more the T_{period} increases, the more all curves tend to reach same limit, and this limit depends only on SIR and selected LDC.

Finally it should be noted that the conclusions reported in this clause are based only on the generic behavior of two periodic links interfering each other. Therefore it is straightforward to understand that **arguments exposed herein hold for almost any couple of interferer/victim services based on periodic transmissions, and they are not only limited to WiMAX and UWB.**

A.4.2 High level description of the mathematical model used for evaluating LDC trading versus P_{tx} in the single interferer scenario

In order to get a better understanding of the described behaviors and furthermore a forecast about other cases not covered by [i.32], a mathematical model is needed, having the goal to explain the UDP packet loss versus SIR curves drawn in Figures A.2 and A.3, and, more generally, the experimental results described in [i.32].

The model basically implements equations (A.1) and (A.2), modified in a more appropriate form which may be found in clause B.1 (see equations (B.1), (B.2), (B.3) and (B.4)). From previous discussion it is clear that an important parameter required by the model is the probability of losing a colliding packet, namely PLPC (see equations (B.1), (B.2), (B.3) and (B.4)), i.e. the probability that a packet of the victim service, colliding against a packet of the jamming link, would get lost at the victim receiver side. It is worth noting that the PLPC influences the PER at PHY layer (i.e. the PER involved in equations (A.1) and (A.2)), and in its turn the PER at PHY layer influences the PER at UDP layer (depending e.g. on how many PHY layers packet are used for transmitting a single UDP packet), therefore it may be indirectly computed by the UDP PER, available from [i.32].

Moreover, parameters like T_{DD} and T_{frame} are implied in equations (A.1) and (A.2), according to WiMAX standard and compliant with the experimental setting described in [i.32] are required by the model.

Retrieving all this information is not trivial, because these are related to low level PHY layers parameters, and they are REF_MOBILEWIMAX_PARTInot fully described in [i.32] mainly describes higher layers parameters, like UDP throughput and QoS of UDP and TCP protocols, and no information is available about the low level performances of the WiMAX at PHY layers.

Being the access to PLPC, T_{DD} and T_{frame} not straightforward, an indirect evaluation of such parameters is required, starting from information available on the higher level protocol, like the measured UDP throughput (see e.g. Figure B.2 and Table B.1 in clause B.1.2) and other information available on WiMAX standard. In order to do this kind of evaluation, the model references some general parameters of the WiMAX PHY layer that may be retrieved in [i.33]. Details of this evaluation are described in clause B.1.1.

Once these parameters have been evaluated, the model needs a validation that may be achieved by verifying its capability to reproduce the curves in Figure A.2. The comparison of simulation results against JRC experimental data is shown in Figure A.6: the good matching may be seen achieved with respect to results shown in Figure A.2.

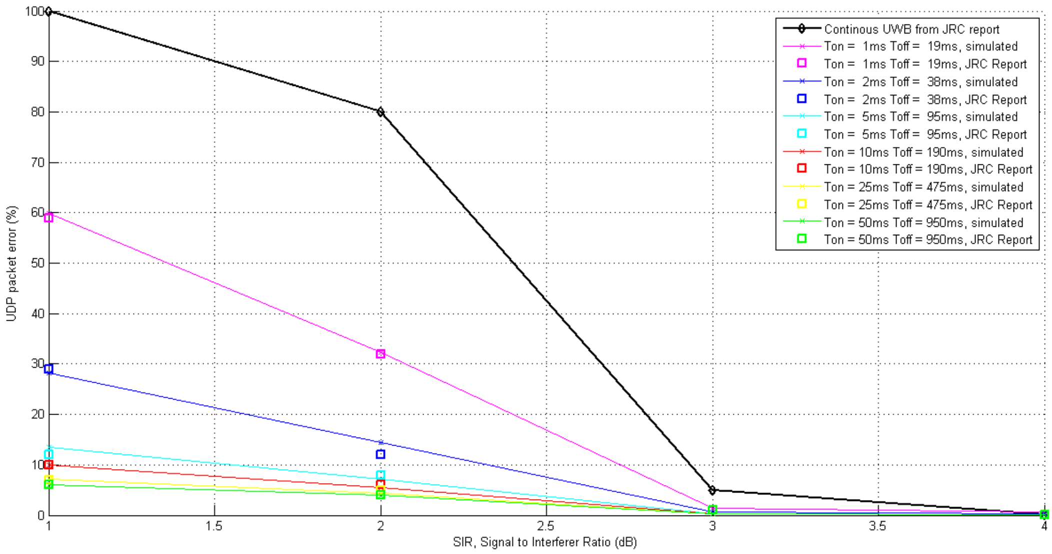


Figure A.6: Simulations results of WiMAX UDP PER versus SIR, 5 % of duty cycle, compared against the relevant experimental data from [i.32]

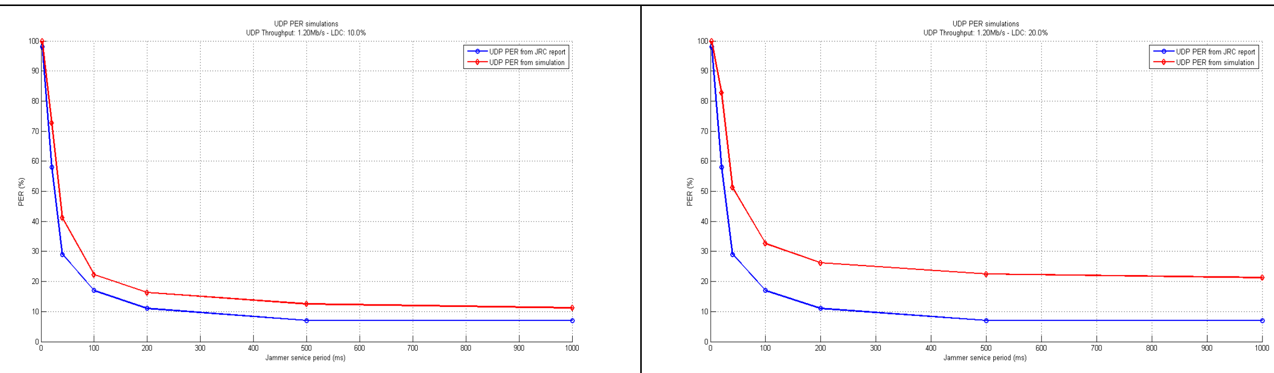
Given this good matching, it may be concluded that the model is validated and it may be extended to cases not covered by [i.32].

Further details about this single interferer scenario mathematical model are provided in Annex B.

A.4.3 Simulations results of trading LDC against TX power in single interferer scenario

By adopting the model described in clause A.4.2 and, in more detail in clause B.1, new cases may be analyzed not covered by [i.32], like increasing duty cycle values from 5 % up to 50 %.

In Figure A.7 the cases of LDC = 10 % and LDC = 20 % and SIR = 1,0 dB are shown: given this low SIR level, it is assumed PLPC = 100 % at PHY layer.



(a) (b)

Figure A.7: Simulation results for LDC = 10 % (a) and LDC = 20 % (b), SIR = 1,0 dB (PLCP = 100 %) (PER data from JRC report are related only to DC = 5 %)

Both these figures demonstrate that, **given a predefined LDC, PER is decreased as far as T_{period} is increased**. This confirms what was already observed, i.e. once the victim service T_{period} is known, and the jamming service LDC, there are no further advantages in limiting T_{on}: **the greater T_{period} and LDC are established, and T_{on} and T_{off} accordingly, the better PER will be achieved at victim link**. This better achievable PER value is equal to T_{on}/T_{period}, i.e. the jammer duty cycle itself.

On the other hand, from these figures one should note that the possibility to increase LDC has a drawback for this single interference scenario: in fact it can be noted that when LDC = 10 %, the best achievable PER is ≈ 10 %; when LDC = 20 %, the best achievable PER is ≈ 20 %.

