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TECHNICAL REPORT

**Short Range Devices (SRD) using Ultra Wide Band (UWB);
Technical Report
Part 1: UWB signal characteristics
and overview CEPT/ECC and EC regulation**

Reference
DTR/ERM-TGUWB-007-1

Keywords
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 1 of a multi-part deliverable covering UWB signal characteristics and related mitigation techniques, as identified below:

Part 1: "UWB signal characteristics and overview CEPT&ECC and EC regulation";

Part 2: "UWB mitigation techniques";

Part 3: "World wide UWB regulation".

Modal verbs terminology

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

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Introduction

Ultra Wide Band (UWB) radio technology enables a new generation of location tracking systems and sensor devices as well as high-speed data devices for short range communication purposes.

It opens new markets with a variety of innovative applications.

UWB devices may form an integral part of other portable electronic equipment such as future generation cellular phones or laptops equipped with UWB enabled short range air interfaces.

In addition, UWB devices with an operating bandwidth of several hundreds of MHz up to several GHz allow tens of centimetre-level accuracy real time localization and positioning even in the presence of severe multipath effects caused by walls, furniture or any other harsh radio propagation environments.

It is a viable positioning and sensor technology that meets industrial requirements in the following markets:

1) Healthcare
2) Workplace/Smart Office
3) Public buildings
4) Security
5) Defence training
6) Entertainment
7) Logistics, warehouses
8) Manufacturing assembly lines
9) Road and rail vehicles sensor networks
10) Public transportation
11) Level Gauging
12) Professional ground- and wall probing

1 Scope

The present document summarize the available information about the typical transmission signal characteristics used by Ultra Wideband (UWB) devices, including the references to the relevant standards and CEPT/ECC and EC regulation framework.

Different frequency ranges have been identified or are under study for applications based on UWB technology:

Table 1: Overview UWB application in CEPT/ECC, EC and ETSI (with related Harmonised Standards)

Application	Frequency Ranges [GHz]	ETSI Standard	Remark
Generic, non-specific	3,1 to 4,8 6 to 9	ETSI EN 302 065-1 [i.23]	Former ETSI EN 302 065
Location Tracking below 10 GHz	3,1 to 4,8 6 to 9	ETSI EN 302 065-2 [i.24]	Location Tracking Type 2 (LT 2)
Location tracking called Type 1	6 to 9		Former ETSI EN 302 500 [i.62]
Location tracking called Type 2	3,1 to 4,8		
Location Application for emergency Services (LAES)	3,4 to 4,8		
Location Tracking for automotive & transportation environment (LTT)	3,1 to 4,8 6 to 8,5	ETSI EN 302 065-3 [i.25]	
Building Material Analysis (BMA)	2,2 to 8,5	ETSI EN 302 435 [i.19]	In the future covered by ETSI EN 302 065-4 [i.63]
Object Discrimination and Characterization (ODC)	2,2 to 8,5	ETSI EN 302 498 [i.21]	In the future covered by ETSI EN 302 065-4 [i.63]
Professional Ground- and Wall Probing Radars	0,030 to 12,4	ETSI EN 302 066 [i.20]	ETSI EG 202 730 [i.42]
Short Range Radar 24 GHz	21,65 to 26,65	ETSI EN 302 288	In progress, alternative option to use 24 GHz to 29 GHz frequency range
Long Range Radar 77 GHz	76 to 77	ETSI EN 301 091	Not listed as UWB but devices use signals with BW > 500 MHz
Short Range Radar 79 GHz	77 to 81	ETSI EN 302 264	
Tank Level Probing Radar (TLPR)	4,5 to 7 8,5 to 10,6 24,05 to 27 57 to 64 75 to 85	ETSI EN 302 372 [i.27]	
Level Probing Radars (LPR)	6,0 to 8,5 24,05 to 26,5 57 to 64 75 to 85	ETSI EN 302 729 [i.26]	

2 References

2.1 Normative 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 reference 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.

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

Not applicable.

2.2 Informative references

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

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

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

[i.1] 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/DEC/(06)04: "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.

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

[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 10: "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 9: "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 103 181-2 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB);Transmission characteristics; Part 2: UWB mitigation techniques".

[i.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 302065-3 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, Part 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, Part 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, Part 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 frequency 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, Part 1 and 2 (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, Part 1 and 2 (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] JRC: "Report on Radio Frequency Compatibility Measurements between UWB LDC Devices and Mobile WiMAX (IEEE 802.16e-2005) BWA Systems", July 26-27, 2010.

[i.33] Wimax Forum: "Mobile WiMAX - Part 1: A Technical Overview and Performance Evaluation", August, 2006.

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

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

[i.36] Joaquim Fortuny-Guasch: "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 0,85GHz and 11GHz, IPSC, October 2006.20.

[i.37] EC DEC on UWB (2014/702/EU): "Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC on allowing the use of the radio spectrum for equipment using ultra-wideband technology in a harmonised manner in the Community".

[i.38] ECC/REC(11)10: "Location tracking application for emergency and disaster situations", November 2011.

[i.39] ECC/REC(11)09: "UWB Location Tracking Systems TYPE 2 (LT2)", November 2011.

[i.40] ECC Report 167: "Practical implementation of registration/coordination mechanism for UWB LT2 systems", May 2011.

[i.41] ECC/DEC(12)03: "ECC Decision of 2 November 2012 on the harmonised conditions for UWB applications onboard aircraft".

[i.42] ETSI EG 202 730: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Code of Practice in respect of the control, use and application of Ground Probing Radar (GPR) and Wall Probing Radar (WPR) systems and equipment".

[i.43] ECC/DEC(06)08: "ECC Decision of 1 December 2006 on the conditions for use of the radio spectrum by Ground- and Wall- Probing Radar (GPR/WPR) imaging systems".

[i.44] ECC/DEC(11)02: "ECC Decision of 11 March 2011 on industrial Level Probing Radars (LPR) operating in frequency bands 6 - 8,5 GHz, 24.05 - 26.5 GHz, 57 - 64 GHz and 75 - 85 GHz".

[i.45] ERC REC 70-03 Annex 6, final version: "Relating to the Use of Short Range Devices (SRD)" Tromsø 1997. Subsequent amendments 07 February 2014.

NOTE: Available on EFIS database www.efis.dk.

[i.46] ETSI TR 101 994-1 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB) Part 1: Communications applications".

[i.47] ETSI TR 101 994-2: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB); Part 2: Ground- and Wall- Probing Radar applications; System Reference Document".

[i.48] ETSI TR 102 495-3: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical Characteristics for SRD equipment using Ultra-Wideband Sensor Technology (UWB); Part 3: Location tracking applications type 1 operating in the frequency band from 6 GHz to 8,5 GHz for indoor, portable and mobile outdoor applications".

[i.49] ETSI TR 102 495-5: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB); Part 5: Location tracking applications type 2 operating in the frequency bands from 3,4 GHz to 4,8 GHz and from 6 GHz to 8,5 GHz for person and object tracking and industrial applications".

[i.50] ETSI TR 102 495-7: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB); Part 7: Location tracking and sensor applications for automotive and transportation environments operating in the frequency bands from 3,1 GHz to 4,8 GHz and 6 GHz to 8,5 GHz".

[i.51] ETSI TR 102 496: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Technical characteristics for Location tracking Applications for Emergency Services (LAES) in disaster situations operating within the frequency range from 3,4 GHz to 4,8 GHz".

[i.52] ETSI TR 101 538: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); UWB location tracking devices in the railroad environment".

[i.53] ETSI TS 103 085: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB) for Location and Tracking railroad applications; RF conformance testing".

[i.54] CEPT Report 34: "Report B from CEPT to European Commission in response to the Mandate 4 on Ultra-Wideband (UWB)".

[i.55] ETSI TR 102 347: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detecting Movement; Radio equipment operating around e.g. 5,8 GHz, 10 GHz, 25 GHz, 61 GHz, 77 GHz; System Reference Document for Tank Level Probing Radar (TLPR)".

[i.56] ETSI TR 102 601: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System reference document; Short Range Devices (SRD); Equipment for Detecting Movement using Ultra Wide Band (UWB) radar sensing technology; Level Probing Radar (LPR) - sensor equipment operating in the frequency bands 6 GHz to 8,5 GHz; 24,05 GHz to 26,5 GHz; 57 GHz to 64 GHz and 75 GHz to 85 GHz".

[i.57] ECC Report 139: "Impact of Level Probing Radars (LPR), using Ultra-Wideband Technology on Radiocommunications Services".

[i.58] ECC Report 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".

[i.59] ETSI TR 102 834: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Technical Characteristics for airborne Ultra-WideBand (UWB) applications operating in the frequency bands from 3,1 GHz to 4,8 GHz and 6 GHz to 8,5 GHz".

[i.60] ECMA-368:"High Rate Ultra Wideband PHY and MAC Standard", ECMA international, 3rd Edition, Geneva, December 2008.

[i.61] EU Commission Decision 2013/752/EU implementing Decision of 11 December 2013 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2005/928/EC.

[i.62] ETSI EN 302 500 parts 1 and 2 (V1.2.1): "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 8,5 GHz".

[i.63] ETSI EN 302 065-4: "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 4: Material Sensing devices using UWB technology below 10,6 GHz".

[i.64] IEEE™ 802.15.4f-2012: "IEEE Standard for Local and metropolitan area networks - Part 15.4: Low Rate Wireless Personal Area Networks (LR-WPANs)".

[i.65] ETSI EN 303 883: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB); Measurement Techniques".

3 Symbols and abbreviations

3.1 Symbols

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

dBi	antenna gain relative to isotropic radiator in decibel
dBm	Absolute power level expressed in decibels relative to 1 mW
EP	Energy per pulse
f	frequency
f0	start frequency
fE	stop frequency
Δf	step width
GHz	Giga Hertz
kb	Boltzmann constant
mW	Milliwatt
MHz	Mega Hertz
n	number of hopps
N0	Noise floor
R0	predefined antenna impedance
T	Temperature
Tc	Chip period
t0	Start time
tE	Stop time
Δthopp	time for one step
Δton	time transmission on (one step)
Tp	pulse period
Ttxa	Transmitter active time
Ttxi	Transmitter idle time

V0	Peak Voltage Amplitude

3.2 Abbreviations

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

ABL	Anchor Based Location
AFL	Anchor Free Location
APC	Automatic Power Control
BMA	Building Material Analyses
BPSK	Binary Phase Shift Keying
BW	Band Width
CEPT	Commission Européenne des Postes et Télécommunications
DAA	Detect and Avoid
DC	Duty Cycle
DEC	Decision
e.i.r.p.	equivalent isotropic radiated power
EC	European Commission
ECC	European Communication Comity
ECMA	European Computer Manufacturers Association
EESS	Earth Exploration Satellite Services
EN	European Norm
FH	Frequency Hopping
FMCW	Frequency Modulated Continuous Wave
FS	Fixed Services
FSK	Frequency Shift Keying
FSS	Fixed Satellite services
GPR	Ground Probing Radar
IF	Intermediate Frequency
LAES	Location Application for emergency Services
LAN	Local Area Network
LBT	Listen before talk
LDC	Low Duty Cycle
LPR	Level Probing Radar
LT	Location Tracking
LTT	Location Tracking for automotive and environment
MB	Multi Band
MSS	Mobile Satellite Services
ODC	Object Discrimination and Characterization
OFDM	Orthogonal Frequency Division Multiplexing
OOK	On-Off Keying
PAM	Pulse Amplitude Modulation
PPM	Pulse Position Modulation
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density
RAS	Radio Astronomy Services
REC	Recommendation
RF	Radio Frequency
RFID	Radio Frequency Identification Device
RNSS	Radio Navigation Satellite Services
SRD	Short Range Devices
TLPR	Tank Level Probing Radar
TPC	Transmit Power Control
TR	Technical Report
TRT	Thales Research and Technology
TS	Technical Specification
UWB	Ultra Wide Band
WPR	Wall Probing Radar

4 CEPT/ECC and EC UWB Framework

4.1 UWB Definition:

UWB Definition out from 2007/131/EC [i.2]:

"'equipment using ultra-wideband technology' means equipment incorporating, as an integral part or as an accessory, technology for short-range radiocommunication, involving the intentional generation and transmission of radio-frequency energy that spreads over a frequency range wider than 50 MHz, which may overlap several frequency bands allocated to radiocommunication services."

Figures 1, 2 and 3 show an overview on the current regulatory and standardization framework of UWB in CEPT/ECC, EC and ETSI. A written overview is given in table 2.

- Figure 1: Generic, location tracking, vehicular and specific sensor UWB
- Figure 2: Railway environment, (tank) level probing and ground/wall probing
- Figure 3: Automotive applications (not all seen as UWB)

NOTE: The overviews are reflecting the status at the time of the publication of the present document. Based on the new Radio Equipment Directive (RED) in EC-Countries amendments of all ETSI harmonised standards will be necessary. This could lead to a rearrangement of the standard (numbering, merging of standards, etc.) but in most cases the numbers will kept (only document version will be changed).

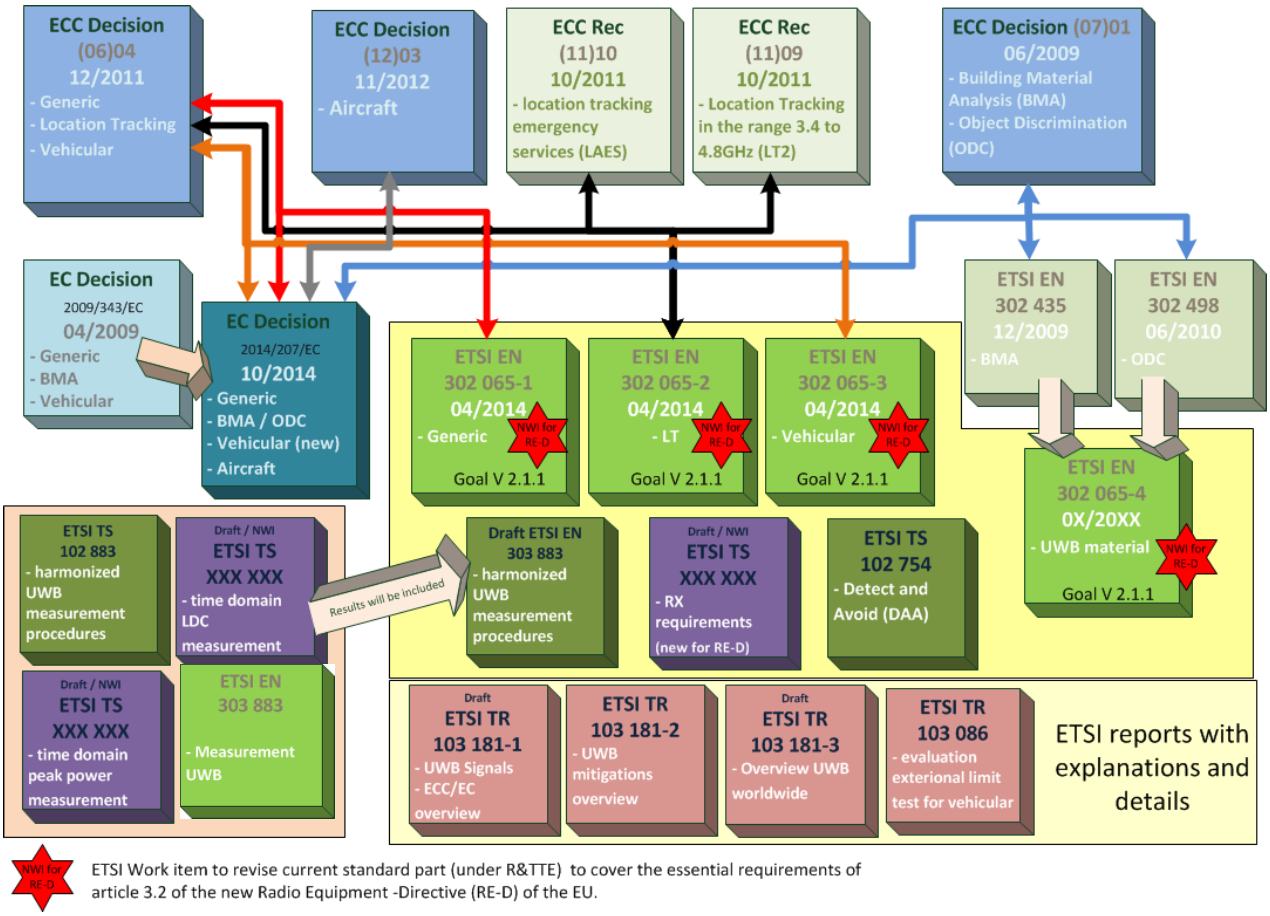
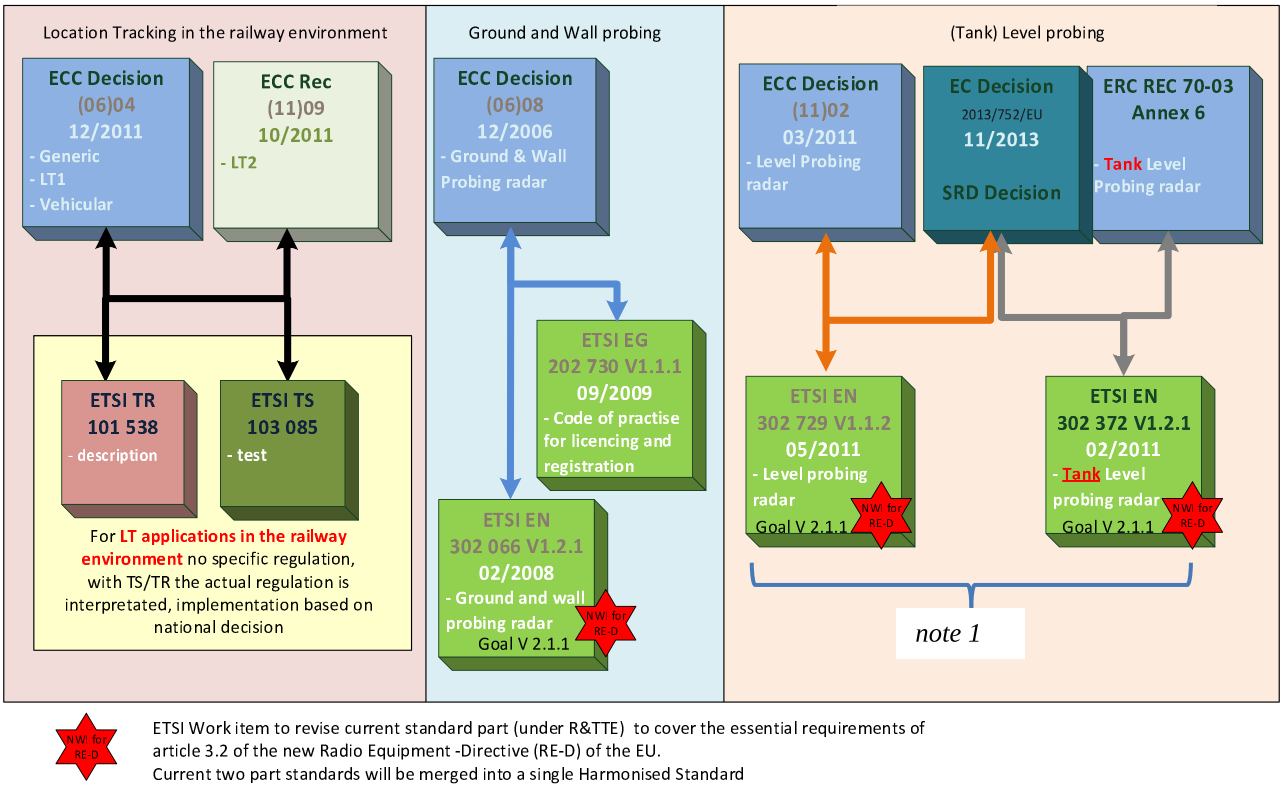