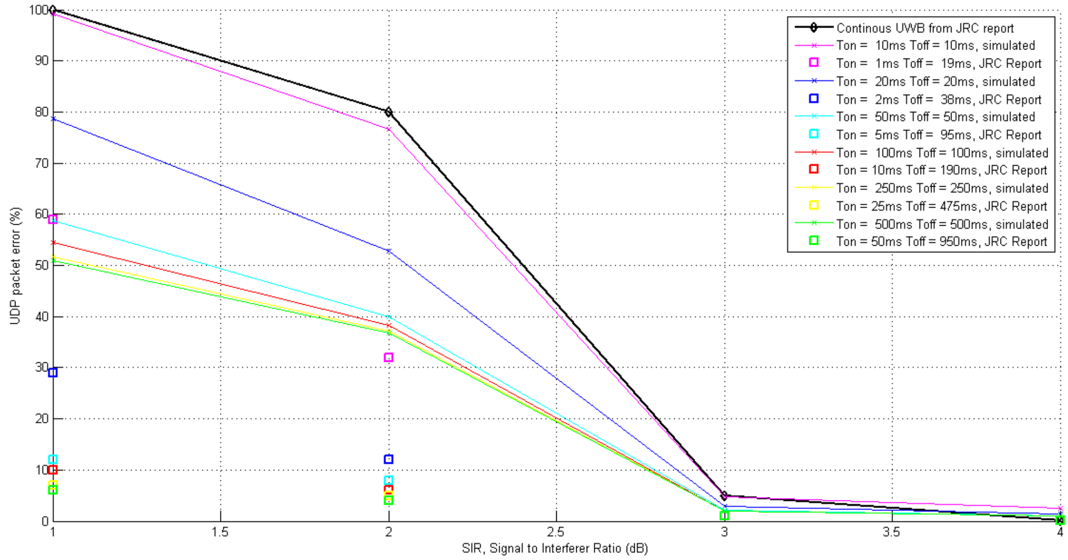
This is expected from equations (A.2) and (B.4) at very low SIR values: best PER cannot be lower than jammer duty cycle, under the assumption of low SIR such that PLPC ≈ 100 % and PLPC(SIR) ≈ 100 %.

This behavior is due to the fact that the presented cases are worst cases such that the probability of losing a frame given a collision is the highest one. In the more general case the very sharp PER reduction due to SIR reduction even of few dB - as described in clause A.4.1 - should be taken into account: and the limit toward which the PER tends, as long as T_{on} increases, is PLPC(SIR)×LDC, as described in equation (A.2). Therefore, in case PLPC(SIR) < 100 % the whole PER will be significantly reduced.

In order to highlight how strongly the increasing of SIR affects the decreasing of PER let us now consider a new case, i.e. the case of LDC=50 %, that may be considered a kind of "worst case duty cycle". It is worth noting that there are no data in [i.32] and [i.8], covering this case.

According to equation (A.2), the best PER would be not lower than 50 % when SIR=1,0 dB. In Figure A.8 simulation results are shown for SIR=1,0 dB to 4,0 dB and duty cycle =50 %: it is seen that a 50 % duty cycle greatly increases the value of PER with respect to 5 % (squared dots, JRC experimental results). However this is true only at SIR values between 1,0 dB and 2,0 dB: when the SIR decreases below 3,0 dB, the UDP PER decreases below 5 %. This is the straightforward consequence of the fact that PER for the continuous jammer (dotted line, i.e. Duty Cycle = 100 %) is an upper bound for any other duty cycle value.

These data confirm that increasing the SIR, i.e. reducing the TX power, allows increasing the LDC even beyond a pure linear law.



NOTE: Experimental data (square dots) are extracted from [i.32].

Figure A.8: Simulation results of WiMAX UDP PER versus UWB interference, 50 % of duty cycle

A.4.4 Conclusion about single interferer scenario

From the analysis presented in JRC Report [i.32] a mathematical model has been built and validated against data therein presented. The model provides good matches with true experimental data included in this report. Although the model is built by starting from experimental results reported in [i.32], i.e. an experiment where the victim service is a WiMAX link, it is based on very simple and general assumptions, and the general conclusions may be applied to any kind of periodic transmission interfering each other and different than WiMAX.

The model and the related simulation results demonstrate that, for a single interferer scenario, trading of transmitted power against LDC linear in dB is admissible and even advantageous. The main reason for this is given by the fact that the probability of destroying a packet after a collision is not always 100 % and, moreover, it is not an absolute quantity: it depends on the SIR, therefore it depends on the power transmitted by the jammer: the lower the power transmitted by the jammer, the higher duty cycle is admissible, in order to keep same performances.

Therefore, in a single interferer scenario, a linear trading of PSD against LDC linearly in dB gives even a meaningful reduction of interferer power at victim side, providing two kind of benefits:

- Proportional decreasing of the minimum safe distance, that may be reduced by about 30 % each time the duty cycle is doubled and the transmitted power is reduced by 3 dB (see Table A.1).
- Strong reduction of PER at victim side, due to the fact that varying the SIR by very few dB the PER varies from its best case to its worst case (within a range of 1 dB to 4 dB see Figures A.2 and A.3, extracted from [i.32]. This is a general PER behavior, and it holds for most telecommunication protocol: this is due to the fact that the PER varies almost exponentially with the BER, thus exhibiting an "almost threshold" effect.

A second important conclusion achieved by means of the presented analysis is that, once a specific LDC has been stated and a predefined SIR is given, the best PER is achieved when (T_{on}+T_{off}) increases. This result was the conclusion of the theoretical analysis, and it was experimentally derived in ECC Report 170 [i.8], Annex 5, clause 3, or JRC Report [i.32] (those are the same information).

This is due to the fact that PER at receiver side depends on four parameters (see equations (A.2) and (A.3), in this annex, and equations (B.1), (B.2), (B.3) and (B.4) in Annex B):

- The jammer link duty cycle, LDC.
- The ratio between victim frames duration and the jamming frame repetition time.
- The ratio between victim frame repetition time and the jamming frame repetition time.

- The signal to interferer ratio, SIR.

There are no other parameters affecting the PER, at least as main observable effects.

Therefore there is no advantage in limiting T_{on} and T_{off} and LDC, all together: it is only needed to limit LDC and the transmitter power accordingly.

A.5 Aggregated scenario analysis

A.5.1 Introduction

In the aggregated scenario, a plurality of emitters is affecting a single victim receiver.

At a first level of approximation, the effect of duty cycle mitigation results in an average PSD reduction pro rata. In fact, it is straightforward that, under the assumption of a "perfect" average of many transmitters, each transmitting a predefined maximum power level, say $P_{tx}(n)$, and each adopting a predefined duty cycle limit, say LDC(n), the average power is a weighted sum of all transmitted powers, i.e.

$$P_{txavg} = \sum_{n=1}^{N} LDC(n) P_{tx}(n) \tag{A.3}$$

This equation only requires assuming the transmitters to be **uncorrelated each other**, thus each transmitted signal is statistically independent from any other transmitted signal and, moreover, the observation time at receiver side, i.e. **the integration time should be sufficiently longer than T_{period} of each single emitter**. These assumptions are commonly adopted in spectrum analyses documents currently available. In those cased the T_{on} and T_{off} intervals inserted by each single interferer disappear, producing a whole signals average and causing a relevant reduction of whole PSD.

Therefore in this scenario the meaningful parameter related to the interferer aggregated field is the whole averaged PSD, being LDC included in this computation. Hence, the meaningful limitation to impose over each single interferer is the limitation of maximum and averaged PSD, and not duty cycle limitations: **should any LDC limitations be imposed, they can be converted in dB attenuation, decreasing the whole averaged interferer PSD**. Moreover, according to this principle, **should the PSD limit of each interfering device be decreased, the LDC limit might be indeed increased accordingly, without any additional impact over the aggregate PSD and the global link quality**.

A clear example of this point and related protection criteria applicable to an aggregated scenario are provided in [i.7] and [i.34], related to Radio Astronomy Services (RAS): in fact, in [i.34] protection criteria for RAS is stated as minimum interference power threshold, computed by integrating the interfering signal over a time window of 2 000 seconds, without any mentioning of duty cycle characteristics at transmitter side, and this is shown in Table A.3. Moreover, in [i.7] Duty Cycle mitigation is mentioned but it is transformed in attenuation dB, lowering the maximum interference level, as reported in Table A.2.