Figure 1: Regulation and Standardization - overview 1



NOTE: These two applications are covered by the EC Decision 2013/752/EU [i.61] for SRD.
It should be noted that these devices use Ultra-Wide Band (UWB) modulation technology. However, the industrial nature of these applications places them in a different regulatory category than the generic UWB devices described by ECC/DEC/(06)04 [i.3] and some other kinds of specific UWB applications meant for use by the general public.

Figure 2: Regulation and Standardization - overview 2

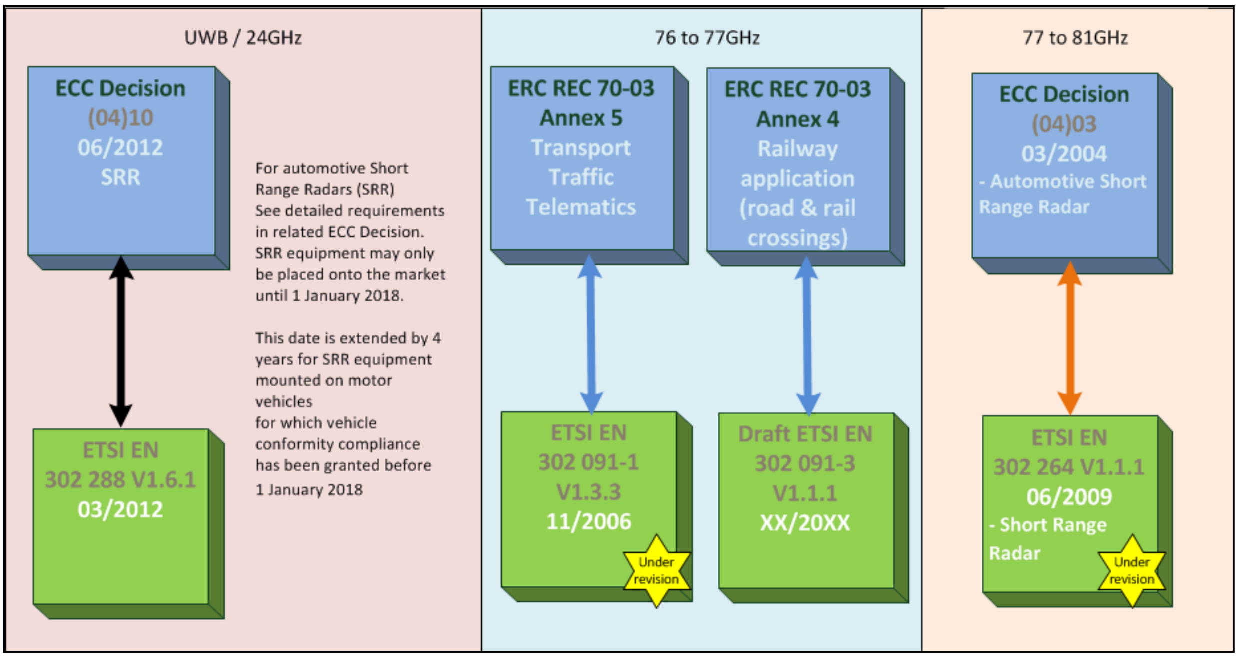


Figure 3: Regulation and Standardization - overview 3

Table 2: UWB application in CEPT/ECC,EC and ETSI (with related Harmonised Standards)

UWB Application	[GHz]	ETSI Harmonised Standard	Current CEPT/ECC and EC regulation	Mitigation technique
Generic, non-specific details clause 4.2	3,1 to 4,8 6 to 9	ETSI EN 302 065-1 [i.23]	ECC/DEC (06)04 amended (2011) [i.3] and in EC DEC 2014/702/EC [i.37]	• LDC (5 %/s + 0,5 %/h) in the range 3,1 to 4,8 • DAA (ETSI TS 102 754 [i.14]) Both mitigation techniques since the first ECC/DEC(06)04 [i.3]
Location Tracking below 10 GHz, see clause 4.2,2				
Location tracking type 1 details clause 4.2.2.1	6 to 9	ETSI EN 302 065-2 [i.24]	ECC/DEC (06)04 amended (2011) [i.3] and in EC DEC 2014/702/EC [i.37]	• DAA in 8,5 to 9GHz The Generic DAA usage was used since the revision of ETSI EN 302 500 [i.62]
Location tracking type 2 details clause 4.2.2.2	3,1 to 4,8		ECC/REC (11)10 [i.38]	Sight registration ECC report 167 [i.40] Compatibility studies in ECC report 170 [i.8]
Location Application for emergency Services (LAES) details clause 4.2.2.3	3,4 to 4,8		ECC/REC (11)09 [i.39]	Sight registration ECC report 167 [i.40] Compatibility studies in ECC report 170 [i.8]
Location Tracking for automotive & transportation environment (LTT) Details clause 4.2.3	3,1 to 4,8 6 to 8,5	ETSI EN 302 065-3 [i.25]	ECC/DEC (06)04 amended (2011) [i.3] and in EC DEC 2014/702/EC [i.37]	• Generic LDC (was used for vehicular applications since the amendment of ECC/DEC(06)04 [i.3] • Total power control (TPC) since the first ECC DEC(06)04 [i.3] • New LDC since amendment ECC/DEC(06)04 (year 2011), ECC report 170 [i.8] • Exterior limit since amendment ECC/DEC(06)04, ECC report 170 [i.8] and ETSI TR 103 086 [i.16] • DAA
Building Material Analysis (BMA) Details clause 4.2.5.1	2,2 to 8,5	ETSI EN 302 435 [i.19]	ECC/DEC(07)01 amended (2009) [i.4] and in EC DEC 2014/702/EC [i.37]	• LBT • Total radiated power (TG3 report)
Object Discrimination and Characterization (ODC) Details clause 4.2.5.2	2,2 to 8,5	ETSI EN 302 498 [i.21]	Included in ECC/DEC(07)01 amended (2009) [i.4] and in EC DEC 2014/702/EC [i.37]	• LBT (ECC report 123 [i.7]) • Total radiated power • Duty Cycle
aircraft/airborne Details clause 4.2,7	6 to 8,5		ECC/DEC(12)03 [i.41]	
Professional Ground- and Wall Probing Radars Details clause 4.2.4	0,030 to 12,4	ETSI EN 302 066 [i.20]	ECC/DEC(06)08 [i.43]	ETSI EG 202 730 [i.42]

UWB Application	[GHz]	ETSI Harmonised Standard	Current CEPT/ECC and EC regulation	Mitigation technique
Tank Level Probing Radar (TLPR) Details clause 4.2.6.1	4,5 to 7 8,5 to 10,6 24,05 to 27 57 to 64 75 to 85	ETSI EN 302 372 [i.27]	ERC/REC 70-03 Annex 6 [i.45]	
Level Probing Radars (LPR) Details clause 4.2.6.2	6,0 to 8,5 24,05 to 26,5 57 to 64 75 to 85	ETSI EN 302 729 [i.26]	ECC/DEC(11)02 [i.44]	

4.2 Brief description UWB applications in CEPT/ECC and EC

4.2.1 Generic applications

4.2.1.1 Applications

Generic UWB applications are covered by ETSI EN302 065-1 [i.23] and described in System Reference Document ETSI TR 101 994-1 [i.46]

Such UWB technologies are mainly used for short range communications or precise location and tracking, or short range radar/imaging sensors. During the regulatory and standardization discussion in CEPT/ECC and EC specific regulation and standards for example location tracking and sensor application were prepared.

The UWB technologies can basically split down into two groups:

- Impulse based technologies: this kind of technology consists of a series of impulses created from a dc voltage step whose rise time can be modified to provide the maximum useful number of spectral emission frequencies. The derived impulse can then be suitably modified by the use of filters to locate the resulting waveform within a specific frequency spectrum range. This filter can be a standalone filter or incorporated into an antenna design to reduce emissions outside the designated frequency spectrum.
- RF carrier based technologies: this is based upon classical radio carrier technology suitably modulated by a baseband modulating process. The modulating process should produce a bandwidth in excess of 50 MHz to be defined as UWB. Different modulating processes are used to transmit the data information to the receiver and can consist of a series of single hopping frequencies or multi-tone carriers. This technology can be used for both direct and non-direct line of sight communications, any reflected or time delayed emissions being suppressed by the receiver input circuits.

For both of these techniques, modulation may include pulse positioning in time (with or without carrier modulation), pulse suppression and other techniques to convey information.

UWB transmitters equipment as per the ECC/DEC/(06)04 [i.3] and EC DEC 2014/702/EC [i.37], conforming to ETSI EN 302 065-1 [i.23] are not allowed to be installed at fixed outdoor locations, for use in flying models, aircraft and other forms of aviation.

It may be a fixed, mobile or portable application, e.g.:

- stand-alone radio equipment with or without its own control provisions;
- plug-in radio devices intended for use with, or within, a variety of host systems, e.g. personal computers, hand-held terminals, etc.;
- plug-in radio devices intended for use within combined equipment, e.g. cable modems, set-top boxes, access points, etc.;
- combined equipment or a combination of a plug-in radio device and a specific type of host equipment.

The relevant regulation for generic and LT1 is in ECC/DEC(06)04 [i.3] and EC DEC 2104/702/EC [i.37].

4.2.1.2 Regulated Limits for General Case

The General Case will also cover location tracking, LT1 applications (see clause 4.2.2.).

The technical requirements below are not applicable to:

- devices and infrastructure used at a fixed outdoor location or connected to a fixed outdoor antenna;
- devices installed in flying models, aircraft and other aviation;
- devices installed in road and rail vehicles.

Table 3: Maximum e.i.r.p. limits/generic case

	Generic without mitigation		Generic LDC Device implemented, note 1 only		Generic DAA Device implemented, note 2 only	
Frequency range (GHz)	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**
Below 1,6	-90	-50	-90	-50	-90 d	-50
1,6 to 2,7	-85	-45	-85	-45	-85	-45
2,7 to 3,4	-70	-36	-70 dB	-36	-70	-36
3,1 to 3,4	-70	-36	-41,3 (see note 1)	0 (see note 1)	-41,3 (see note 2)	0 (see note 2)
3,4 to 3,8	-80	-40	-41,3 (see note 1)	0 (see note 1)	-41,3 (see note 2)	0 (see note 2)
3,8 to 4,2	-70	-30	-41,3 (see note 1)	0 (see note 1)	-41,3 (see note 2)	0 (see note 2)
4,2 to 4,8	-70	-30	-41,3 (see note 1)	0 (see note 1)	-41,3 (see note 2)	0 (see note 2)
4,8 to 6	-70	-30	-70	-30	-70	-30
6 to 8,5	-41,3	0	-41,3	0	-41,3	0
8,5 to 10,6	-65	-25	-65	-25	-41,3 (see note 2)	0 (see note 2)
Above 10,6	-85	-45	-85 d	-45	-85	-45

NOTE 1: Within the band 3,1 GHz to 4,8 GHz, devices implementing **Low Duty Cycle (LDC) mitigation technique** (see ETSI TR 103 181-2 [i.15]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

NOTE 2: Within the bands 3,1 GHz to 4,8 GHz and 8,5 GHz to 9 GHz, devices implementing **Detect And Avoid (DAA) mitigation technique** (see ETSI TR 103 181-2 [i.15]) are permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz.

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

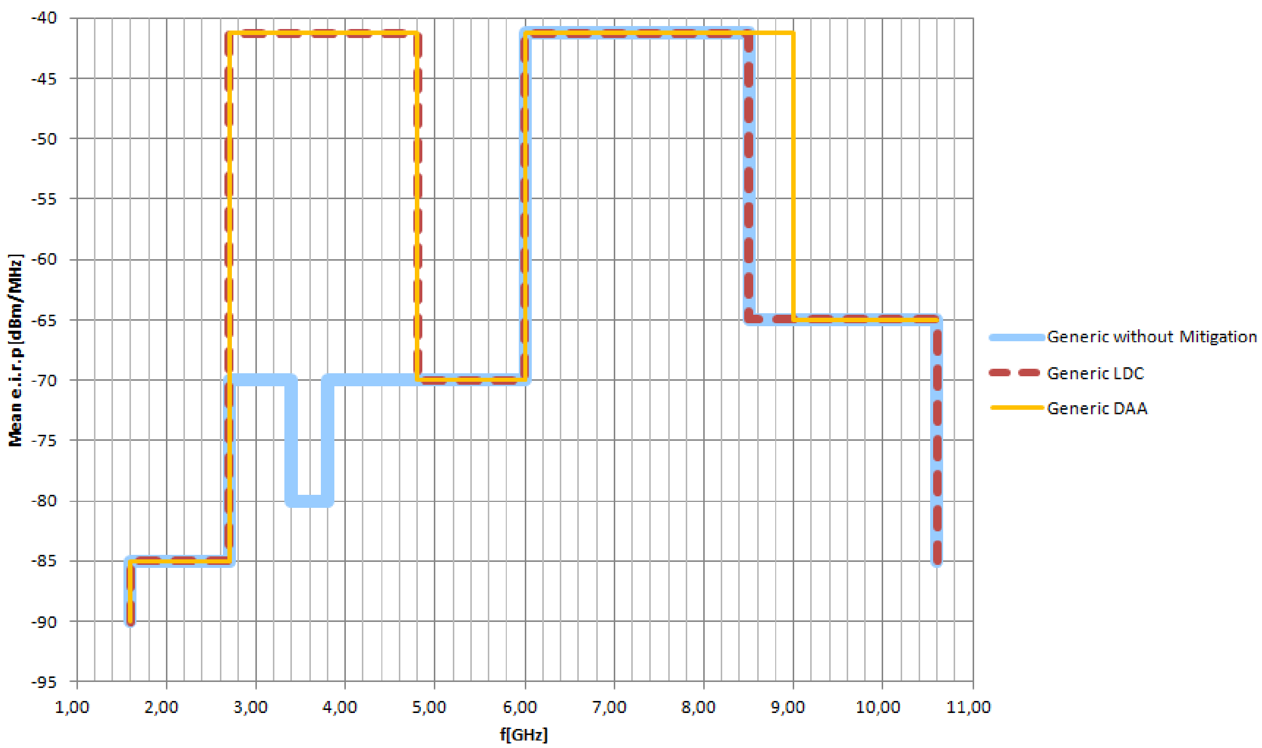


Figure 4: Mean power limits for UWB generic and LT1 cases (with and without mitigations)

4.2.2 Location tracking

4.2.2.1 Location tracking applications

UWB location tracking applications are covered by ETSI EN 302 065-2 [i.24]. and described in System Reference Documents ETSI TR 102 495-3 [i.48], ETSI TR 102 495-5 [i.49] and ETSI TR 102 496 [i.51].