Therefore, it is important to notice that the point related to LDC evaluation in aggregated scenario is not how to compute the average power of many uncorrelated transmitters, that would be an almost trivial computation by means of equation (A.3). Rather than this, the phenomenon in the time domain needs to be analyzed in order to understand whether the cumulative effects of aggregated scenario might leave a victim service enough time free of jammer to successfully complete its transmission.

The situation is described well in Figure A.9: the red signal is the jammer signal aggregated from many interferers, each using a predefined duty cycle. When the signal is summed over all jammers, the signal provides a time behavior with peaks of signal interleaved with intervals free of interference. These last intervals may be used for successful transmissions by the victim service and they are the key for understanding effectiveness of LDC.

Such kinds of effects of LDC in the time domain will be analysed in detail.

Table A.2: Protection criteria for radio Astronomy Services stated in Recommendation ITU-R RA 769-2 [i.30]

Frequency f (MHz)	Assumed spectral line channel bandwidth Δf (kHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity[(2)] (noise fluctuations)		Threshold interference levels[(1) (2)]		
				Temperature ΔT (mK)	Power spectral density ΔP_S (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m²))	Spectral pfd S_H (dB(W/(m² · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
327	10	40	60	22.3	–245	–215	–204	–244
1 420	20	12	10	3.48	–253	–220	–196	–239
1 612	20	12	10	3.48	–253	–220	–194	–238
1 665	20	12	10	3.48	–253	–220	–194	–237
4 830	50	12	10	2.20	–255	–218	–183	–230
14 488	150	15	15	1.73	–256	–214	–169	–221
22 200	250	35	30	2.91	–254	–210	–162	–216
23 700	250	35	30	2.91	–254	–210	–161	–215
43 000	500	25	65	2.84	–254	–207	–153	–210
48 000	500	30	65	3.00	–254	–207	–152	–209
88 600	1 000	12	30	0.94	–259	–209	–148	–208
150 000	1 000	14	30	0.98	–259	–209	–144	–204
220 000	1 000	20	43	1.41	–257	–207	–139	–199
265 000	1 000	25	50	1.68	–256	–206	–137	–197

* This Table is not intended to give a complete list of spectral-line bands, but only representative examples throughout the spectrum.

(1) An integration time of 2 000 s has been assumed; if integration times of 15 min, 1 h, 2 h, 5 h or 10 h are used, the relevant values in the Table should be adjusted by +1.7, –1.3, –2.8, –4.8 or –6.3 dB respectively.

(2) The interference levels given are those which apply for measurements of the total power received by a single antenna. Less stringent levels may be appropriate for other types of measurements, as discussed in § 2.2. For transmitters in the GSO, it is desirable that the levels need to be adjusted by –15 dB, as explained in § 2.1.

Table A.3: Mitigations for RAS single entry scenario (a) and aggregated scenario (b) in ECC Report 123 [i.7]

Mitigations	Application B: non fixed	Application A: fixed
Additional wall attenuation	0 dB	0 dB
Duty Cycle 10%	10 dB	0 dB
TPC (not always activated)	0 dB	1.1 dB
ODC Elevation pattern from -20 to +30°	0dB	20 dB
sum of mitigations	**10 dB**	**21.1 dB**

(a)

Mitigations	Application B: non fixed	Application A: fixed
Additional TRP limitation	10 dB	0 dB
Additional wall attenuation	7.4 dB	7.4 dB
TPC	0 dB	1.1 dB
Duty Cycle 10%	10 dB	0 dB
ODC Elevation pattern from -10 to +30°	0dB	20 dB
sum of mitigations	**27.4 dB**	**28.5 dB**

(b)

A.5.2 High level description of the mathematical model used for evaluating LDC versus P_{tx} trading in the aggregated interferer scenario

In this clause a time domain model for evaluating impact of LDC in an aggregated scenario is defined. The model is herein described at high level, further details may be retrieved in Annex B.

A typical aggregate signal from many transmitters using LDC mitigation is shown in Figure A.9: it is basically a sequence of peaks separated by some "silence" windows. These last may be used by the victim service for successful transmissions.

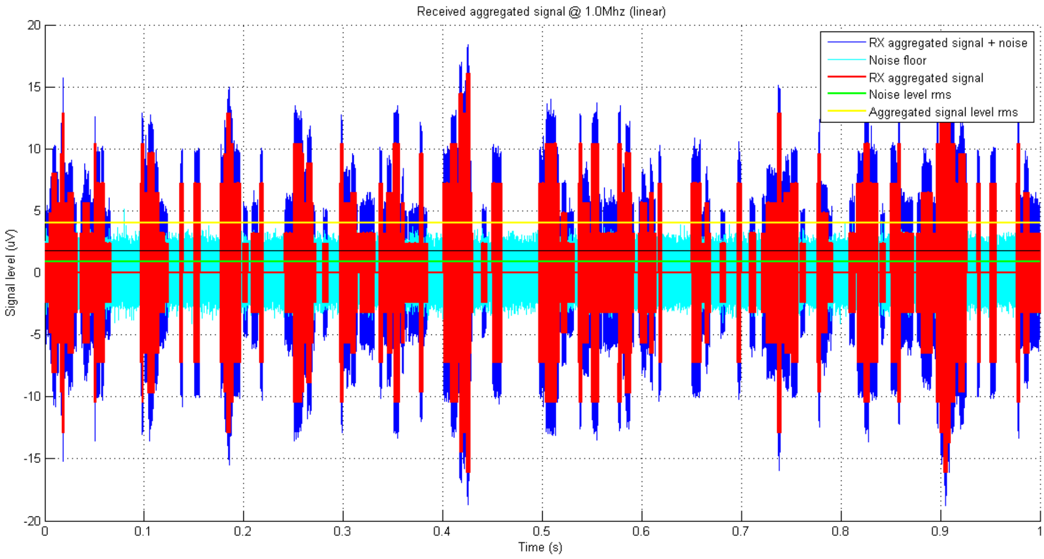


Figure A.9: Example of aggregate transmission at 1,0 MHz victim receiverTransmissions may occur when the aggregated signal (red) is below V_{guard} and they cannot occur in other time intervals

In general, a condition for the victim service to successfully complete its transmission is that the aggregate signal does not exceed a predefined threshold level, and this should happen for a predefined time interval sufficient to guarantee the transmission of a complete frame. This definition is formally stated in Annex B by means of equations (B.8), (B.9) and (B.10) which are used to build the model allowing evaluation of aggregate interference.

Assuming therefore to be able to measure such clean windows available for the victim frame transmissions, let us consider a predefined observation interval, say T_{obs}, and suppose to find N clean windows within T_{obs}; let ΔT_k be the related time durations. For a given victim service a "transmission time availability ratio", say Q_a, is defined as follows:

$$Q_a = \frac{\sum_{k=1}^{N} \Delta T_k}{T_{obs}} \tag{A.4}$$

In case $T_{guard} = 0$, this parameter will be called an "absolute availability ratio", say Q_{aa}; in case $T_{guard} > 0$, this parameter is called a "relative availability ratio" (i.e. relative to T_{guard}), say Q_{ar}. Note that in general $Q_{aa} \geq Q_{ar}$.

These two parameters, Q_{ar} and Q_{aa}, provide a benchmark to measure the performance degradation in the time domain when a jammer is affecting a victim service. The evaluation of trading PSD against LDC will be based on these parameters: first, the transmission availability ratios are calculated, by applying current regulations, i.e. PSD = -41,3 dBm/MHz and LDC = 5 %, and the achieved values for Q_{aa} and Q_{ar} will be considered a benchmark. Then LDC is increased up to 50 %, and PSD is decreased until similar values of Q_{aa} and/or Q_{ar} are satisfied. The results will be compared against the desired trading law, i.e. decreasing PSD and increasing LDC accordingly, linearly in dB.

To complete the model, some scenarios defining how the transmitter are spread around the victim receiver are required. The presented model uses two different scenarios, a high density scenario and a lower density scenario:

- The **high density scenario** assumes a set of 64 interfering transmitters distributed over a small square grid, having 32 m side (i.e. about 1 000 m^2). The resulting density is 1 transmitter per 16 m^2. This may be a likely distribution for an office, an industrial plant, etc.