UWB devices operate at a bandwidth of several GHz, thus allowing centimetre-level localization and positioning even in the presence of severe multipath effects caused by walls, furniture etc. Hence, usage of UWB technology may enable a new generation of sensors, named Location Tracking sensors and open new markets with very different applications. For such sensors, high precision in range measurement is required.

In UWB location tracking sensors, small mobile or portable tags, operating as either transmitters or receivers, or both, are attached to the objects to be located, or are carried by personnel within an area under surveillance. A network of fixed equipment around the area to be covered, communicate with the tags. By analysing, e.g. the time-of-arrival and/or angle-of-arrival of the radio signal relative to the known reference stations, the 2D/3D position of the tag can be found. Typically, the range between a tag and a reference station might be up to 200 m, depending on the area to be observed.

Such systems may significantly enhance the security and safety of persons monitored in different applications such as process industries, healthcare, prisons (guards) and lone workers. Therefore, UWB is a viable positioning technology that meets industrial requirements in the following markets:

- Healthcare.
- Workplace/Office.
- Public buildings.
- Security.
- Defence training.
- Professional multimedia production.
- Logistics, warehouses.
- Manufacturing assembly lines.
- Prisons and correctional institutes.
- Large and hazardous industrial sites, such as oil refineries.
- Entertainment.

As it can be seen, applications of UWB location tracking technology are many and varied. Within hospitals, equipment, patients and doctors can be located quickly to speed up response to an incident. In the workplace, computers and communications systems can be shared between personnel, and automatically configured for a particular user as they walk up to equipment. In high-security environments, authorized personnel can be tracked, and unauthorized persons quickly identified when passive sensors (e.g. infra-red sensors) detect the presence of a person who is not located by the tracking system. Additionally, in industrial and agricultural environments the system can be used to track products through an assembly line and to monitor animal behaviour (e.g. in the dairy industry).

More in detail, the list below indicates some of the many applications of UWB Location Tracking technology in each of a number of environments - it is in no way intended to be an exhaustive list:

- Healthcare:
  - Streamlining hospital processes (locating staff, finding wandering patients).
  - Asset tracking and management (finding equipment, evaluating equipment usage).
  - Safety (panic alarms with position-finding capability).

- Industrial & logistics asset tracking:
  - Location tracking of high value assets, pallets or fork-lifts.
  - Tracking is not limited to one building but to every possible location in the whole area., therefore outdoor usage is necessary.
  - Halls are typically very large and installation of infrastructure (network, cabling, and sensors) is very expensive. Therefore an increase of the operating range is very beneficial. People and asset tracking in public places.
  - Security applications. Since September 11th security is a number one topic in public places. "Command and Control" systems that know where operational personnel are can raise alarm if they enter critical zones. Integration with camera tracking, resource management for rapid response are examples of applications where mixed indoor/outdoor usage is necessary.
  - Collision avoidance between container wagons.
  - Workflow management and quality control: There are very stringent requirements regarding who is allowed to execute maintenance work at an aircraft. Location tracking enables control of these requirements in real time and the documentation of completed work steps.
- Safety applications in hazardous environments:
  - To know where people are in emergency situations. For example there are rules that in a catastrophic case everybody should leave an oil platform within 20 minutes. Real time location tracking can support this in training situations as well as in a real situation, therefore outdoor usage is necessary.
  - Control the workflow of employees. For example there are rules how long employees are allowed to work in high radiation environments in a nuclear plant. The integration of a tracking system combined with a radio-dosimeter enables accurate and reliable tracking of the workers in radioactive areas gathering dosimeter readings.

As the capability of UWB devices for tracking becomes more well-known, many further applications will be identified.

4.2.2.2 Location tracking type 1 (LT1)

Location tracking type 1, LT1 [i.48], are intended for applications in the frequency band from 6 GHz to 8,5/9 GHz for indoor, portable and mobile outdoor applications. This was the original spectrum request for UWB location tracking applications, and it was initially covered by ETSI TR 102 495-3 [i.48]. The related limits are covered by the generic UWB regulation in the range 6 GHz to 9 GHz.

A detailed limit table is shown in clause 4.2.1.2.

4.2.2.3 Location tracking type 2 (LT2)

This original request for UWB Location Tracking sensors that led to definition of LT1 sensors was enhanced by the proposals covered in ETSI TR 102 495-5 [i.49]. Therefore, these additional location tracking devices were called type 2, LT2. The performance attributes of LT2 devices is the frequency range from 3,4 GHz to 4,8 GHz in addition to the 6 GHz to 8,5 GHz frequency range used by LT1 sensors.

It is foreseen that individual licensing of operators, for fixed outdoor usage, in the range 3,4 GHz to 4,8 GHz on a site-specific The requirements are described in ECC/REC(11)09 [i.39]. Under the ECC/REC(11)09 [i.39] in conjunction with ECC report 167 [i.40] a fixed outdoor operation could be permitted.

The regulated limits are given in ECC/REC(11)09 [i.39].

Table 4: Maximum e.i.r.p. for fixed outdoor installations

Frequency range (GHz)	Maximum mean e.i.r.p. spectral density with passive LDC mitigation	Maximum mean e.i.r.p. spectral density with Mitigation
Below 1,6	-90 dBm/MHz	-90 dBm/MHz
1,6 to 2,7	-85 dBm/MHz	-85 dBm/MHz
2,7 to 3,1	-70 dBm/MHz	-70 dBm/MHz
3,1 to 3,4	-70 dBm/MHz [i.39]	-41,3 dBm/MHz (see note 1)
3,4 to 4,8	-41,3 dBm/MHz (see notes 2 and 3)	-41,3 dBm/MHz (see notes 2 and 3)
4,8 to 10,6	-70 dBm/MHz	-70 dBm/MHz
Above 10,6	-85 dBm/MHz	-85 dBm/MHz
NOTE 1: Within the band 3,1 GHz to 3,4 GHz, terminals implementing Detect-And-Avoid (DAA) mitigation technique (see technical parameters for DAA in the band 3,1 GHz to 3,4 GHz as defined in ECC/DEC/(06)04) [i.3] may be permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz. A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms also apply. NOTE 2: A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms apply. NOTE 3: 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.		

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

Table 5: Maximum e.i.r.p. for mobile (in and outdoor) and fixed indoor

Frequency range (GHz)	Maximum mean e.i.r.p. spectral density with passive LDC mitigation	Maximum mean e.i.r.p. spectral density with additional Mitigation note 1
Below 1,6	-90 dBm/MHz	-90 dBm/MHz
1,6 to 2,7	-85 dBm/MHz	-85 dBm/MHz
2,7 to 3,4	-70 dBm/MHz	-41,3 dBm/MHz (see note 1)
3,4 to 4,8	-41,3 dBm/MHz (see note 2)	-41,3 dBm/MHz (see note 2)
4,8 to 10,6	-70 dBm/MHz	-70 dBm/MHz
Above 10,6 GHz	-85 dBm/MHz	-85 dBm/MHz
NOTE 1: Within the band 3,1 GHz to 3,4 GHz, terminals implementing Detect-And-Avoid (DAA) mitigation technique (see technical parameters for DAA in the band 3,1 GHz to 3,4 GHz as defined in ECC/DEC/(06)04) [i.3] may be permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz. A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms also apply. NOTE 2: A maximum duty cycle of 5 % per transmitter per second and a maximum Ton = 25 ms apply. The duty cycle should also be limited to 1,5 % per minute or equipment should implement an alternative mitigation technique that provides at least equivalent protection.		

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

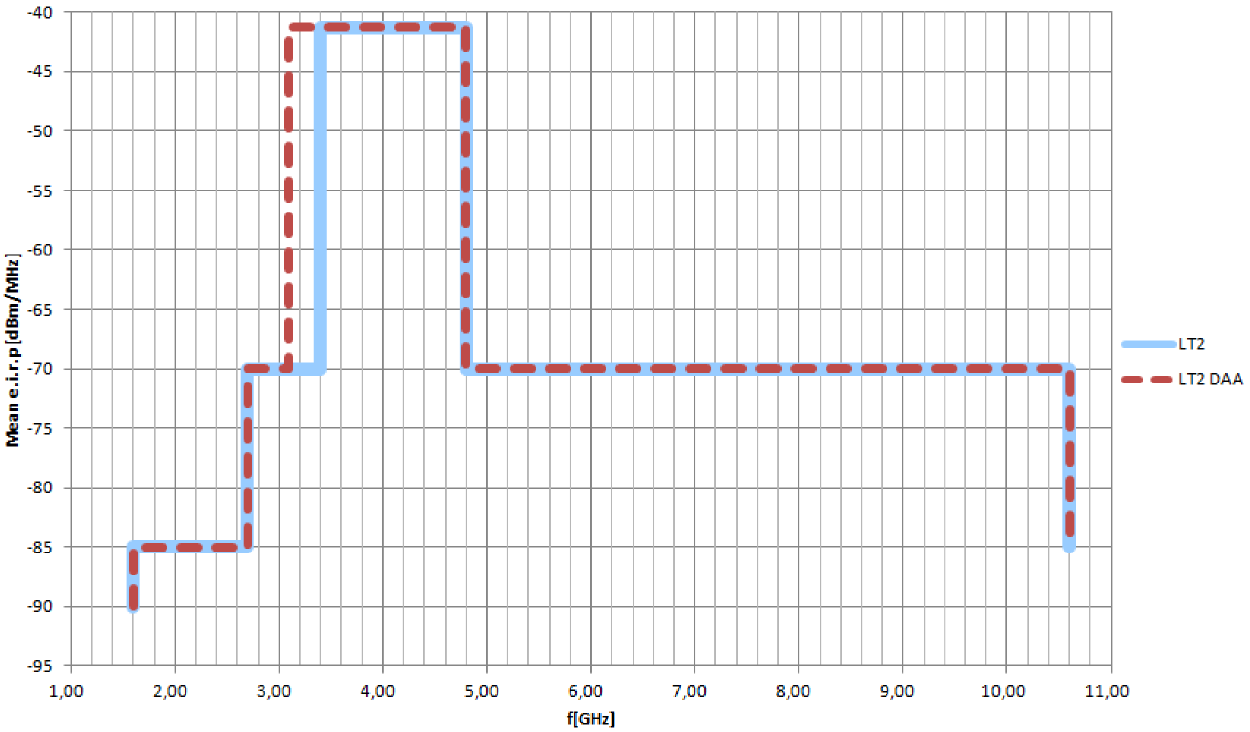


Figure 5: Mean power limits for UWB LT2 cases (with and without mitigations)

4.2.2.4 Location Application for Emergency Services (LAES)

Location Tracking sensor for Emergency Services (LAES) are a class of special short-range location tracking sensors specifically intended to become an essential part of the Public safety operations. These applications are intended to be used in emergency situations. For these systems, no fixed installations are available to perform the localization as the place of events are not known in advance.

A LAES system is composed of a set of nodes deployed as an ad-hoc network. It will provide accurate positioning information of objects or persons which are inside the building which is affected by the event. This means that the required signals necessarily demand a high bandwidth to provide the required accuracy which is better than one metre.

Two systems architecture can be used for LAES:

- Anchor Based Localization (ABL); and
- Anchor Free Localization (AFL).

For ABL systems at least three fixed reference points which are inside or outside the building located in the sensitive area are needed. For AFL systems, there is no need of reference points but a sufficient connectivity between the nodes inside the building is needed in order to obtain ranging information between all nodes. This implies that a high signal power is required in order to enable the penetration of obstacles (walls, etc.) and to enable a sufficient link distance between nodes inside the building. Based on these requirements, an increased power compared to other regulations of the UWB devices that will be used in such situation is needed.

The users of the proposed system will be government agencies responsible for public safety primarily and so would be clearly defined organizations. It is suggested in the proposed regulation that users should be licensed, but not sites, since the equipment would only be operated when and where an emergency situation occurs. As described in ETSI TR 102 496 [i.51], applications are used temporarily by emergency services in all aspects of disaster situations, including disaster prevention.

There is evidence that such a system will significantly enhance the security and sustainability of life of persons and therefore will provide a socio-economic benefit.

The regulated limits are given in ECC/REC(11)10 [i.38].

Table 6: Maximum e.i.r.p. for LAES systems

Frequency range (GHz)	Maximum mean e.i.r.p. spectral density (dBm/MHz)	Maximum peak e.i.r.p. (defined in dBm/ 50 MHz)
Below 1,6	-90	-50
1,6 to 2,7	-85	-45
2,7 to 3,1	-70	-36
3,1 to 3,4 (see note 1)	-70; -41,3 (see note 1)	-36; 0 (see note 1)
3,4 to 4,2 (see note 2)	-21,3 (see note 2)	20 (see note 2)
4,2 to 4,8 (see note 2)	-41,3 (see note 2)	0 (see note 2)
4,8 to 10,6	-70	-30
Above 10,6	-85	-45
NOTE 1: Within the band 3,1 to 3,4 GHz, systems implementing Detect And Avoid (DAA) mitigation technique (see technical parameters for DAA in band 3,1 to 3,4 GHz as defined in ECC/DEC/(06)04) [i.3] may be permitted to operate with a maximum mean e.i.r.p. spectral density of -41,3 dBm/MHz and a maximum peak e.i.r.p. of 0 dBm defined in 50 MHz. A maximum duty cycle of 5 % per transmitter per second also applies.		
NOTE 2: A maximum duty cycle of 5 % per transmitter per second applies.		

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

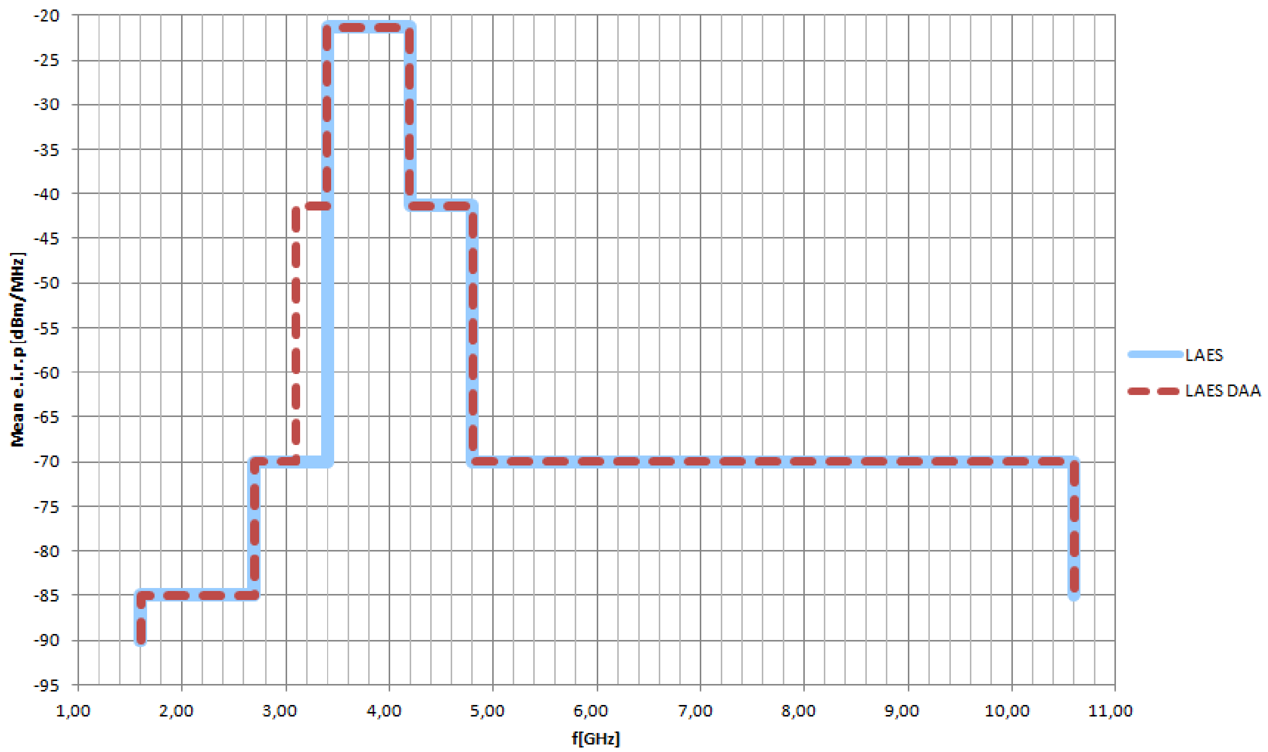


Figure 6: Mean power limits for UWB LAES cases (with and without mitigations)

4.2.2.5 Location tracking in the railway environment

These applications are described in ETSI TR 101 538 [i.52]. No specific requirements has been identified beyond the existing regulatory framework. The interpretation of the existing rules are described in ETSI TS 103 085 [i.53]. The applications could be based on by the LT1 and LT2 regulation and the corresponding harmonised standards.

4.2.3 Ground based vehicular applications

UWB application specific for ground based vehicular applications are covered by ETSI EN 302 065-3 [i.25] and described in System Reference Document ETSI TR 102 495-7 [i.50].

ETSI EN 302 065-3 [i.25] applies to transceivers, transmitters and receivers utilizing Ultra WideBand (UWB) technologies. They are used for short range communication and sensor applications in ground based vehicles. Such applications may operate in the frequency range from 3,1 GHz to 4,8 GHz or from 6 GHz to 9 GHz.

The main characteristic of such road and rail applications are:

- They are subjected to aggregation effects
- They are not fixed, but they are moving at a speed generally comprised between 20Km/h and 300Km/h.

This usage profile is specific of this kind of applications, therefore, any device or sensor mounted over a road or rail vehicle should be considered within the scope of ETSI EN 302 065-3 [i.25], e.g.:

- stand-alone radio equipment with or without its own control provisions;
- plug-in radio devices intended for use with, or within, a variety of host systems, e.g. personal computers, etc.;
- plug-in radio devices intended for use within combined equipment, e.g. modems, access points, etc.;
- equipment for the communication inside and outside of road and rail vehicles;
- equipment for the localization of devices inside and outside of road and rail vehicles, e.g. hand-held devices.

On the other hand, any application related to road and rail vehicle, having fixed transmitters mounted on road or rail infrastructure, is not to be considered within the scope of road and rail UWB standard [i.25]: for fixed rail/road infrastructure tracking applications, ETSI EN 302 065-2 [i.24] apply.

The relevant regulation for UWB devices installed in ground based vehicles are in ECC/DEC(06)04 [i.3] and 2104/702/EC [i.37].

Table 7: Maximum e.i.r.p. limits for UWB onboard vehicles, Generic and with implementation LDC mitigation

	Without mitigation		Device implemented note 1 only	
Frequency range (GHz)	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**
Below 1,6	-90	-50	-90	-50
1,6 to 2,7	-85	-45	-85	-45
2,7 to 3,1	-70	-36	-70	-36
3,1 to 3,4	-70	-36	-41,3 (see note 1)	0 (see note 1)
3,4 to 3,8	-80	-40	-41,3 (see note 1)	0 (see note 1)
3,8 to 4,2	-70	-30	-41,3 (see note 1)	0 (see note 1)
4,2 to 4,8	-70	-30	-41,3 (see note 1)	0 (see note 1)
4,8 to 6	-70	-30	-70	-30
6 to 8,5	-53,3	-13.3	-41,3 (see note 1)	0 (see note 1)
8,5 to 10,6	-65	-25	-65	-25
Above 10,6	-85	-45	-85	-45
NOTE 1: Within the band 3,1 GHz to 4,8 GHz and 6 GHz to 8,5 GHz, devices implementing Low Duty Cycle (LDC) mitigation technique. Operation is in addition subject to the implementation of an exterior limit (see Annex 5 of EC/DEC(06)04 [i.3] or ETSI TR 103 181-2 [i.15]) for -53,3 dBm/MHz.				

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

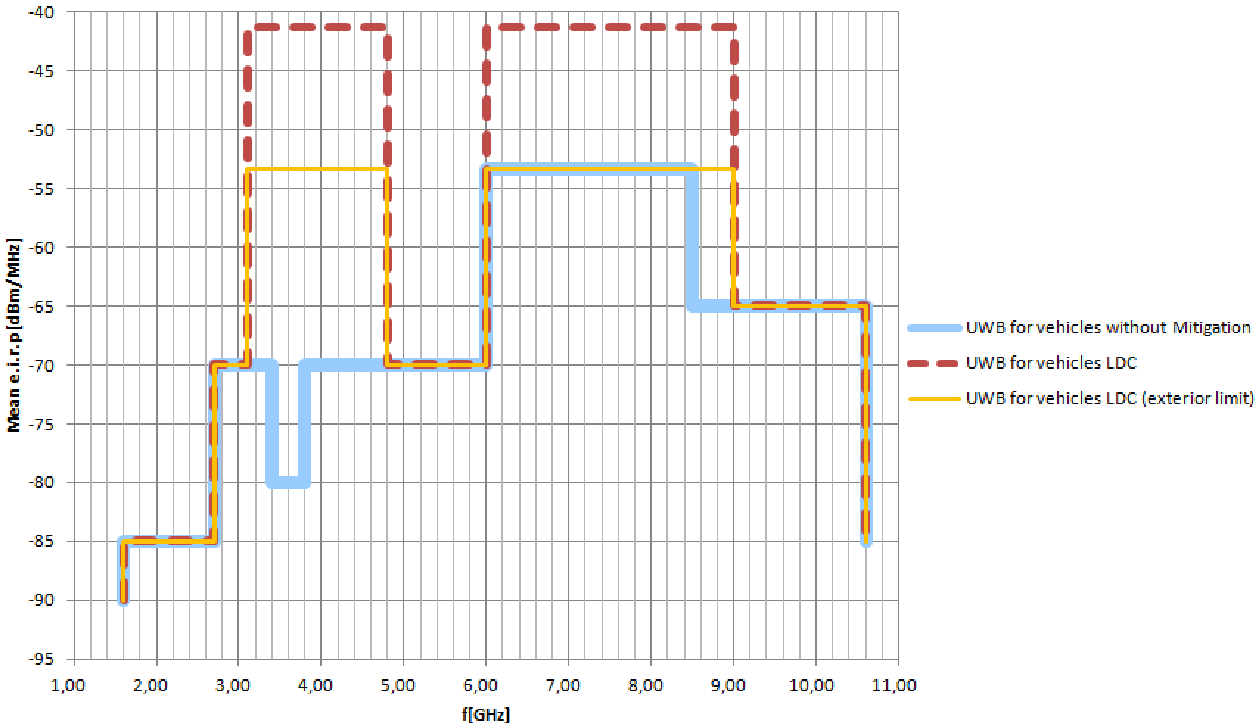


Figure 7: Mean power limits for UWB ground based vehicular cases (without and with LDC mitigations)

Table 8: Maximum e.i.r.p. limits for UWB onboard vehicles, with implementation DAA mitigation or with TPC mitigation

	Device implemented note 1 only		Device implemented note 2 only	
Frequency range (GHz)	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**	**Maximum mean e.i.r.p. spectral density (dBm/MHz)**	**Maximum peak e.i.r.p. (dBm/50 MHz)**
Below 1,6	-90	-50	-90	-50
1,6 to 2,7	-85	-45	-85	-45
2,7 to 3,1	-70	-36	-70	-36
3,1 to 3,4	-41,3 (see note 2)	0	-70	-36
3,4 to 3,8	-41,3	0	-80	-40
3,8 to 4,2	-41,3	0	-70	-30
4,2 to 4,8	-41,3	0	-70	-30
4,8 to 6	-70	-30	-70	-30
6 to 8,5	-53,3	-13,3	-41,3	0
8,5 to 10,6	-41,3	0	-65	-25
Above 10,6	-85 dB	-45	-85 dB	-45

NOTE 1: Within the bands 3,1 GHz to 4,8 GHz and 8,5 GHz to 9 GHz, devices implementing Detect And Avoid (DAA) mitigation technique (see ETSI TR 103 181-2 [i.15) Operation is in addition subject to the implementation of Transmit Power Control (TPC) mitigation technique and an exterior limit (see ETSI TR 103 181-2 [i.15) of -53,3 dBm/MHz.

NOTE 2: Within the band 6 GHz to 8,5 GHz devices implementing Transmit Power Control (TPC) mitigation technique and an exterior limit (see ETSI TR 103 181-2 [i.15) of -53,3 dBm/MHz .

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

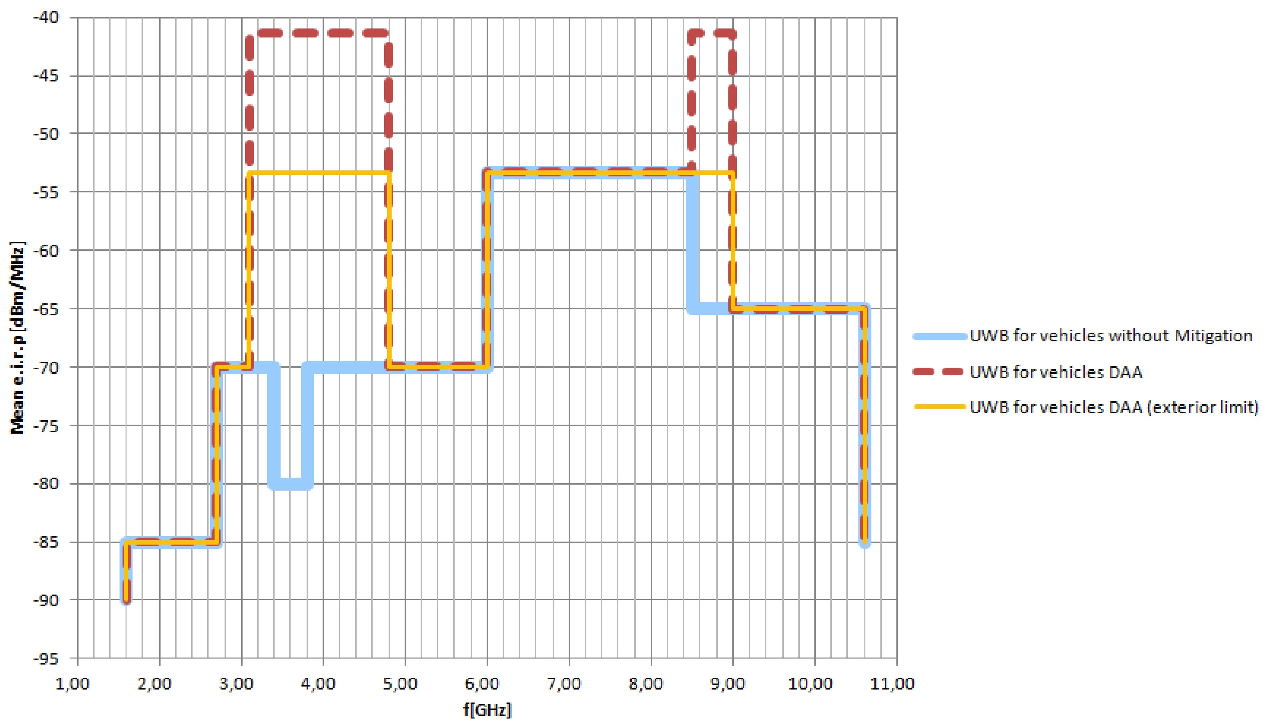


Figure 8: Mean power limits for UWB ground based vehicular cases (with DAA or TPC mitigations)

4.2.4 Material Sensing devices

4.2.4.1 Material sensing devices BMA and ODC

4.2.4.1.1 Overview

Material sensing devices were defined in ECC/DEC/(07)01 [i.4] and EC DEC 2014/702/EC [i.37], as devices *"enabling radio determination application designed to detect the location of objects within a structure or to determine the physical properties of a material"*.

Material Sensing devices differs from Location Tracking sensors in that they do not provide precise 2D/3D localization of objects and/or people in a wide area, they only detect the presence or render the positions of objects or human tissue in close proximity of the sensor, even though different materials or structures like walls and ground. There are different kind of sensors that may be considered, described in the following clauses.

Building Material Devices (BMA) actually covered in ETSI EN 302 435 [i.19], ETSI TR 102 495-1 [i.17] and Object Discrimination and Characterization (ODC) actually covered in ETSI EN 302 498 [i.21], ETSI TR 102 495-2 [i.18] will be covered in future in a new joined harmonised standard ETSI EN 302 065-4 [i.63].

4.2.4.1.2 Building Material Analysis (BMA)

Ultra wideband technology enables a new generation of devices for building material analysis (BMA) and classification of buried objects and material.

The non-destructive scanning of building structures offers large economical advantage compared to conventional destructive methods.

These handheld devices are lightweight and are manually operated at low power. They exhibit a low activity factor during operation. The typical total operational duration is limited to a few minutes as the area of interest is usually confined to a few m² and the measurement results are instantaneously available.

Due to the low activity factor, the limited activation time per task, the nature of the applications, random use over time and location of the usage, no aggregation occurs.

The devices are designed to work only in direct contact to the building structure being scanned and are designed to couple the electromagnetic signal directly into the building structure. The devices will not operate without physical contact to the building structure to be investigated.

Parasitic, undesired radiation into free space is significantly reduced due to the device design and the additional attenuation of the measured building structure. Equipment features (e.g. deactivation switch, dynamic power control, listen-before-talk) may reduce such radiation even further.

Frequencies in the lower GHz range are necessary to penetrate lossy building materials, such as concrete, because they exhibit a large attenuation which increases with frequency and to minimize clutter. A large bandwidth is required to ensure sufficient measurement resolution, needed for object identification, separation and classification.

The relevant regulation for UWB BMA devices are in ECC/DEC(07)01 [i.4] and EC DEC 2014/702/EC [i.37].

BMA Devices permitted under this Decision fulfil the following requirements:

- Transmitter-On only if manually operated with a non-locking switch (e.g. it may be a sensor for the presence of the operators hand) plus 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);
- The BMA transmitter has to switch-off after max 10 s without movement;
- The Total Radiated Power spectral density has to be 5 dB below the maximum mean e.i.r.p. spectral density limits in table 9 below;

The necessary measurement scenario and setup of BMA devices (in combination with the "defined test wall" in ECC/DEC(07)01) [i.4] is shown in figure 9. Details of the measurement procedure are described in ETSI EN 302 435 [i.19]

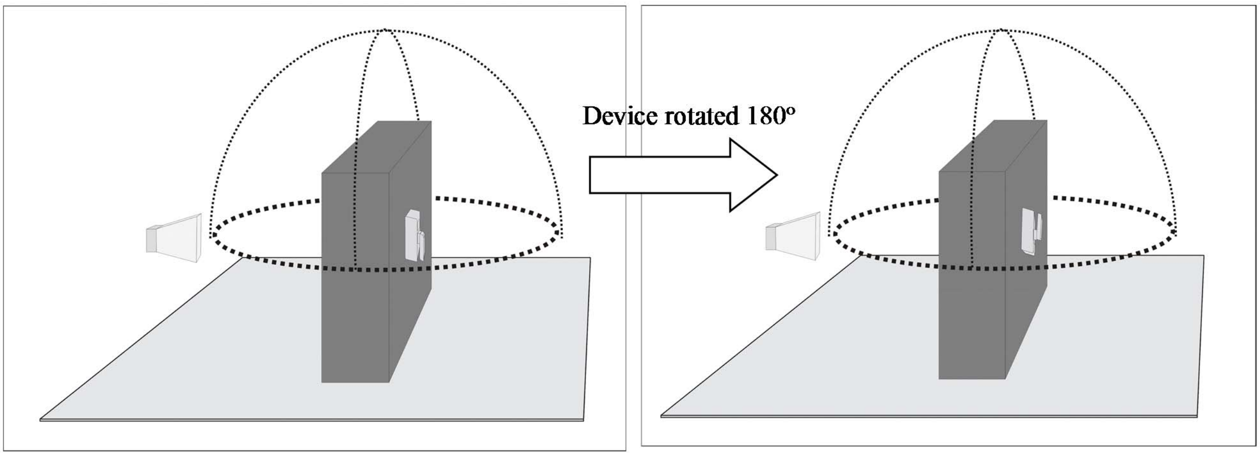


Figure 9: Measurement arrangement for emission measurements of BMA devices

Table 9: Maximum e.i.r.p. limits for BMA

Frequency range (GHz)	Maximum mean e.i.r.p spectral density (dBm/MHz)	Maximum mean e.i.r.p spectral density (dBm/MHz) with mitigation
Below 1,73	-85	-70 (see note 1)
1,73 to 2,2	-65	-65
2,2 to 2,5	-50	-50
2,5 to 2,69	-65	-55 (see note 1)
2,69 to 2,7	-55 (see note 2)	-55 (see note 2)
2,7 to 3,4	-70	- 50 (see note 1)
3,4 to 4,8	-50	-50
4,8 to 5	-55 (see note 2)	-55 (see note 2)
5 to 8,5	-50	-50
Above 8,5	-85	-85
NOTE 1: Devices using a Listen Before Talk (LBT) mechanism, as described in the harmonised standard ETSI EN 302 435 [i.19], are permitted to operate in frequency range 1,215 GHz to 1,73 GHz with a maximum mean e.i.r.p. spectral density of -70 dBm/MHz and in the frequency ranges 2,5 GHz to 2,69 GHz and 2,7 GHz to 3,4 GHz with a maximum mean e.i.r.p. spectral density of -50 dBm/MHz.		
NOTE 2: To protect the RAS bands 2,69 GHz to 2,7 GHz and 4,8 GHz to 5 GHz, the Total Radiated Power spectral density has to be below -65 dBm/MHz. This limits the average over the complete sphere around the measurement scenario (figure 9).		