- The **lower density scenario** assumes the transmitters are distributed on concentric rings, over a whole circular area of about 1,0 Km^2, populated by means of a whole of 5 000 transmitters. The resulting density is 1 transmitter each 200 square meters. This may be considered a likely distribution for outdoor scenarios.

Further details about these scenarios are reported in Annex B.

Montecarlo simulations were performed over both scenarios; in the simulations some parameters where fixed, while other parameters were randomly changed at each simulation run.

Fixed parameters are:

- Transmitted power: it has been assumed each emitter transmits the maximum power allowed by UWB regulation, i.e. -41,3 dBm for current regulations, or the proposed PSD value when simulating other proposed PSD.

- Bandwidth: it has been assumed 500 MHz, in all simulations. Hence each transmitter is assumed to transmit -14,3 dBm in case of current regulation.

- LDC: all transmitters are supposed to use same LDC.

- T_{guard} and $V_{guard.}$

- Position on the grid for high density distribution scenario: no randomization is adopted for transmitters positions on grid.

Non fixed parameters, changed at each Montecarlo run, are:

- T_{on} and T_{off}: providing that each device satisfies the selected LDC limit, T_{on} and T_{off} are changed from device to device and from simulation to simulation. However T_{off} are generated such to provide 38 ms mean value, according to current regulations. Moreover, a minimum T_{off}, of 1,0 ms has been imposed.

- Position on the rings for low density distribution scenario: a randomization of 25 % of minimum distance from the victim has been adopted with respect to default nodes position. This means that, in case a node is placed by default on the n-th ring, it may be randomly moved by 25 % of distance existing between the victim and the nearest node.

For all simulations, a value of 1,0 ms has been adopted for T_{guard}, both in high density and low density scenario. The noise floor has been computed according to the well-known formula:

$$V_n = \sqrt{4\pi k_b T_o R_o B_w} \tag{A.5}$$

where a 50 ohm impedance has been adopted both for the radio links and the noise; finally, simulations consider a 24°C environment temperature.

A.5.3 Simulation results and analysis in high density scenario (grid)

In this case, the threshold level V_{guard} has been set at noise floor plus 6 dB; moreover, 100 loops have been simulated for each analyzed PSD value. Results are provided in Table A.4.

It is seen that trading PSD against LDC linearly in dB guarantees almost equivalence with the standard case of 5 % and PSD=-41,3 dBm/MHz, within 2,2 dB tolerance. Note that in this emitters distribution there are 4 nodes at same minimum distance from the victim, namely 2,8 m (see Annex B, Figure B.4). Moreover, this scenario results very dense, and can be considered a worst case.

Table A.4: Simulation results related to different possible regulations for high density scenario

LDC	PSD dBm/MHz	PSD difference wrt linear trading (dB)	mean(Q_{aa})	std(Q_{aa})	mean(Q_{ar})	std(Q_{ar})
5 %	-41,3	0,0	54,4 %	2,2 %	48,0 %	3,5 %
10 %	-45,0	-0,7	52,5 %	1,8 %	49,0 %	3,0 %
20 %	-49,5	-2,2	51,8 %	1,0 %	49,5 %	1,6 %
40 %	-52,5	-2,2	51,0 %	0,9 %	49,8 %	2,2 %
50 %	-53,5	-2,2	52,7 %	0,7 %	51,8 %	0,8 %

NOTE 1: Emitters are spaced over a grid at 4,0 m from each other, and 4 emitters at 2,8 m minimum distance from the victim.

NOTE 2: T_{guard}=1,0 ms, V_{guard} =Noise Floor + 6dB. Green row represents current regulations.

In Table A.5 the grid spacing and the protection criterion have been changed: the emitters are placed at a distance of 14,1 m from each other. This corresponds to a minimum distance from the victim of 10 m. On the other hand, the protection criterion has been set at same level as noise floor, i.e. 6,0 dB lower than in previous case.

It is seen that in this case, in order to keep same figures for Q_{aa} and Q_{ar}, no additional attenuation is needed in addition to the linear trading in dB: on the contrary, **in this case values of Q_{aa} and Q_{ar} are even improved by trading PSD against LDC linearly in dB**.

It should be noted that in this case the emitter density is about 1 emitter each 200 m^2. Thus this cannot exactly be defined as a "high density scenario", since the emitters density is comparable to the lower density scenario.

Table A.5: Simulation results related to different possible regulations for high density scenario

LDC	PSD dBm/MHz	PSD difference wrt linear trading (dB)	mean(Q_{aa})	std(Q_{aa})	mean(Q_{ar})	std(Q_{ar})
5 %	-41,3	0,0	81,6 %	1,9 %	80,8 %	2,3 %
10 %	-44,3	0,0	**88,5 %**	1,1 %	**87,5 %**	1,3 %
20 %	-47,3	0,0	**95,0 %**	0,6 %	**94,6 %**	1,4 %
40 %	-50,3	0,0	**99,9 %**	< 0,1 %	**99,9 %**	< 0,1 %
50 %	-51,3	0,0	**100 %**	< 0,1 %	**100 %**	< 0,1 %

NOTE 1: Emitters are spaced over a grid at 14,1 m from each other, and 4 emitters are placed at 10 m minimum distance from the victim.

NOTE 2: T_{guard}=1,0 ms, V_{guard} =Noise Floor level.

NOTE 3: Results highlighted in green show performances better than regulations currently in force.

A.5.4 Simulation results and analysis in lower density scenario (rings)

In this case, due to the great number of emitters considered per each simulation run, only 10 simulation runs have been considered for each analyzed case. Moreover, the distance of each transmitter from the victim node has been randomized. The amount of this randomization is ±25 % of minimum radius, this radius also being the distance between two consecutive rings. The threshold level, V_{guard}, has been set at noise floor level.

Table A.6 shows simulation results for 5 K emitters distributed over 1 km^2 area. It is seen that in this case trading the PSD against LDC linearly in dB guarantees almost equivalence with the standard case of 5 % and PSD = -41,3 dBm/MHz, within 1,1 dB tolerance. It is worth highlighting that this density corresponds to 5 times the density distribution of transmitter considered for rural or outdoor scenarios: in fact for that kind of scenario a density in the range of 1 000 transmitters per square kilometer is generally considered high (see e.g. [i.34]).

Table A.6: Simulation results related to different possible regulations for lower density scenario

			Mean(Q_{aa})	std(Q_{aa})	mean(Q_{ar})	std(Q_{ar})
LDC	PSD dBm/MHz	PSD difference wrt linear trading (dB)				
5 %	-41,3	0,0	75,9 %	1,8 %	73,6 %	2,1 %
10 %	-44,7	-0,4	74,7 %	0,8 %	73,1 %	0,8 %
20 %	-47,9	-0,6	75,0 %	1,6 %	74,6 %	2,0 %
40 %	-51,4	-1,1	74,3 %	0,4 %	73,7 %	0,4 %
50 %	-52,2	-0,9	76,6 %	0,7 %	76,0 %	0,7 %
NOTE 1: Emitter density is 1 emitter each 200 m^2, and 1 emitter is placed at 5,7 m minimum distance from the victim.						
NOTE 2: T_{guard}=1,0 ms, V_{guard} =Noise Floor level.						

In Table A.7 the emitter density has been lowered from 1 emitter per each 200 m^2 down to 1 emitter per each 1 000 m^2, thus 1 000 emitters over a whole area of 1 km^2 have been distributed. The V_{guard} has been lowered from noise floor level to 6 dB below the noise floor.

Table A.7: Simulation results related to different possible regulations for lower density scenario

			Mean(Q_{aa})	std(Q_{aa})	mean(Q_{ar})	std(Q_{ar})
LDC	PSD dBm/MHz	PSD difference wrt linear trading (dB)				
5 %	-41,3	0,0	86,1 %	1,7 %	85,5 %	1,8 %
10 %	-44,3	0,0	**87,4 %**	0,5 %	**87,0 %**	0,6 %
20 %	-48,2	-0,9	86,7 %	0,5 %	86,4 %	0,4 %
40 %	-50,3	0,0	**93,3 %**	0,5 %	**93,0 %**	0,5 %
50 %	-51,3	0,0	**99,7 %**	0,1 %	**99,7 %**	0,1 %
NOTE 1: Emitter density is 1 emitter each 1 000 m^2, and 1 emitters is placed at 12,8 m minimum distance from the victim.						
NOTE 2: T_{guard}=1,0 ms, V_{guard} =Noise Floor level - 6 dB.						
NOTE 3: Results highlighted in green show performances better than regulations currently in force.						