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

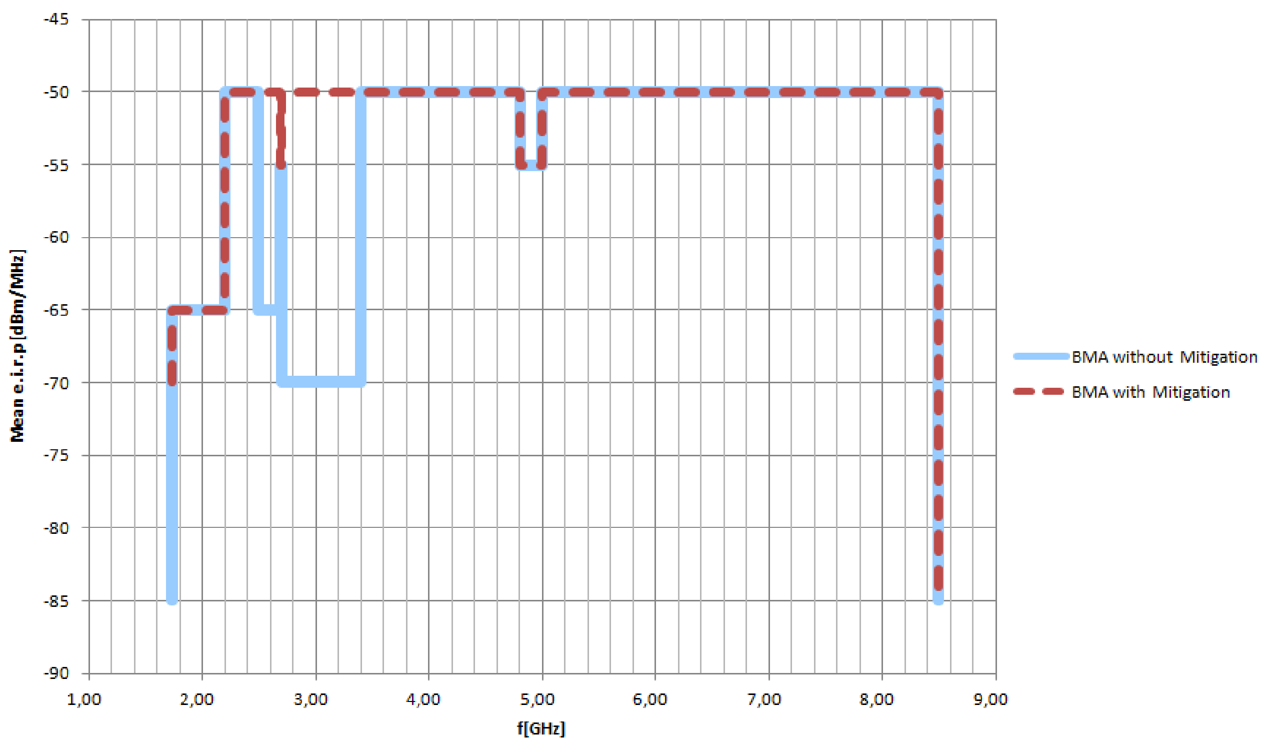


Figure 10: mean power limits for UWB BMA (with or without mitigations)

4.2.4.1.3 Object Discrimination and Characterization (ODC)

As in the case of BMA, properties of ultra wide band technology, and namely the very short wavelength, enables a new generation of sensors, allowing the identification and classification of objects, 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. Such sensors are the so-called Object Discrimination and Characterization sensors (ODC).

Applications for such devices are widespread. The following list gives an overview:

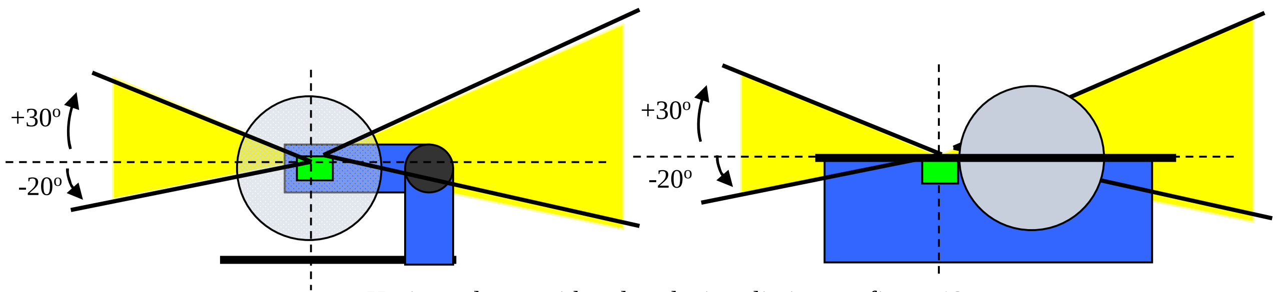
- Position detection and identification of human extremities for enhanced operational safety with potentially dangerous tools.
- Pre-impact protection and pre-impact detection or direct contact avoidance for hidden objects to be detected for building work applications.

Frequencies in the lower GHz range are prerequisite for such a kind of object classification equipment, allowing the electromagnetic wave to penetrate objects like cloth or human tissue. The wave penetrating an object inside returns much more information (such as inhomogeneities, object composition, dielectricity, etc.) about the object than just the surface reflection. A certain bandwidth is required to receive a characteristic response from the target and to ensure sufficient resolution needed for target separation.

As per CEPT Report 34 [i.54] and ECC Report 123 [i.7], "ODC devices are characterized by emissions only when in contact or close proximity to the investigated material." Consequently the radiation pattern should be mainly directed to the "object", and not in other directions. They operate in the frequency range 2,2 GHz to 8,5 GHz, so that a directional antenna has not so large dimensions and can provide further mitigation of the signal radiated externally. More details can be found in ETSI TR 102 495-2 [i.18],and in the relevant ETSI standard ETSI EN 302 498 [i.21], where quantities to be tested for conformance (emissions, total power, PRF) are stated with their relevant limits.

The relevant regulation for UWB ODC devices differentiate between quasi fixed and mobile usage see in addition ECC/DEC(07)01 [i.4] and EC DEC 2104/702/EC [i.37]

Therefore the necessary measurement scenarios and setups are shown in figure 11 and figure 12 for the quasi fixed and figure 14 for the mobile use. Details of the measurement procedure are described in ETSI EN 302 435 [i.19].



Horizontal area with reduced e.i.r.p limits, see figure 12.

Figure 11: Test set-up for e.i.r.p. measurement for ODC, quasi fixed usage, example table saws

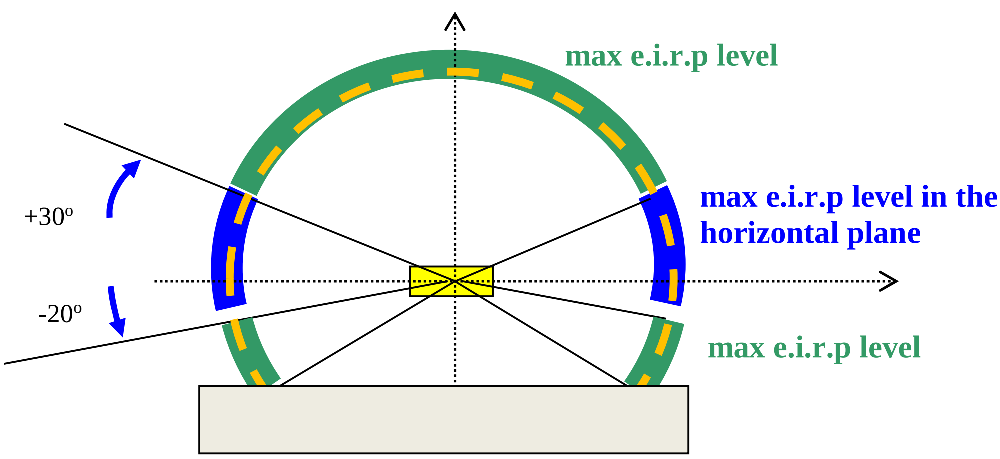


Figure 12: Spatial requirements for quasi fixed test set-up

For the quasi fixed use-cases the following limits are required.

Table 10: Maximum e.i.r.p. limits (quasi fixed installation)

Frequency range (GHz)	Maximum mean e.i.r.p spectral density (dBm/MHz)	max PSD in the horizontal plane (-20 to 30° elevation) (dBm/MHz)
Below 1,73	-85	-85
1,73 to 2,2	-65	- 70
2,2 to 2,5	-50	-50
2,5 to 2,69	-65, -50 (see note 1)	-70
2,69 to 2,7	-55	-75
2,7 to 2,9	-50	-70
2,9 to 3,4	-50	-70
3,4 to 3,8	-50	-70
3,8 to 4,8	-50	-50
4,8 to 5	-55	- 75
5 to 5,25	-50	-50
5,25 to 5,35	-50	- 60
5,35 to 5,6	-50	-50
5,6 to 5,65	-50	-65
5,65 to 5,725	-50	-60
5,725 to 8,5	-50	-50
8,5 to 10,6	-65	-65
Above 10,6	-85	-85
NOTE 1: Devices using a Listen Before Talk (LBT) mechanism, as described in the harmonised standard ETSI EN 302 498 [i.21], which meet the technical requirements defined in the related regulation, are permitted to operate in frequency ranges 2,5 GHz to 2,69 and 2,9 GHz to 3,4 GHz with a maximum mean e.i.r.p. spectral density of -50 dBm/MHz.		

For detailed mitigation description, see ETSI TR 103 181-2 [i.15].

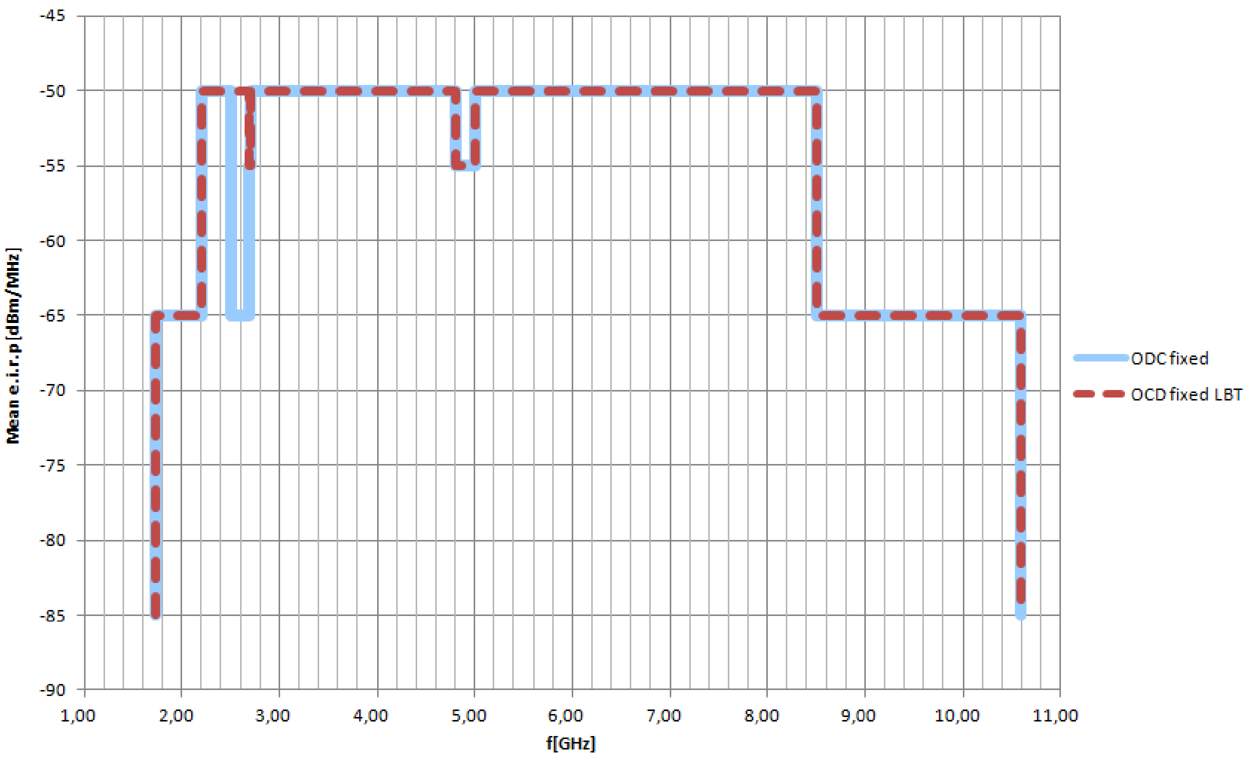


Figure 13: Mean power limits for UWB ODC quasi fixed usage (with or without mitigations)

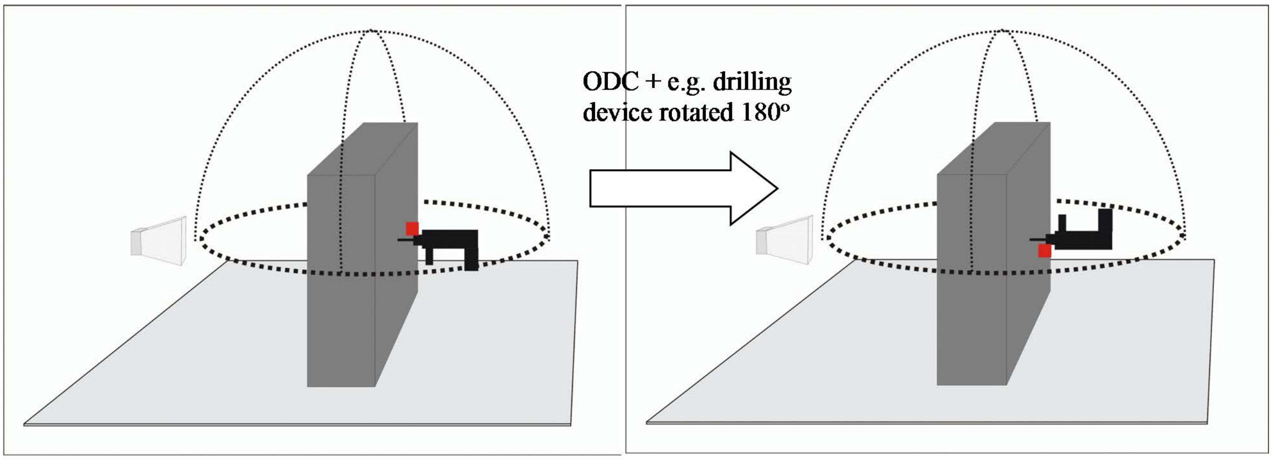


Figure 14: Measurement arrangement for emission measurements of mobile ODC use-cases, example break through protection drilling devices

Table 11: Maximum e.i.r.p. limits (non fixed usage)

Frequency range (GHz)	Maximum mean e.i.r.p. spectral density without LBT mitigation (dBm/MHz)	Maximum mean e.i.r.p. spectral density with LBT mitigations (dBm/MHz)
Below 1,73	-85	-85
1,73 to 2,2	-70	-70
2,2 to 2,5	-50	-50
2,5 to 2,69	-65	-50 (see note 1 and 2)
2,69 to 2,7 GHz	-70 (see note 3)	-70 (see note 3)
2,7 to 2,9 GHz	-70	-70
2,9 to 3,4 GHz	-70	- 50 (see note 1)
3,4 to 3,8 GHz	-50 (see notes 2 and 3)	-50 (see notes 2 and 3)
3,8 to 4,8 GHz	-50	-50
4,8 to 5 GHz	-55 (see notes 2 and 3)	-55 (see notes 2 and 3)
5 to 5,25 GHz	-50	-50
5,25 to 5,35 GHz	-60	-60
5,35 to 5,6 GHz	-50	-50
5,6 to 5,65 GHz	-65	-65
5,65 to 5,725 GHz	-60	-60
5,725 to 8,5 GHz	-50	-50
8,5 to 10,6 GHz	-65	-65
Above 10,6 GHz	-85	-85

NOTE 1: Devices using a Listen Before Talk (LBT).

NOTE 2: To protect the radio services, non fixed installations (application B) fulfil the following requirement for Total Radiated Power:

a) In the frequency ranges 2,5 GHz to 2,69 GHz and 4,8 GHz to 5 GHz, the Total Radiated Power spectral density has to be 10 dB below the max e.i.r.p. spectral density;

b) In the frequency ranges 3,4 GHz to 3,8 GHz, the Total Radiated Power spectral density has to be 5 dB below the max e.i.r.p. spectral density.

NOTE 3: Limitation of the Duty Cycle to 10 % per second.