The results show that there is no need to decrease the PSD below the limits stated by the linear trading in dB, except the case of LDC = 20 %, where the PSD level sufficient to guarantee the required protection is 1,0 dB lower than the traded PSD. Furthermore, it is important to highlight that in this low density scenario values of Q_{aa} and Q_{ar} are generally improved.

From these simulations, it is seen that, in a very high density scenario, in order to provide same time free for transmission by increasing duty cycle, a law of PSD that differs a maximum of 2,2 dB from trading PSD against LDC linearly in dB could be adopted. This is well below the uncertainty of PSD measure, that are normally stated in the order of ±3 dB.

Moreover, **as the emitters density decreases, the law of PSD against LDC linearly trading in dB may even improve the whole average time available for transmission - i.e. Q_{aa} and Q_{ar} - at victim receiver side.** This may be viewed as the fact that, by decreasing the emitters density, only the nearest emitters to the victim are more and more relevant: hence, in the limit of emitters density per area decreasing toward zero, the case of single interfere scenario is approached, where the benefits of reducing PSD by trading with LDC where highlighted in previous clauses.

Finally, it may be concluded that a linear trading is admissible, within admissible measurement errors, and does not cause further observable degradation of victim services with respect to current regulations, but may even provide benefit at victim receiver side, depending on the emitters density.

A.5.5 Conclusions for aggregated interferer scenario

For aggregated interferers scenario, it is straightforward that analysis in the spectrum domain, based on the hypotheses of uncorrelated transmitter and integration time much higher than the jammer link frame period is perfectly consistent with trading of PSD against LDC linearly in dB (see equation (A.3)). Thus, the analysis of related potential issues needs to be made in the time domain.

To this end, a benchmark based on the percent of time available to the victim link to transmit has been defined (i.e. the percent of time the victim link sees an aggregate noise lower than a predefined threshold), and results have been simulated in different scenarios.

It is seen that for higher density scenarios (Tables A.5 and A.7), the difference between the benchmark and the trading of PSD against LDC linearly in dB are limited between -0,4 dB and -2,2 dB: these values are well below the measurement error admitted for RF tests, that typically may range ±3 dB.

Moreover, specifically from Tables A.5 and A.7, it is seen that when the emitters density decreases, and the minimum distance from the victim decreases accordingly, the percent of average time available for transmission (i.e. Qaa and Qar in those mentioned tables) may even be increased with respect to the situation stated by current rules in force.

Annex B: Details on the mathematical models used for the evaluation of trading LDC against transmitted power

B.1 Mathematical model for the single interferer scenario

In the following clauses the mathematical models used in Annex A are described in greater detail.

B.1.1 Model of interference between a single jammer transmission and a generic victim service

Let us consider the effects of a jamming burst transmission having a predefined duty cycle, say $LDC_{J,}$ against a generic victim wireless service. It is assumed that the two transmissions, the victim and the jammer, transmit frames having a predefined durations, at predefined time intervals. Both the jamming transmission and the victim service are characterized by a fixed packet duration, say T_{on} and T_{frame}, respectively, and a predefined repetition time of transmission, say T_{period} and T_{DD}. The situation is shown in Figure A.1.

Basing on these timing parameters, probability of collision and probability of losing frames will be evaluated. It is worth considering that assumptions for this model are very general, therefore they are applicable straightforward to a lot of practical cases (e.g. all periodic transmissions jamming each other).

In this model the frame duration and the inter-frame period of the jamming burst are such that T_{period}-T_{on} = T_{off}; finally, T_{DD} - T_{frame} = T_{IFS} is the inter-frame spacing between two consecutive frames transmitted by the victim link. No assumptions are made about T_{period} and T_{DD} for victim and jamming services, thus these variables may be constant or randomly distributed around their average values.

Let LDC_J be the jamming service duty cycle, and define a victim service duty cycle LDC_V, according to following equations:

$$LDC_J = \frac{T_{on}}{T_{on} + T_{off}} = \frac{T_{on}}{T_{period}} \tag{B.1}$$

$$LDC_V = \frac{T_{frame}}{T_{frame} + T_{IFS}} = \frac{T_{frame}}{T_{DD}} \tag{B.2}$$

In Figure A.1 can be seen a first frame from the victim link, that is free of collision, and a second frame, partially colliding with a victim burst. In order to calculate PER at victim receiver side, it is supposed that any victim frame is lost when it partially or fully collides against a jamming burst, whilst any frame free of collision is correctly received by the victim receiver side: this assumption represents the worst case, since in general there is a probability lower than 100 % of losing a service frame given a collision against a jammer frame, hence this hypothesis will be removed further.

Specifically, said $T_{start}(n)$ the instant of beginning of the n-th frame of victim link, conditions such that no collision occurs for the n-th frame are the following:

$$\begin{matrix} T_{start}(n) > hT_{period} + T_{on} \\ T_{start}(n) + T_{frame} < (h+1)T_{period} \end{matrix} , \forall n, h \tag{B.3}$$

Previous conditions may be rewritten as follows:

$$\begin{cases} \dfrac{T_{start}(n)}{T_{period}} > h + LDC_J \\ \dfrac{T_{start}(n)}{T_{period}} < h + 1 - \dfrac{T_{frame}}{T_{period}} \end{cases}, \qquad \forall n, h$$

(B.4)

Assuming some jitter may affect $T_{start}(n)$ with respect to its theoretical value - that would nominally be $n \times T_{DD}$ - conditions for avoiding collisions expressed by previous equations may be rewritten as follows:

$$\begin{cases} n\dfrac{T_{DD}}{T_{period}} + \dfrac{\Delta T(n)}{T_{period}} > h + LDC_J \\ n\dfrac{T_{DD}}{T_{period}} + \dfrac{\Delta T(n)}{T_{period}} < h - \dfrac{T_{frame}}{T_{period}} \end{cases}, \ \forall n, h$$

(B.5)

being $\Delta T(n)$ the jitter, i.e. a quantity that may be null or randomly distributed.

Probability that events described by equation (B.5) occur (i.e. no collision for the n-th victim packet) defines mathematical conditions for PER computation. Hence, given the statistical properties of the variable $\Delta T(n)$, it may be stated that *PER depends only on the jamming link duty cycle* LDC_J*, and on the ratios of the victim frames duration* T_{frame} *and the frame repetition time* T_{DD}*, referred to the jammer frame period* T_{period}. There are no other parameters truly affecting the PER in case of single interferer scenario. Hence, no separated T_{on} and T_{off} limitations are required: **limiting LDC and providing rules about T_{period} (e.g. to be greater than a predefined value) would be sufficient to protect a specific radio service, given the ratios T_{DD}/T_{period} and T_{frame}/T_{period}.**

Equation (B.5) allows computing an important parameter, namely the probability that a collision occurs between a victim frame and a jammer frame, PoC. This probability is therefore expressed only as function of LDC, and the ratios T_{DD}/T_{period} and T_{frame}/T_{period}:

$$PoC = f\left(LDC, \frac{T_{DD}}{T_{period}}, \frac{T_{frame}}{T_{period}}\right)$$

(B.6)

Furthermore, assuming that each collision produces the loss of the colliding packet, equation (B.5) allows calculating the PER.

It is important to highlight that *PER computation by means of equation* (B.5) *expresses a worst case condition*: in fact the assumption that that any packet collision produces the loss of a victim service packet, at 100 % of probability corresponds only to very low SIR values. In the reality the probability to lose a packet given a collision in general is not 100 %, and it may be very low at high SIR levels.

Equation (B.5) may be simulated in order to achieve probability of collision, PoC, and related packet error rate - under the highlighted limitations, given the jamming link duty cycle LDC_J, and the ratios T_{start}/T_{period}, and T_{frame}/T_{period}.

B.1.2 Validation of the model: matching and comparison with results of JRC report

The presented model is going to be applied now to results reported in [i.32] and [i.8], in order to get a validation of the model itself. This analysis required the usage of some characteristics of WiMAX protocol described in [i.33].

To apply the model to the experimental results, first it is considered that for WiMAX T_{DD} = 5 ms moreover, due to the fact that in the experiment described in [i.8] the WiMAX Downlink was configured at 29 symbols per each T_{DD} slot, given the WiMAX symbol time of 102,9 µs a PHY layer downlink frame of 102,9 µs × 29 = 2,98 ms is considered, repeated each 5 ms. Hence in the presented model it is assumed T_{frame} = 2,98 ms and T_{DD} = 5 ms.

Consider now that each UDP packet used in [i.32],for the test carried 1 470 bytes, thus, given the nominal throughput of 1,66 Mb/s, the time for transferring each UDP packets turns out to be 1 470×8/1,66 Mb/s=7,1ms. Considering 5 ms for transferring each WiMAX PHY packet, this means that an average of 1,42 WiMAX PHY packets for transferring 1 UDP packet, i.e. 7,1 ms/5 ms is needed. Thus, the conclusion is that some PHY packets include data of a single UDP packet, whilst other PHY packets include data of 2 UDP packets: in an average sense, one may say that about 142 PHY layer packets to carry 100 UDP packets are needed, and in an average sense, each 142 PHY packets 100 packets will carry information related to only 1 UDP packet, while 42 packets will carry information related to 2 UDP packets.

It may be noted that each time a PHY packet is lost, carrying information related to two UDP packets, 2 UDP packets are lost. Due to the fact that UDP does not use any acknowledgment, this means that UDP packet error rate will be higher than PHY packet error rate. This fact should be taken into account in the model when transforming PHY PER into UDP PER, that are not same quantities. In Figure B.1 this behavior is shown.

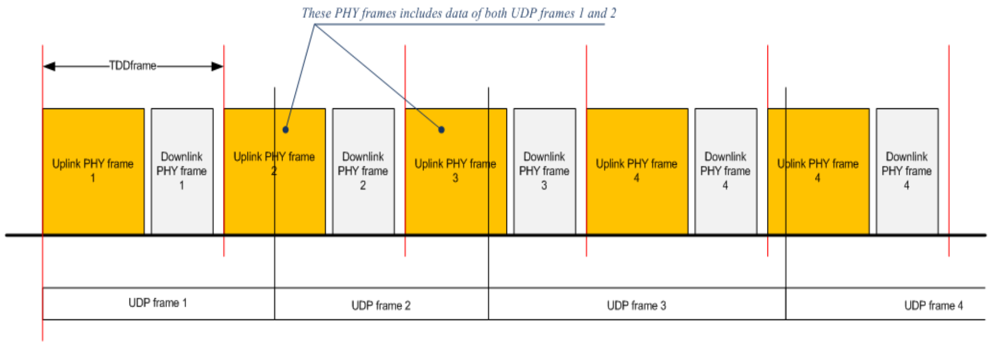


Figure B.1: Example of distribution of UDP frames over PHY frames

The model also requires information about the throughput used by UDP layer: in fact the UDP throughput determines how many PHY packets are included per each UDP packet, and this is very important when computing UDP PER from PHY PER. However the throughput effective values may vary, given the received signal strength (RSSI) and/or the kind of interference - i.e. T_{on} and T_{off}, as it may be seen from Figure B.2.

Measured throughput values are reported in Figure B.2 and Table B.1 (i.e. Figure 4 and Table 4 from [i.32]. In Table B.1 throughput are related to a received power (RSSI) of -90,6 dBm, by varying T_{on} and T_{off} at LDC=5 %; in Figure B.2 throughput is reported in function of the RSSI. Note that the best throughput resulted lower than the maximum achievable value of 1,66 Mb/s, achieved in absence of interferer when RSSI = -90,6 dBm: this is likely due QoS management that typically reduces throughput in presence of link performance degradations.

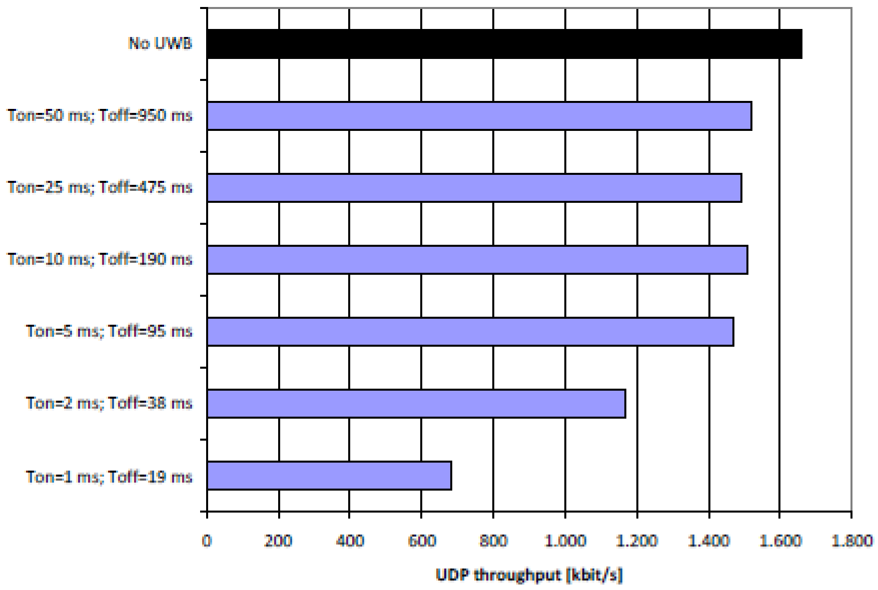


Figure B.2: WiMAX UDP throughput for different UWB LDC schemes, UWB distance = 0,5 m, RSSI = -90,6 dBm, (Figure 4 from [i.32])

Table B.1: WiMAX UDP throughput for different RSSI, Table 4 (from [i.32])

RSSI [dBm]	DL modulation/ FEC	UDP Throughput [Kbits/s]	FTP throughput [Kbits/s]
-91.2	QPSK-CTC-1/2	1660	643
-90.6	QPSK-CTC-1/2	1660	1638
-76.5	QPSK-CTC-3/4	2500	2341
-75.7	QAM16-CTC-1/2	3340	2979
-71.1	QAM16-CTC-3/4	5022	4681
-67.1	QAM64-CTC-2/3	6705	4681
-66.4	QAM64-CTC-3/4	7546	4681
-62.0	QAM64-CTC-5/6	8372	5461

Unfortunately, it is not straightforward getting the true throughput values the victim service was working with during the measurement campaign described in [i.32], and specifically for the test shown in Figures A.2 and A.3. In fact the throughput in Table B.1 have been measured at -90,6 dBm, whilst Figures A.2 anda A.3, are referred to RSSI = -84,6 dBm. Hence a guaranteed reproduction of data of Figure A.2 is not possible, due to lack of information about throughput involved in Figure A.2. In fact, being the RSSI at victim receiver side increased by 6 dB over the interferer signal level, it is likely to be assumed that during the experiment throughput was increased with respect to values reported in Table B.1.

This drawback will be resolved by searching the throughput values providing the best reproduction of Figure A.2 and verifying that they belong to a range of values consistent with data included in Figure B.2 and Table B.1.

To get a validation of the model described up to now, first, consider Figure A.2 and remind that for points corresponding to SIR < 1,0 dB each collision produces a packet loss. Hence the presented model should be able to reproduce these points.

In Table B.2, different simulation results achieved by the described model are reported and compared with true experimental results provided in [i.32], and namely the points corresponding to SIR = 1,0 in Figure A.2, at various throughput values. Each simulations where made over 2 millions of frame per each iteration, by assuming that a collision produces a loss of a packet with 100 % of probability.