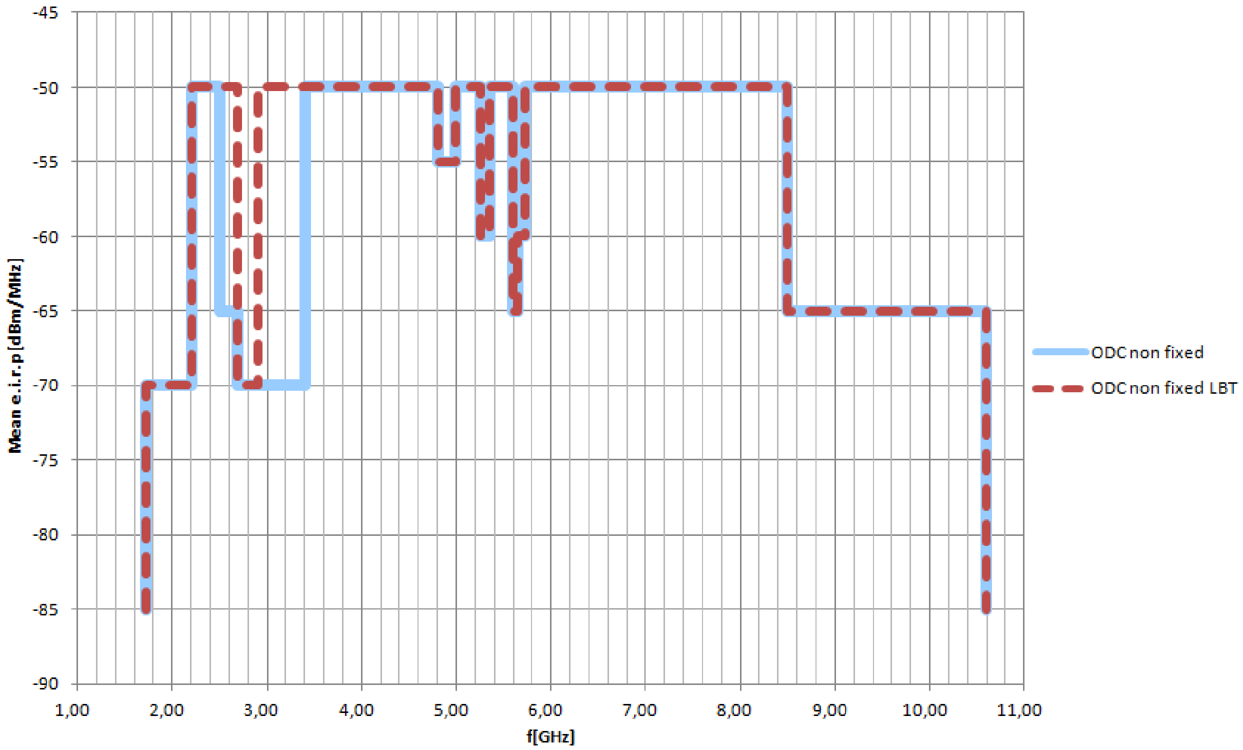


Figure 15: Mean power limits for UWB ODC mobile usage

4.2.4.2 Concrete inspections and imaging: professional Ground and Wall Probing Radars (GPR-WPR)

Ground Probing Radars (GPR) and Wall Probing Radars (WPR) are UWB sensors mainly used in survey and detection applications. They are basically radar systems, in which the sensor is in close proximity to the materials being investigated. This therefore does not include radars operated from aircraft or spacecraft. Moreover, the GPR/WPR applications are not intended for communications purposes, and the intended signal is not radiated into free space.

GPR and WPR Equipment cannot be considered consumer applications, on the contrary they are intended to be used by competent professional personnel.

In ECC/DEC(06)08 [i.43], GPR/WPR systems have been defined, and they are covered by ETSI EN 302 066 [i.20]:

- A GPR is an imaging system based on a field disturbance sensor that is designed to operate only when in contact with, or within one meter of, the ground for the purpose of detecting or obtaining the images of buried objects or determining the physical properties within the ground. They operate over approximately one decade in the frequency range 30 MHz to 12,4 GHz. The energy from the GPR is intentionally directed down into the ground for this purpose. Any horizontal radiation from this equipment is caused by leakage and is considered as undesired emission.

- A WPR is an imaging system based on a field disturbance sensor that is designed to detect the location of objects contained within a "wall" or to determine the physical properties within the "wall", operating in the frequency range 30 MHz to 12,4 GHz". The "wall" is a building material structure or any other concrete structure, the side of a bridge, the wall of a mine or another physical structure that is dense enough and thick enough to absorb the majority of the signal transmitted by the imaging system; The sensor radiates directly into a "wall".

Other equipments that may be considered within this class of sensors are equipment fitted with integral antennas and without antenna connector, or equipment which uses different imaging heads (antennas) with an antenna connector, to allow operation at different frequencies.

4.2.5 (Tank) Level probing application

4.2.5.1 Overview

This kind of sensors operates (at UWB frequencies) in the frequency range 4,5 to 7 GHz and 8,5 to 10,6 GHz. They are generally inserted in a tank, open or closed, to detect the level, so that the radiation pattern is directive to the level to be detected. However, some unintentional radiated of the tank exist, although significantly reduced with respect to the maximum radiation. To further mitigate this radiation, care should be taken to use low side lobes antennas. More details can be found in the related ETSI EN 302 372 TLPR [i.27] and ETSI EN 302 729 LPR [i.26], where quantities to be tested for conformance (emissions, e.i.r.p., duty cycle, etc.) are stated with their relevant limits.

4.2.5.2 Tank Level Probing Radar

The objective of TLPR systems is to accurately and reliably measure substance levels contained within a closed (not open) metallic tank or reinforced concrete tank, or similar enclosure structure made of comparable attenuating material. TLPRs use either a time of flight or FMCW principle to measure level. For time of flight the TLPR transmits a short pulse (of about 1 nanosecond) into the tank and measures the time it takes for this pulse to travel through the tank and bounce off the surface back to the TLPR. For FMCW the TLPR changes the transmitted frequency at a known change rate, and then compare transmitted frequency to received frequency. The frequency difference is proportional to the distance to the surface. In all applications, the objective of the TLPR designer and user is to contain the radiated energy inside the tank. Any radiation outside of the tank is caused by leakage and is considered as unintentional emission.

TLPRs provide high accuracy and outstanding reliability, high resistance to dirt and tank atmosphere, regardless of the substance in the tank, its temperature or pressure, allowing precise control of manufacturing processes and storage facilities.

Currently TLPRs find main applications, for example, in the following industries:

- refineries;
- chemical;
- petrochemical;
- pharmaceutical;
- power engineering;
- custody transfer;
- food and beverage;
- cement, powder, wood chips and other solid material applications;
- aviation fuel depots;
- water and sewage treatment, etc.

Detailed descriptions can be found in the related ETSI System Reference Document ETSI TR 102 347 [i.55] and the related ETSI EN 302 372 [i.27].

UWB Tank Level Probing Radar (TLPR) applications operate in the following frequency bands or part hereof as specified in table 11.

Table 12: Frequency bands designated to Tank Level Probing Radars (TLPR)

	Frequency Bands/frequencies (GHz)
Transmit and Receive	4,5 to 7
Transmit and Receive	8,5 to 10,6
Transmit and Receive	24,05 to 26,5
Transmit and Receive	57 to 64
Transmit and Receive	75 to 85

Table 12 shows a list of the frequency bands as designated to Tank Level Probing Radars in the Recommendation CEPT/ERC/REC 70-03 [i.45]. TLPRs are used for tank level measurement applications.

Devices herein named TLPRs and using UWB are intended for operation as Short Range Devices, in which the devices are installed in closed metallic tanks or reinforced concrete tanks, or similar enclosure structures made of comparable attenuating material, holding a substance, liquid or powder.

These applications are to be considered radar applications, therefore they are not intended for communications purposes. Their intended usage excludes any intended radiation into free space.

TLPRs radiate RF signals directly from the tank top downwards to the surface of a substance contained in a closed tank. Any radiation outside of the tank is caused by leakage and is considered as unintentional emission. It applies only to TLPRs fitted with dedicated antennas. The present document does not necessarily include all the characteristics, which may be required by a user, nor does it necessarily represent the optimum performance achievable.

4.2.5.3 Level Probing Radar

LPRs are installed and used in industrial environment concerned with process control to measure the amount of various substances (mostly liquids or granulates). LPRs are used for a wide range of applications such as process control, custody transfer measurement (government legal measurements), water and other liquid monitoring, spilling prevention and other industrial applications. The main purposes of using LPRs are:

- to increase reliability by preventing accidents;
- to increase industrial efficiency, quality and process control;
- to improve environmental conditions in production processes.

Detailed compatibility studies were performed by CEPT and published in ECC Report 139 [i.57]. The studies considered introduction of different kinds of LPR devices in various deployment scenarios and their impact on identified potential victim radiocommunications services and applications used in the same or adjacent bands. The regulatory conditions set out in ECC Decision (11)02 [i.44] were derived from the findings of the ECC Report 139 [i.57]

The outcome of the findings of ECC Report 139 [i.57] resulted in the following technical mitigation requirements:

1) LPR devices should operate only with dedicated/integrated certified antennas, which comply with the requirements for the maximum width of main beam specified in table 14 (column C) below;

2) Emissions of LPR devices should comply with the mean e.i.r.p. spectral density and peak e.i.r.p. limits, specified in table 14 (columns A, B and D);

3) Strict (stable) downward orientation of LPR antennas under any operating conditions should be ensured by appropriate installation;

4) LPR devices to be operated under license-exempt conditions should include technical provisions to limit the radiation in all directions regardless of the installation heights and reflecting material below the LPR. A practical technical solution to achieve this is to have Automatic Power Control (APC) implemented with a dynamic range of at least about 20 dB or an equivalent mitigation technique. APC as well as equivalent techniques for LPR devices are described in the Harmonized European Standard ETSI EN 302 729 [i.26];

5) RAS stations (a list of presently known sites is provided in Annex 3 of ECC report 139 [i.57]) should be additionally protected as follows:

    - From 0 km up to 4 km radius around any RAS station, installation of LPR devices operating in 6,6 GHz, 24 GHz and 75 GHz bands should be prohibited unless a special authorization has been provided by the responsible national administration.

    - From 4 to 40 km around any RAS station, the antenna height of an LPR installation of devices operating in 6,6 GHz, 24 GHz and 75 GHz bands should not exceed 15 m.

Table 13: Essential technical requirements for LPR devices

Frequency band (GHz)	Maximum mean e.i.r.p. spectral density (dBm/MHz) (see notes 1 and 5)	Maximum peak e.i.r.p. (dBm measured in 50 MHz) (see notes 2 and 5)	Maximum antenna beamwidth (degree) (see note 3)	Maximum mean e.i.r.p. spectral density on half-sphere (dBm/MHz) (see notes 4 and 5)
	A	**B**	**C**	**D**
6,0 to 8,5	-33	+7	12	-55
24,05 to 26.5	-14	+26	12	-41,3
57 to 64	-2	+35	8	-41,3
75 to 85	-3	+34	8	-41,3

NOTE 1: Mean e.i.r.p. spectral density within LPR antenna main beam is the average power per unit bandwidth radiated in the direction of the maximum level.

NOTE 2: Peak e.i.r.p. within main beam is the power contained within a 50 MHz bandwidth at the frequency at which the highest mean radiated power occurs. If measured in a bandwidth of x MHz, this level is to be scaled down by a factor of 20log (50/x) dB.

NOTE 3: Defined by -3 dB level, relative to maximum gain. note that in ETSI EN 302 729 [i.26] expressed as ± HalfBeamWidth, here it is expressed as total opening angle. The LPR antenna gain in the elevation angles above 60 degrees from the main beam direction has to fulfil a maximum value of -10 dBi.

NOTE 4: The maximum mean e.i.r.p. spectral density limits on half sphere around LPR installation accounts for both the LPR antenna side-lobe emissions and any reflections from the measured material/object. Compliance with these limits is assumed in case LPR devices comply with measured maximum mean e.i.r.p. spectral density and the maximum peak e.i.r.p. limits within main beam (Table 12, Columns A and B) and use the prescribed antenna (see note 3).

NOTE 5: The related limits in unwanted emissions domain radiated by LPR are those as listed in table 2 of the ECC/DEC (11)02 [i.44] for LPR devices operating in the 6,0 GHz to 8,5 GHz band. For LPR operating in the other bands, the limits for emissions in the unwanted emissions domain are at least 20 dB less than the in-band limits specified in table 1. For LPR operating within the 24,05 Ghz to 26,5 GHz band, the unwanted emissions in the 23,6 GHz to 24,0 GHz "passive band" are at least 30 dB less than the in-band limits specified in table 12.

4.2.6 Airborne

The ECC/DEC(12)03 [i.41] and the ECC report 175 [i.58] describe the use of radio links for communications purposes onboard an aircraft like an emerging field. Motivated by the increasing demand for lighter and more efficient aircraft as well as the demand for the introduction of wireless communications capabilities for passengers and crew, the use of ultra-wideband (UWB) radio technology onboard aircraft is seen as a promising technological option for replacing wires and creating new and innovative applications. In particular applications such as enhanced wireless passenger communications and entertainment, non-safety wireless crew communications as well as non-safety wireless control and monitoring functions are candidates for the initial use of UWB technology.

In the ECC Report 175 [i.58], the results about the compatibility studies are presented, in particular in the section 3: "Fuselage attenuation" and section 4: "Compatibility Studies", there is a detailed description of the "attenuation due to the aircraft" for the coexistence between UWB system (on-board aircraft) and victim systems and in the subsections and there is a complete analysis about all interference cases between this on-board aircraft devices and other systems such as those described in ECC Report 064 [i.5]:

- Fixed Service (FS)
- Mobile Satellite Service (MSS)
- Earth Exploration Satellite Service (EESS)
- Radio Astronomy Service (RAS)
- Radio Navigation Satellite Service (RNSS)
- Fixed Satellite Service (FSS)
- Amateur/Amateur satellite systems (Amateur)
- Maritime mobile service including global maritime distress and safety system (Maritime)
- Aeronautical mobile service and radio determination service (Aeronautical)
- Meteorological radar

and others such as surface search radars, air search radars and earth stations. Below it is transcribed the conclusions of this report:

- *"Compatibility analysis provided above shows that under certain assumptions there is maybe a potential of interference to meteorological-satellite service Earth stations of geostationary satellite systems from UWB airborne applications in frequency band 7450-7550 MHz. The interference deficits vary from 0.4 dB to 3 dB and from 1 dB to 9 dB for 5 m Earth station antenna at 10000 m and 5000 altitudes respectively. The cumulated duration of interference exceeding the I/N criterion of -20 dB vary:*
  - *At 10.000m altitude from 245 seconds at 40° elevation to 367 seconds at 60° elevation*
  - *and at 5.000m altitude from 324 seconds at 60° to 684 seconds.at 20° elevation*
- *Therefore it may be required to consider additional mitigation techniques which could conceivably allow decreasing the impact of UWB airborne on Earth stations of meteorological- satellite service in frequency band 7450-7550 MHz. Otherwise to ensure adequate protection of meteorological-satellite service stations UWB airborne applications should be activated at 10.000 m."*

The table 15 below provides an overview of the results of the compatibility studies which were achieved assuming 2 active devices per aircraft and those UWB devices are operating using 500 MHz channel bandwidth like a conclusion of the ECC Report 175 [i.58].

Detailed descriptions can be found in the related ETSI System Reference Document ETSI TR 102 834 [i.59].

The relevant regulation for UWB airborne devices are in ECC/DEC(12)03 [i.41] and EC DEC 2014/702/EC [i.37].

Table 14: Maximum e.i.r.p. limits

Frequency range (GHz)	Maximum mean e.i.r.p. spectral density	Maximum peak e.i.r.p. (defined in 50 MHz)	Requirements for mitigation techniques
Below 1,6	-90 dBm/MHz	-50 dBm	
1,6 to 2,7	-85 dBm/MHz	-45 dBm	
2,7 to 3,4	-70 dBm/MHz	-36 dBm	
3,4 to 3,8	-80 dBm/MHz	-40 dBm	
3,8 to 4,2	-70 dBm/MHz	-30 dBm	
4,2 to 4,8	-70 dBm/MHz	-30 dBm	
4,8 to 6	-70 dBm/MHz	-30 dBm	
6,0 to 6,650	-41,3 dBm/MHz	0 dBm	
6,650 to 6,6752	-62,3 dBm/MHz	-21 dBm	notch of 21 dB should be implemented to meet a level -62.3 dBm/MHz (see note 1)
6,6752 to 8,5	-41,3 dBm/MHz	0 dBm	7,25 GHz to 7,75 GHz (FSS and MetSat (7,45 GHz to 7,55 GHz) protection) (see notes 1 and 2) 7,75 GHz to 7,9 GHz GHz (MetSat protection) (see notes 1 and 3)
8,5 to 10,6	-65 dBm/MHz	-25 dBm	
Above 10,6	-85 dBm/MHz	-45 dBm	

NOTE 1: Alternative mitigation techniques offering equivalent protection such as the use of shielded portholes could be a solution.

NOTE 2: 7,25 GHz to 7,75 GHz (Fixed Satellite Service) and 7,45 GHz to 7,55 GHz (Meteorological Satellite) protection: -51.3 - 20 * $\log_{10}$(10 [km] / x [km]) (dBm/MHz) for heights above ground above 1 000 m, where x is the aircraft height above ground in kilometres, -71.3 dBm/MHz for heights above ground of 1 000 m and below.

NOTE 3: 7,75 GHz to 7,9 GHz (Meteorological Satellite) protection: -44.3 - 20* $\log_{10}$(10 [km] / x [km]) (dBm/MHz) for heights above ground above 1 000 m, where x is the aircraft height above ground in kilometres, and -64,3 dBm/MHz for heights above ground of 1 000 m and below.

5 UWB Signal definition

5.0 Definition

The present document describes many different types of UWB technologies used for a variety of different applications. The UWB technologies used for these applications can be broken down into two main groups:

1) impulse derived technologies, see clause 5.1

2) frequency modulated/carrier-based, see clause 5.2

3) UWB signal characteristics

An RF signal needs to satisfy some predefined requirements in terms of carrier and bandwidth in order to be qualified as an UWB signal. In table 15, spectrum requirements for UWB radio in Europe, United States and Japan are shown.

Table 15: UWB general Requirements

	Europe	United States	Japan
Bandwidth	> 50 MHz at -13 dB	fractional bandwidth equal to or greater than 0,20, or bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth at -10 dB	> 450 MHz at -10 dB
Operating frequency bands	Whole spectrum	> 960 MHz	- from 3,4 GHz to 4,8 GHz - from 7,25 GHz to 10,25 GHz
Signal limitation	No	At any point in time / modulation on/off	Not applicable

5.1 Impulse derived

Impulse derived UWB technology consists of a series of impulses created from a DC voltage step whose rise-time can be modified to provide the maximum useful number of spectral emission frequencies. This derived impulse can then be suitably modified by the use of filters or mixing with a suitable carrier frequency to locate the resulting waveform within a specific frequency spectrum range. This filter can be a stand-alone filter or incorporated into an antenna design to reduce emissions outside the designated frequency spectrum.