Table B.2: WiMAX UDP packet loss in presence of UWB interference: comparison between experimental results from [i.32] and simulation results from the model described in the present document, LDC = 5 %, SIR = 1,0 dB

	Reference Values: JRC report [i.32], and ECC Report 170 [i.8] RSSI = -84,6 dBm	Simulations @ 1,45 Mb/s		Simulations @ same throughput than JRC report [i.32] and ECC Report 170 [i.8] for RSSI = -90,6 dBm		*Simulations @ throughput best matching data in JRC report [i.32] and ECC Report 170 [i.8]*	
				Mb/s	%	*Mb/s*	*%*
Ton = 50 ms, Toff = 950 ms	6,00 %	6,50 %		0,70	6,40 %	*0,70*	*6,10 %*
Ton = 25 ms, Toff = 4 750 ms	7,00 %	7,90 %		0,70	7,90 %	*0,85*	*7,20 %*
Ton = 10 ms, Toff = 190 ms	10,0 %	12,0 %		1,18	11,5 %	*1,50*	*9,90 %*
Ton = 5 ms, Toff = 95 ms	12,0 %	16,5 %		1,45	16,5 %	*2,30*	*13,50 %*
Ton = 2 ms, Toff = 38 ms	29,0 %	28,5 %		1,45	32,0 %	*2,30*	*28,10 %*
Ton = 1 ms, Toff = 19 ms	59,0 %	45,5 %		1,45	64,5 %	*2,30*	*59,40 %*
Ton = 0,1 ms, Toff = 1,9 ms	98,0 %	100 %		1,45	100 %	*2,30*	*100 %*

It may be seen that simulation results for a constant throughput=1,45 Mb/s (i.e. the maximum admitted for RSSI = -90,6 dBm in presence of interference) are not far from experimental results, reported in the first column of the table; same may be stated for simulation adopting throughput related to RSSI=-90,6 dBm. However, by increasing the throughput as reported in the last two columns of this table, the simulation results provide very accurate matching of the true UDP PER against simulated UDP PER: these columns have been built by increasing the values of throughput, as one could expect from the fact that RSSI in Figures A.2 and A.3 is -84,6 dBm. The estimated throughput values have been chosen optimizing the PER match.

Considering the values of throughput corresponding to -84,6 dBm in, i.e. 2,5 Mb/s without any interferer, and considering the decreasing of the throughput when T_{on} decreases, it is seen that the resulting values of throughput optimizing the PER matches - i.e. from 0,70 Mb/s to 2,30 Mb/s depending on T_{on} - are likely and consistent with the values reported in Figure B.2 and Table B.1, measured during the experimental campaign. Therefore it may be concluded that the built model provides results in good agreement with the experimental results in this case, i.e. SIR = 1,0 dB, when each collision produces a packet loss.

Now a step ahead is required, i.e. removing the hypothesis that each collision produces a packet loss, by considering that the true probability of losing a frame after a collision occurs is not 100 % but it is a function of SIR. To this end, it is needed to distinguish two different kind of packet error rates: the PER, i.e. the *global probability that the victim link loses a packet* given the characteristic of the victim and the jammer (i.e. SIR, T_{on}, T_{off}, T_{period} and T_{DD}), and the *probability of losing a frame when a collision occurs* given a predefined SIR; this last probability corresponds to the PER achieved when the victim is jammed at 100 % duty cycle and at the given SIR, i.e. the parameter PLCP(SIR) defined in clause A.5.2.

The PER turns out to be the product of the related probabilities, i.e. the PLCP in function of SIR and the probability of collision PoC in function of T_{on}, T_{off}, T_{period} and T_{DD}, introduced in previous paragraph, i.e. reminding equation (B.6):

$$PER_{tot} = PoC\left(LDC, \frac{T_{DD}}{T_{period}}, \frac{T_{frame}}{T_{period}} \right) * PLCP(SIR) \tag{B.7}$$

It may be noted that on one hand the term PER is provided by the dotted line in Figure A.2, on the other hand PoC may be derived by the model built on the basis of equation (B.5): hence the unknown term, i.e. PLCP, may be evaluated in a reverse way, by searching those values of PLCP, such that simulations provide the better match with the dotted line in Figure A.2, representing the PER_{whole}. Achieved results are reported in Table 41.

Table B.3: Reverse estimation of probability of losing a frame after a collision when no duty cycle limitation is adopted by the jammer, starting from UDP packet error rate

SIR	UDP packet error rate, PER_{whole} (dotted line in Figure A.2)	Probability of packet loss after a collision, *PLCP* (reverse evaluation)
1,0 dB	100 %	100 %
2,0 dB	80 %	48 %
3,0 dB	5,0 %	2,0 %
4,0 dB	1,0 %	< 1,0 %

The estimated PLCP may be introduced in the model according to equation (B.7) such to achieve PER values related to SIR other than 1,0.

In Figure A.6 (see Annex A) simulation results are shown related to the described model, extended to SIR = 1,0 dB, 2,0 dB, 3,0 dB, 4,0 dB, and the matching between experimental results shown in Figure A.2 and simulated results is good. Optimal throughput reported in last columns of Table B.2 were used, and probability of losing a frame given a collision listed in Table B.3 was used.

Given this very good match between the model and the experimental data, it may finally concluded that the model and the achieved settings are validated and it may be extend to cases not covered by [i.32].

B.2 Mathematical model for the aggregated scenario

B.2.1 Criterion for the evaluation of the trading of PSD against the LDC in an aggregated scenario

The analysis of the aggregated scenario requires establishing a criterion in the time domain that may be used as a benchmark for comparing different cases of trading. This criterion needs necessarily to be based on how much available time a victim receiver sees within an aggregated signal for a clean reception of the frames he is receiving. The situation has been shown in Figure A.9: the time available for a clean reception will be the sum of all time windows such that the level of the aggregated signal does not exceed a predefined protection threshold.

In order to formalize this criterion, let us consider a set of *M* jamming emitters, having a predefined spatial distribution. Each emitter transmits a signal in the form:

$$s_n(t) = u_n(t) V_o(n) \sum_{h=-\infty}^{+\infty} p\left(\frac{t - hT_{period}(n)}{T_{period}(n)}, LDC(n) \right) = V_o(n) u_n(t) q(t,n), \quad n=1,2,.....M \tag{B.8}$$

where:

- $u_n(t)$ are modulating continuous pulsed signals, having a given bandwidth and unitary emitted power.
- $V_o(n)$ are peak values of *n*-th signals, such to provide a given predefined average emitted power when the *n*-th device is continuously on.
- $p(x, \Lambda)$ is a rectangular pulse, having unitary duration, assuming a value 1,0 in the interval [0, Λ], Λ<1, and 0,0 in the interval (Λ,1,0).
- Consequently, $u_n(t)q(t,n)$ is a train of repeated pulses within a series of rectangular windows such that the ratio between sum of duration of active level and whole signal duration is $LDC(n)$.
- $T_{period}(n)$ is the period of transmission used by the n-th transmitter, i.e. T_{on}+T_{off}, and LDC(n) is the LDC used by the n-th transmitter, hence LDC(n) = T_{on}(n)/T_{period}(n).

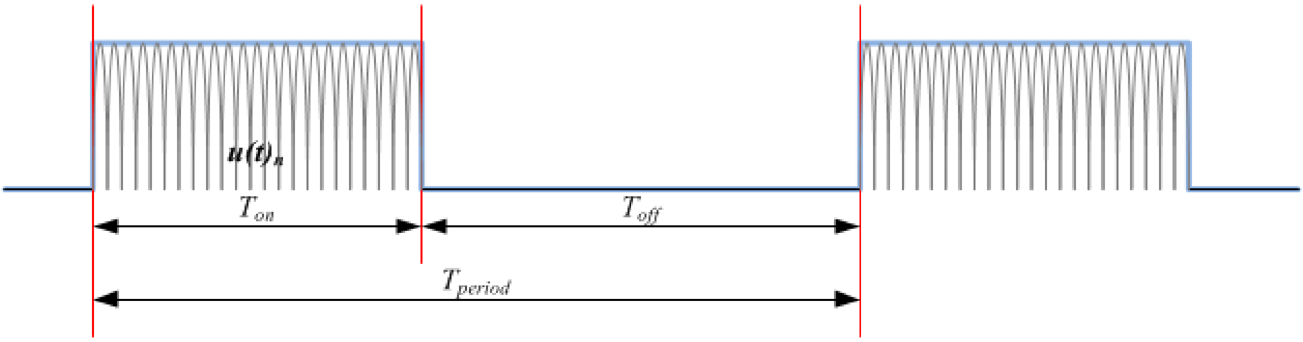


Figure B.3: Windowed-pulsed signal example for the aggregate mathematical model

For the goals of this analysis, in order to speed up simulations avoiding simulation steps in the magnitude of nanoseconds (i.e. inverse of a carrier located higher than 1,0 GHz) and usage of huge amount of RAM memories in the workstation, only the sum of all envelopes $q(t,n)$ over n is considered, say $q_{aggregate}(t)$. The summation of all envelopes is intended in a mean squared sense, i.e.:

$$q_{aggregate}(t) = \sqrt{\sum_{n=1}^{M} V_o^2(n) q^2(t,n)} \tag{B.9}$$

This is a methodology already used in [i.8] (see e.g. clause 4.3.4.2). It provides linear sum of transmitted signal powers, as it would be expected in a scenario where many uncorrelated transmitters were operating.

A sufficient condition to be imposed for guaranteeing that a victim frame transmission successfully occurs is that the aggregate jammer signal level, say $V_{aggregate}$, does not exceed a predefined threshold level, say V_{guard}, which typically is stated as a certain amount of dB with respect to the noise floor. Moreover, since frames of the victim service have a predefined duration, this condition is required for a minimum time interval, say T_{guard}, not lower than the victim frame duration.

Thus in the current analysis a formal criterion for evaluating the compatibility of an aggregate interference with respect to maximum interference requirements, acceptable by a victim service in order to be considered "clean" for transmission, is stated as follows:

- intervals such that $V_{aggregate}<V_{guard}$, and moreover having a duration not lower than T_{guard}, are considered "clean" and **available for transmission**: they are compatible with the victim link requirements;
- remaining intervals on the contrary will be considered not clean, **unavailable for transmission** and not compatible with the victim link requirements.

Therefore, a time window, say $[T_1,T_2]$, will be said to be *clean* or *available for transmission* only in case following equations hold:

$$\begin{aligned} &q_{aggregate}(t) \le V_{guard}, \qquad t \in [T_1, T_2], \\ &q_{aggregate}(t) > V_{guard}, \qquad t \notin [T_1, T_2] \\ &T_2 - T_1 = \Delta T \ge T_{guard} \end{aligned} \tag{B.10}$$

being V_{guard} and T_{guard} predefined parameters, defined such to allow a reliable link for the victim communication.

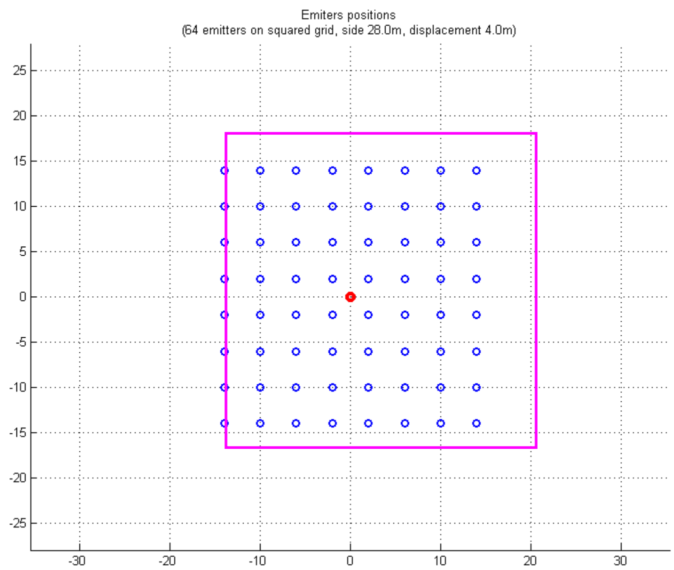
B.2.1 High density and low density aggregated scenarios

At this point of this analysis, it is worth highlighting that the present evaluation is based on a relative comparison of effects on indexes Q_a with respect to current regulations. Therefore the absolute results are not really needed: it is needed only to understand whether, given a predefined scenario, trading of PSD against LDC linearly in dB would not cause degradation of the reference parameter defined by equation (A.4). For this reason, a basic scenario, although realistic enough with respect to this goal, may be used as benchmark, and namely:

- propagation losses are provided by free space losses, no other kind of losses are considered;
- multipath are not considered;
- all antennas, transmitting and receiving, are omnidirectional.

There is no difficulty to improve this scenario by means of more realistic hypotheses, e.g. by introducing sophisticated propagation models, multipath models or antenna patterns different from omnidirectional. However in this step of analysis, although these more complex models might change the absolute results of simulations, it is not expected that these more complex hypotheses might affect the differences between simulation results related to current regulations and those related to other proposed regulations, being such relative differences the specific object of the current analysis.

As for the distribution of the jammer emitters, the following two scenarios are considered:

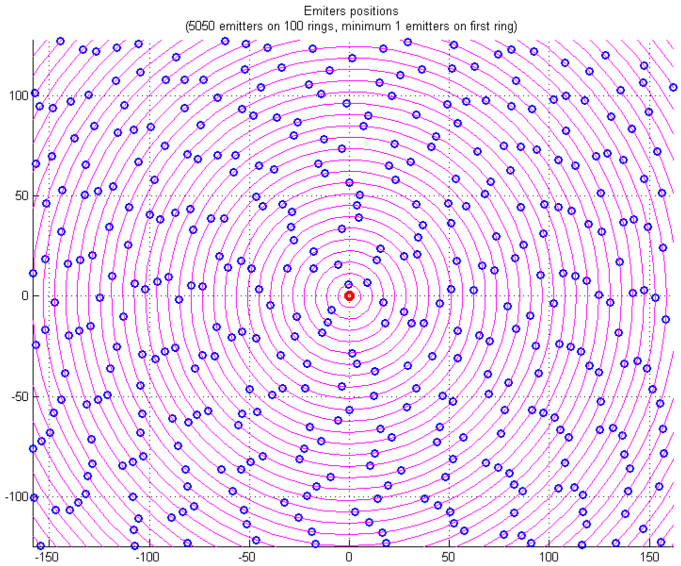


NOTE: Density of emitters is 1 device per 16 m2. The red point is the victim receiver.

Figure B.4: Transmitters distribution over a highly populated grid, used for simulating a transmitter density in indoor environments

Lower density scenario (rings, outdoor environment): This scenario is adopted to model a number of transmitters that may be aggregated when different users are spread over an unbounded outdoor space. This typically may be a rural area or a city (disregarding absorption by buildings). For this scenario it is assumed that transmitters are placed on a set of rings, over an area that may be up to 1,0 Km^2, i.e. 10^6 m^2, or even greater. A detail of this distribution is shown inFigure B.5. For this case, a circular area of about 1,0 Km^2 has been populated by means of 5 000 transmitters.

The placement of transmitters in this area is made according to UWBRings software provided by NTIA, described in [i.34] at clause 5.3, i.e. within this area, a suitable number of concentric rings have been considered at same distances from each other. On each ring a number of emitters proportional to the ring radius has been placed, starting from first ring - i.e. the nearest to the victim receiver - that contains only 1 transmitter. The victim receiver is placed in the center of the circular area. In this case the minimum distance between the victim receiver and the nearest jammer transmitter is about 5,6 m. The density of transmitters is about 1 each 200 square meters, or - it is the same - 5 000 per square kilometer, i.e. 12,5 times lower than in previous case.



NOTE 1: Density of emitters is 1 device per 200 m^2.
NOTE 2: The red point in center of all rings is the victim receiver.

Figure B.5: Low density transmitters distribution over a set of rings, used for simulating a transmitter density in outdoor environments

High density scenario (grid, indoor environment): This scenario is adopted to model a number of transmitters that may be aggregated when different users are collected in a bounded space, that may be a house, an open space office or a shed in a plant. For this scenario it is assumed that transmitters are placed on a "small" square grid, over an area about 1 000 m^2. This situation is shown in Figure B.4: the whole area over which transmitters are distributed is a square area having 32 m side length, such that the whole area is 1 024 m^2. A whole of 64 transmitters are considered, placed over the grid, at a distance of 4 m each other. The victim receiver is placed at center of this grid. In this case the minimum distance between the victim receiver and a jammer transmitter is about 2,8 m. There exist 4 transmitters at this minimum distance in the grid. The density of transmitters is about 1 transmitter each 16 m^2.

History

Document history		
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