The output frequency spectrum of such a system depends on a number of factors. These include, at a minimum, the pulse form/pulse shape used, together with the underlying pulse repetition rate of the system. Additionally, the pulse train can be modified by a number of modulation techniques, either for the purposes of information transfer and/or in order to achieve a more uniform output spectrum than can be generated using a train of pulses alone.

In some systems, the transmitted energy may be summed at the receiver to reproduce the transmitted pulse.

This technology is suitable for direct and non-direct line of sight communications, any reflected or time delayed emissions being suppressed by the receiver input circuits.

5.1.1 Pulse form/Pulse shape

An UWB pulsed radio typically transmits a train of short radio pulses. The duration of each pulse is commonly defined as the time such that the level of the envelope of the transmitted signal is higher than a predefined threshold (e.g.: 10 % of peak). Assuming the pulses to be Gaussian, the waveform for a generic UWB pulse may be expressed as follows:

$$x(t) = V_o e^{-(qB_W t)^2} \quad (1)$$

where:

- V_o is the peak amplitude
- B_W is the signal bandwidth at -10 dB
- q is a constant factor, namely 1,4639…

Given this definition, for an UWB signal having 500 MHz bandwidth, the typical pulse duration T_{on}, considered at values higher than 10 % of peak value, turns out to be about 4,0 nsec (or lower).

Theoretical time and spectral patterns at baseband for different -10 dB bandwidths are shown in figure 16.

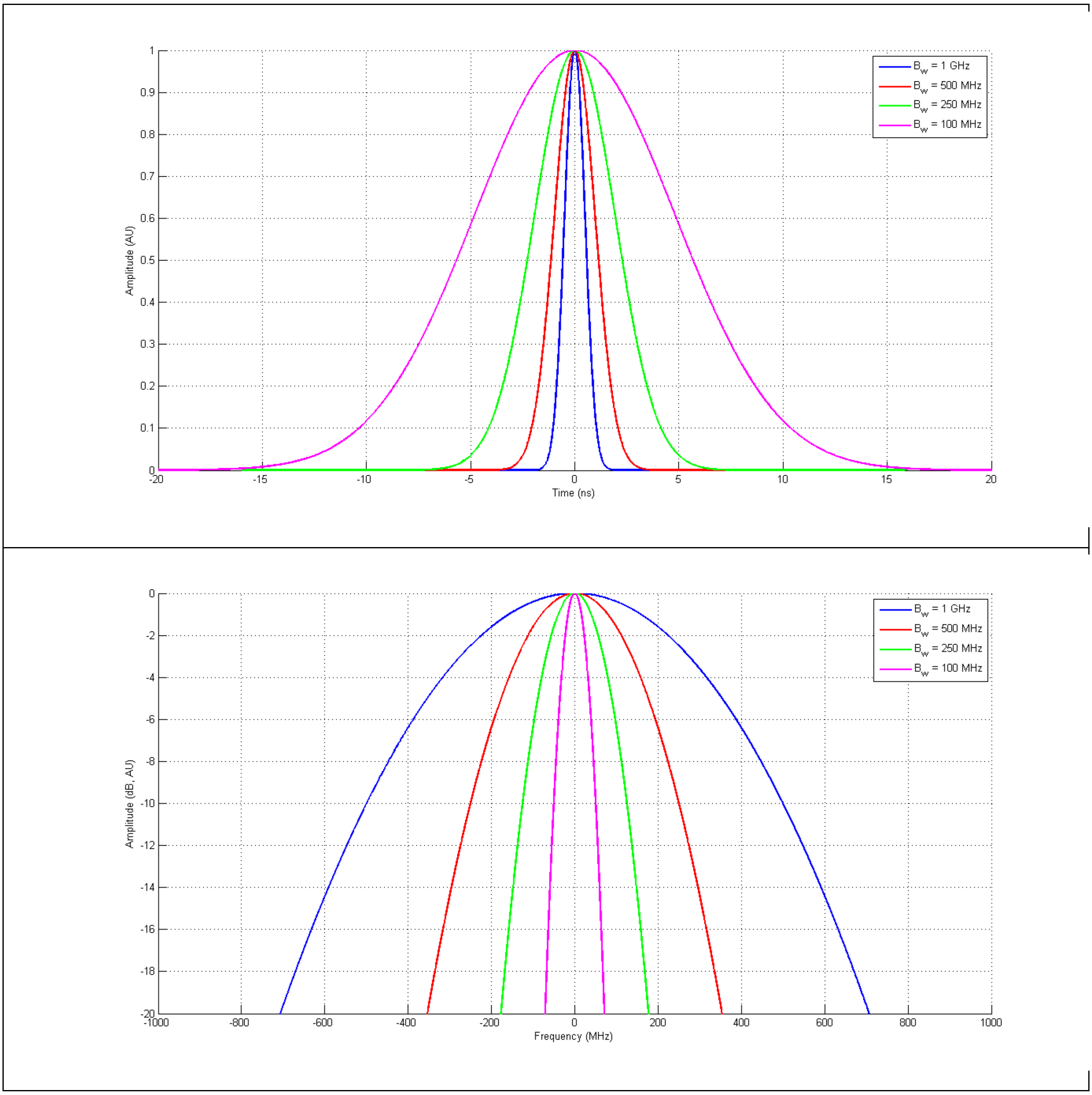


Figure 16: Gaussian UWB pulses: time and spectral patterns for different bandwidth

5.1.2 Characteristics of the fixed Pulse Train

Suppose a series of impulses of the form shown previously are transmitted as a pulse train with fixed pulse spacing and uniform pulse shape, as shown in the time/frequency domain below:

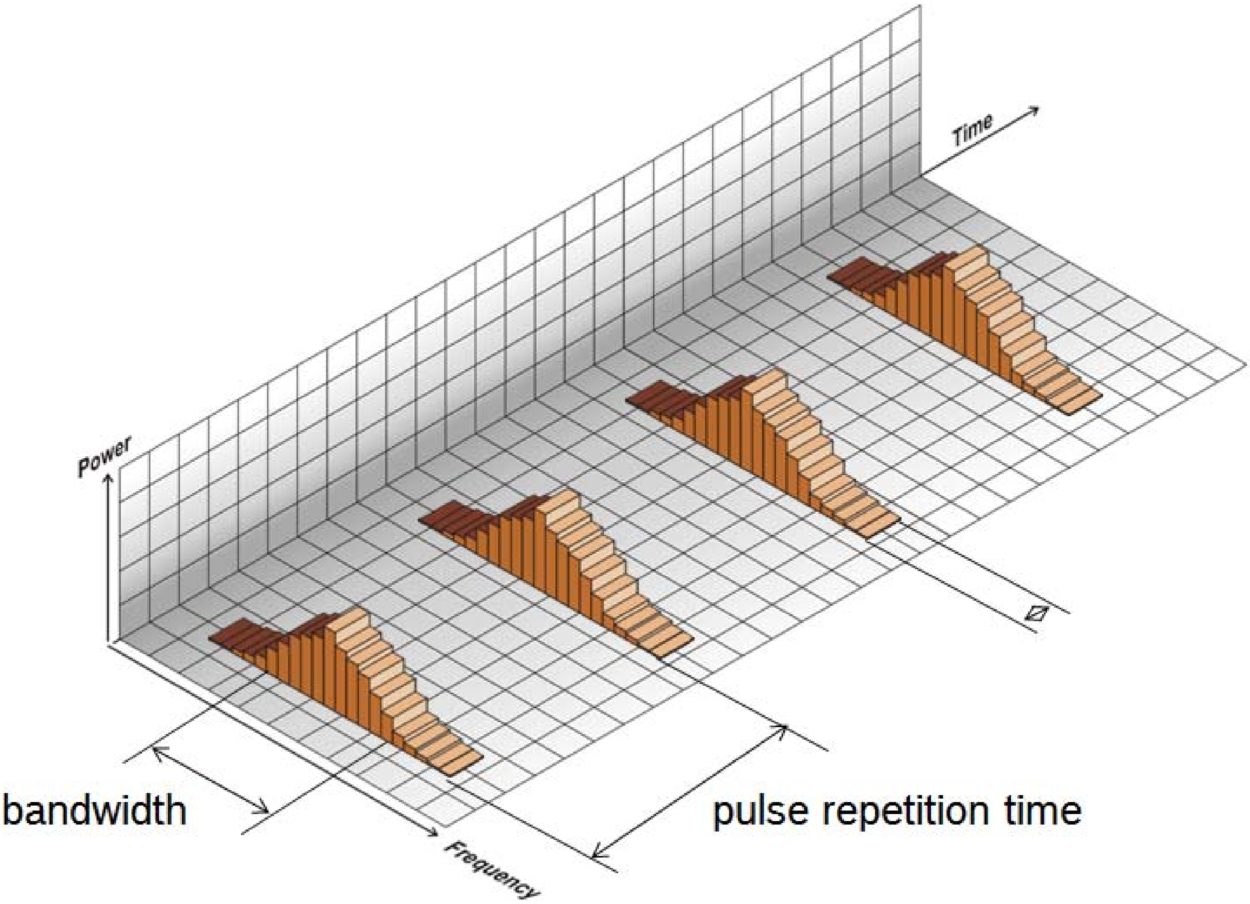


Figure 17: Characteristics of the fixed Pulse Train

The overall output spectrum of the device in the frequency domain is a set of comb lines as show in the plot below. The comb lines sit within the spectrum envelope of the individual UWB pulses, with a comb separation equal to the reciprocal of the pulse repetition rate of the pulse train:

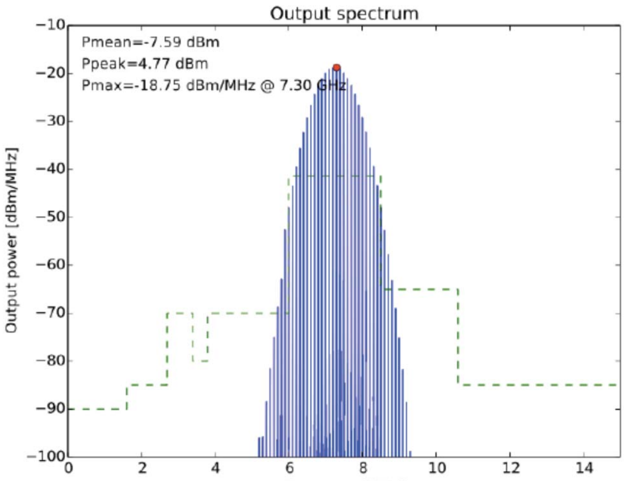


Figure 18: Example of a spectrum of the fixed Pulse Train

No information is conveyed in a continuous pulse train of this nature, but the above diagrams show the fundamental characteristics of impulse UWB systems, which may then be modified by modulation (either for data transfer or spectral smoothing) as discussed in the next clause.

5.1.3 Modulation schemes for pulsed systems

5.1.3.0 Description

There are a wide variety of modulation schemes which may be applied to the impulses in a UWB pulse train to either encode and transfer data, and/or improve the spectral characteristics of the transmitter. In either case, the application of modulation affects the output spectrum of the transmitter.

5.1.3.1 Some example modulation techniques

Many traditional modulation techniques may be applied directly to the pulse train, including:

- On-Off keying (OOK) - the modulation causes pulses in the pulse train to be either transmitted or not transmitted.

Dithering or pulse-position modulation (PPM) - the precise timing of the pulses in the pulse train is varied.

NOTE: Typically, "dithering" is used to refer to a pulse train where the timing of the pulses, compared to the nominal pulse train timings, is varied by only a small amount relative to the inter-pulse time spacing.

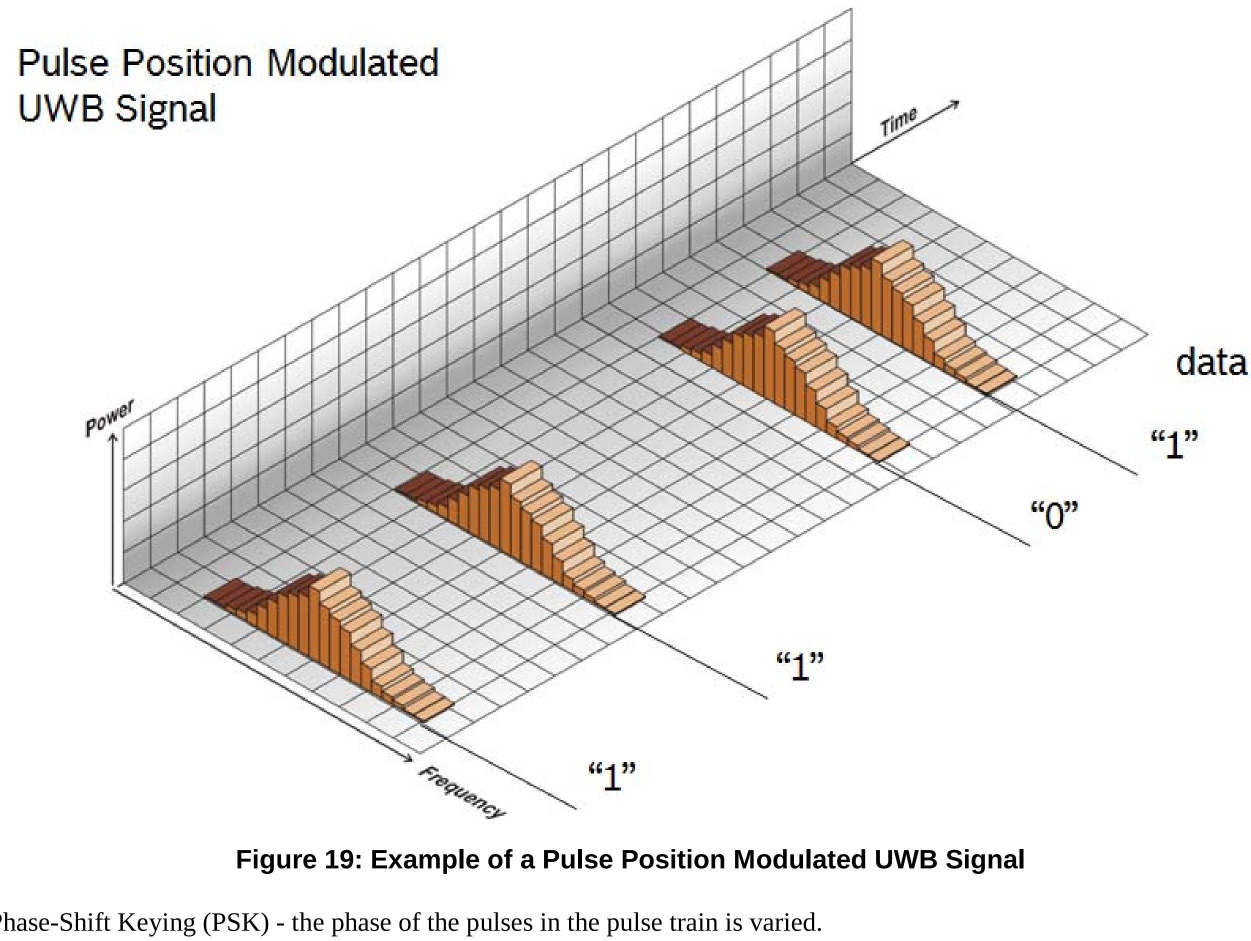


Figure 19: Example of a Pulse Position Modulated UWB Signal

Phase-Shift Keying (PSK) - the phase of the pulses in the pulse train is varied.

NOTE: Binary phase shift keying, BPSK, is shown below - the phase of the pulse is shifted by 180° depending on whether a '1' or and '0' is transmitted.

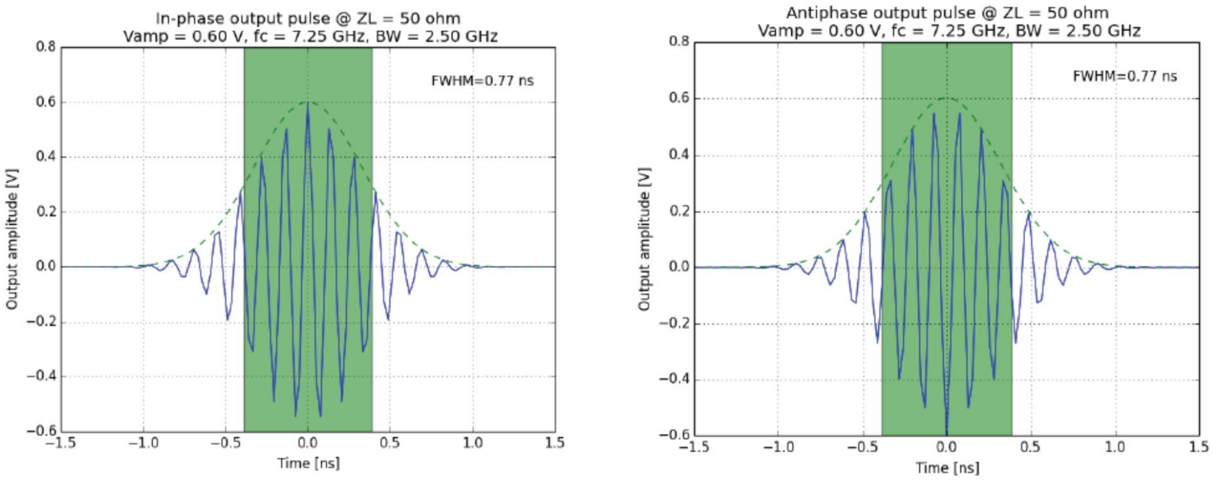


Figure 20: Example of a time signal for binary phase shift keying

Other examples of modulation techniques which might be applied to the impulse train include pulse amplitude modulation (PAM), pulse shape modulation.

5.1.3.2 Use of modulation for data transfer purposes

In some applications (e.g. data communications and location tracking applications) it is necessary to encode data on to the UWB pulse train using a modulation method. (note that there are other applications, e.g. sensing systems, which may not require encoding of the UWB pulse train).

An example of systems which use an encoded UWB pulse train are low-data-rate UWB active RFID systems conforming to the IEEE 802.15.4f [i.64]. These systems consist of a set of ultra-low-power UWB beacons which are typically attached to moving objects, and a set of sensors placed around the environment. By detecting the signals from the beacons at the sensors, the location of each beacon can be determined. The UWB signals transmitted by the beacons obviously include the identity of the beacon, so that the correct source can be ascribed to a signal picked up by a sensor.

The UWB signals transmitted by beacons consist of a 1 MHz pulse train of ~1,25 ns pulses, modulated by on-off keying. A '1' bit is indicated by the presence of a pulse, a '0' is indicated by the absence of a pulse. A typical packet encoded upon the basic 1 MHz pulse train is shown below:

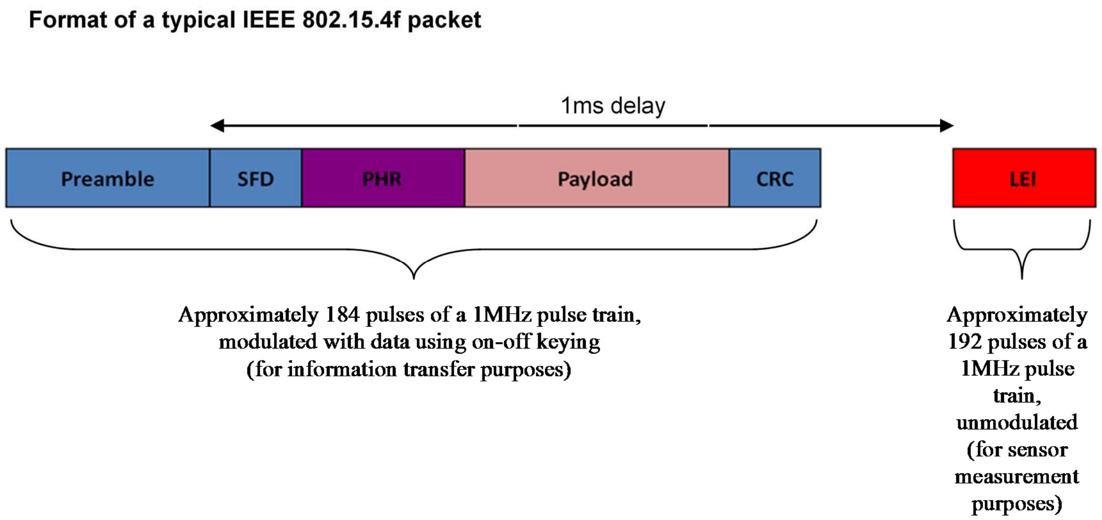


Figure 21: Format of a typical IEEE 802.15.4f packet

5.1.3.3 Use of modulation for spectral smoothing

A pulse-based UWB signal with a constant PRF will generate tones in the spectrum in multiples of the PRF resulting in non-optimal filling of the spectrum mask. By applying additional modulation (which may or may not carry useful data), the tones will be smeared out resulting in a more uniform spectrum density across the transmitted bandwidth. For example, modulation may be applied for spectral smoothing in the following ways:

- On/Off Keying: A randomized sequence of pulses are "swallowed" to spread the spectrum. This technique will reduce the average transmitted power.
- Dithering: Pseudo random phase jitter is applied to the signal. The average transmitted power is not affected. This method is comparable to PPM as described in the data modulation clause above.
- BPSK: The phase of the transmitted pulse is randomly inverted to avoid eliminate the tones. The average transmitted power is not reduced.

Combinations of these techniques may also be used, and, of course, modulation may be applied for both data transfer and spectral shaping to the same underlying pulse train.

Figure 22 show how BPSK can be used as an effective technique to spread the comb-line spectrum produced by a uniform-pulse-spacing signal:

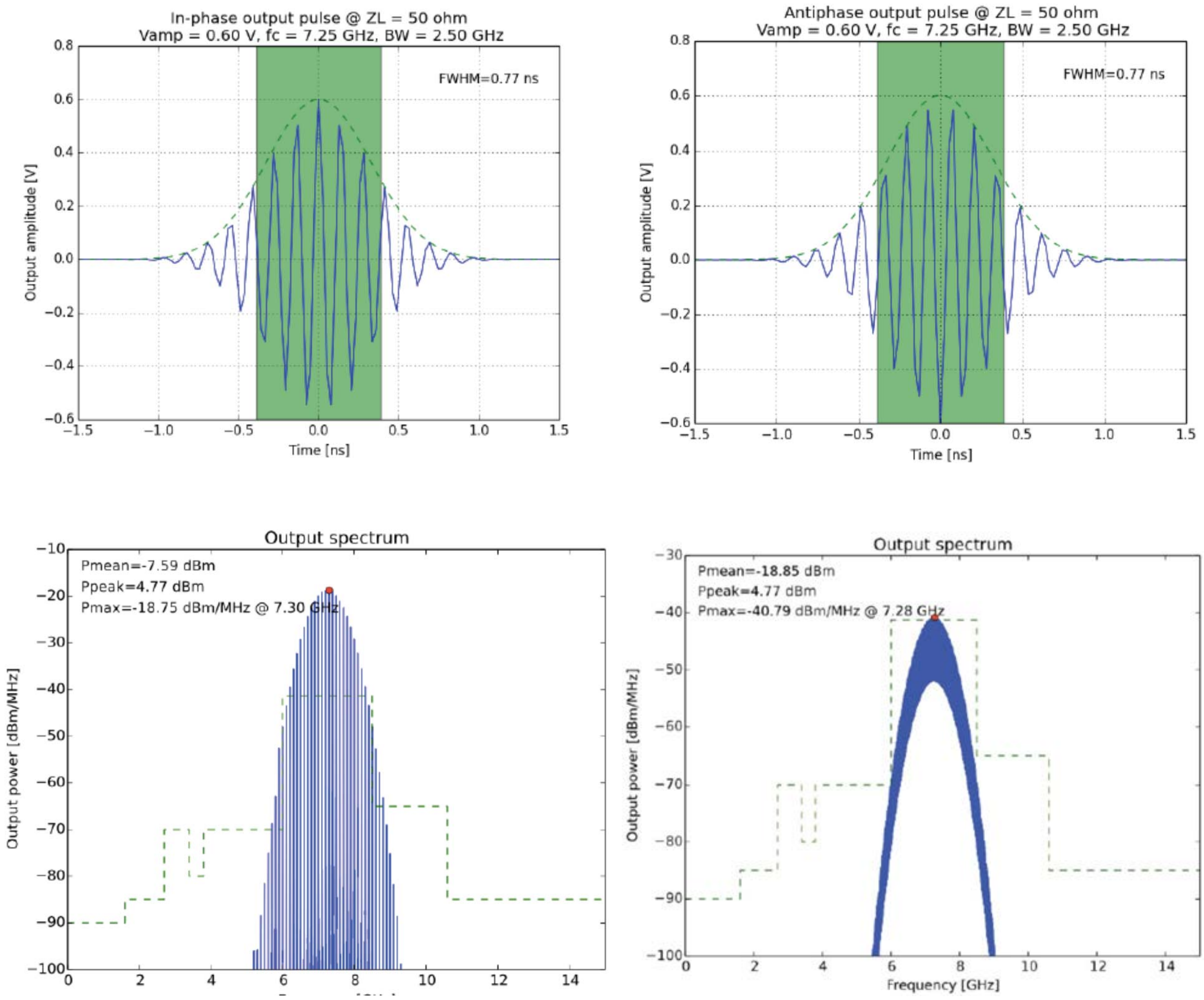


Figure 22: Example of two BPSK signals

5.2 Frequency modulated/carrier-based

5.2.1 Summary

For FMCW, FH, FSK , stepped frequency hopping or similar carrier based modulation schemes, it is important to describe the modulation parameters in order to ensure that the right settings of the measuring receiver are used. Important parameters are the modulation period, deviation or dwell times within a modulation period, rate of modulation (Hz/s).

5.2.2 Frequency hopping/stepping

Frequency hopping (FH) is a well-known technique that is used in radars, ranging transponders, and communications links, for similar reasons. The basic idea is that a relatively narrow-band radio is re-tuned rapidly, so that a set of channels at different radio frequencies are used in succession. The term "hopping" was originally applied to systems where the order of frequencies is randomized. However, it is the general term and is also applied to systems in which the frequencies are used in order, and which are also labelled as stepped-frequency. The processing of the multiple frequency channels can be either coherent or incoherent.

Frequency hopping has the following major advantages:

- It reduces interference, both due to the FH signal in other receivers and in the FH receiver. It utilizes a number of frequencies in quick succession, so if one of them is being used by another link then any interference will only occur while both are using the same frequency. This interference will thus be short-lived and only occupy a small fraction of the duration of a cycle covering all frequencies. Provided most channels are not being used locally, the FH link will be free of interference most of the time.

- In the coherent case, it is true UWB, so its time or range resolution is inversely proportional to the overall bandwidth, but its IF bandwidth is quite small. This makes both transmit and receive circuits easier to make, and so cheaper.

- Its receiver has a narrow bandwidth, and is tuned across the band during normal operation. It is thus able, inherently, to monitor the band for other radio signals, in order to implement a "detect and avoid" or "listen before talk" function.

- Provided the receiver can distinguish between desired signals (from transmitters in its own system) and other signals, it can suppress interference by omitting any affected frequencies from its processing. This processing then compensate with the gaps in the received spectrum, and this does degrade the system performance. However, this degradation may be small dependent on the kind of system, if only a few frequencies are affected.

- Once it is established that some frequencies are in use by another system or service that should be protected, the relevant frequencies can be omitted from the transmission, so there is a gap in the spectrum. This has the same effect in the receiver as has just been described for interference suppression by omitting frequencies.

- As the worldwide radio regulation for UWB is not aligned, these systems give the possibility to be easily adjusted to different frequency masks in different regions or countries.

- In radars there is also a kind of diversity gain due to changing the RF, in which case the technique is also called agility.

- In military systems it provides resistance to jamming. This is for similar reasons to its resistance to interference, except that now the hop sequence should be unpredictable.

This list does not include the advantages of UWB itself, only of implementing it as FH-UWB.

The following describes a frequency-hopping UWB system for local positioning systems. For the indoor and local positioning application, all but the last two advantages are important. In most FH systems (such as Wireless LAN and other links at 2,5 GHz) each channel is used individually, and the performance of the link corresponds in all respects to the bandwidth of one channel. When FH-UWB is used for positioning, all channels are processed together coherently, synthesizing a system with an RF bandwidth equal to the whole occupied bandwidth. This yields the fine ranging resolution that is required for positioning in cluttered environments. However, in other respects the system's performance still corresponds to a single channel's bandwidth; notably its data capacity.

The receiver technology employed is that of a carrier-based data radio, comparable to a 3G mobile phone but capable of frequency tuning over a much wider range and much faster. At each RF dwell (one channel) a short burst of coded carrier is transmitted, and when received it is integrated to recover the carrier phase and in some cases data bits as well. The sequence of frequencies used can be selected in several ways, but the most common choices are a linear sweep (also called a stepped chirp) and a pseudo-random sequence. These differ in their behaviour in the presence of a frequency offset between transmitter and receiver, due to local oscillator offset or Doppler shift. In the TRT FH-UWB system, a linear step sequence is preferred, and the frequency locking process is based on it.

A diagram of a small part of a linear FH-UWB or stepped-frequency signal is shown in figure 23.

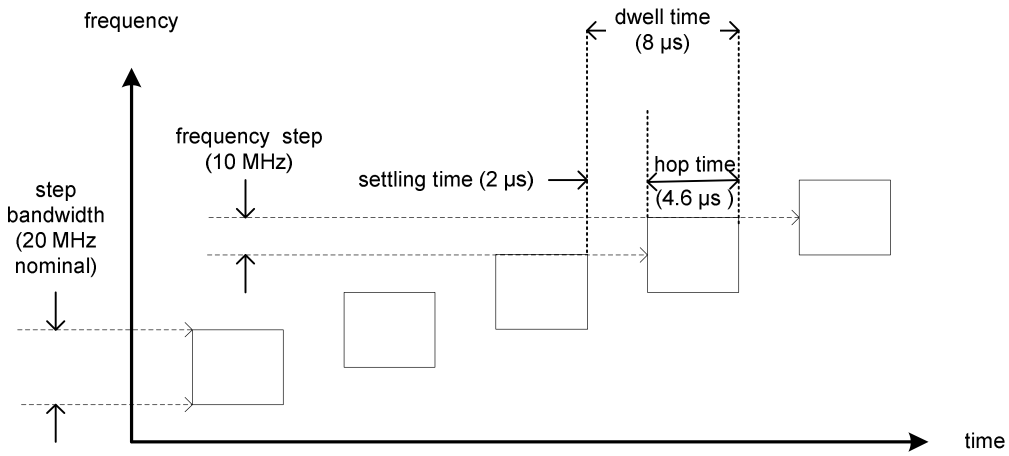


Figure 23: Small part of a linear FH-UWB signal

Figure 24, and those that follow, are based on the parameters of a specific FH-UWB signal currently implemented for indoor positioning systems. The same signal type can be used with different signal designs to suit a different application.

The full sequence contains 124 steps (or hops), so covering 1 230 GHz between centre frequencies or 1 250 GHz overall. The proportions of the drawing above thus give a misleading impression of the amount of the band occupied at any one time. Figure 24 shows the stepped-frequency UWB signal, drawn to scale, together with a 28 MHz bandwidth representing the widest of the Wimax options.

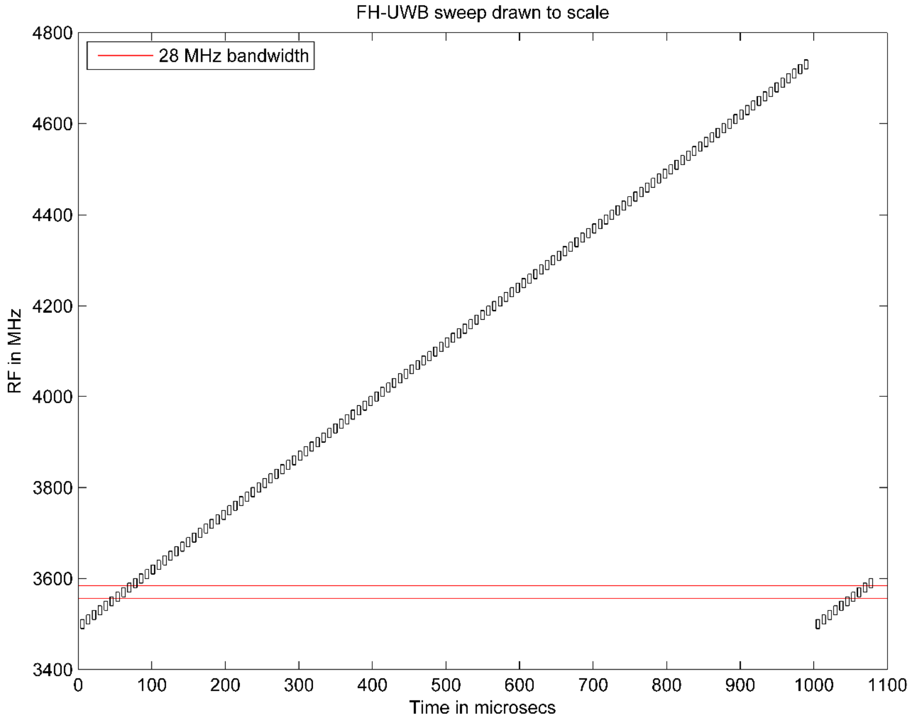


Figure 24: Stepped-frequency UWB signal together with a 28 MHz bandwidth representing the widest of the Wimax options

In reality, the spectrum of the signal burst in each hop is not rectangular, but represents the binary phase code that is applied.

Figure 25 shows a measured spectrum of a system that can be used for building material analysis (BMA) with different settings. The example stepped-frequency signal has 24 steps between 2 and 3 GHz. It can be observed that the spectrum looks very much like the spectrum of a pulse based system. However, in the time domain only one frequency/channel is active at once. The spectrum does also not reflect, if the hops are run through linearly (stepped-frequency) or in an arbitrary order (real hopping).

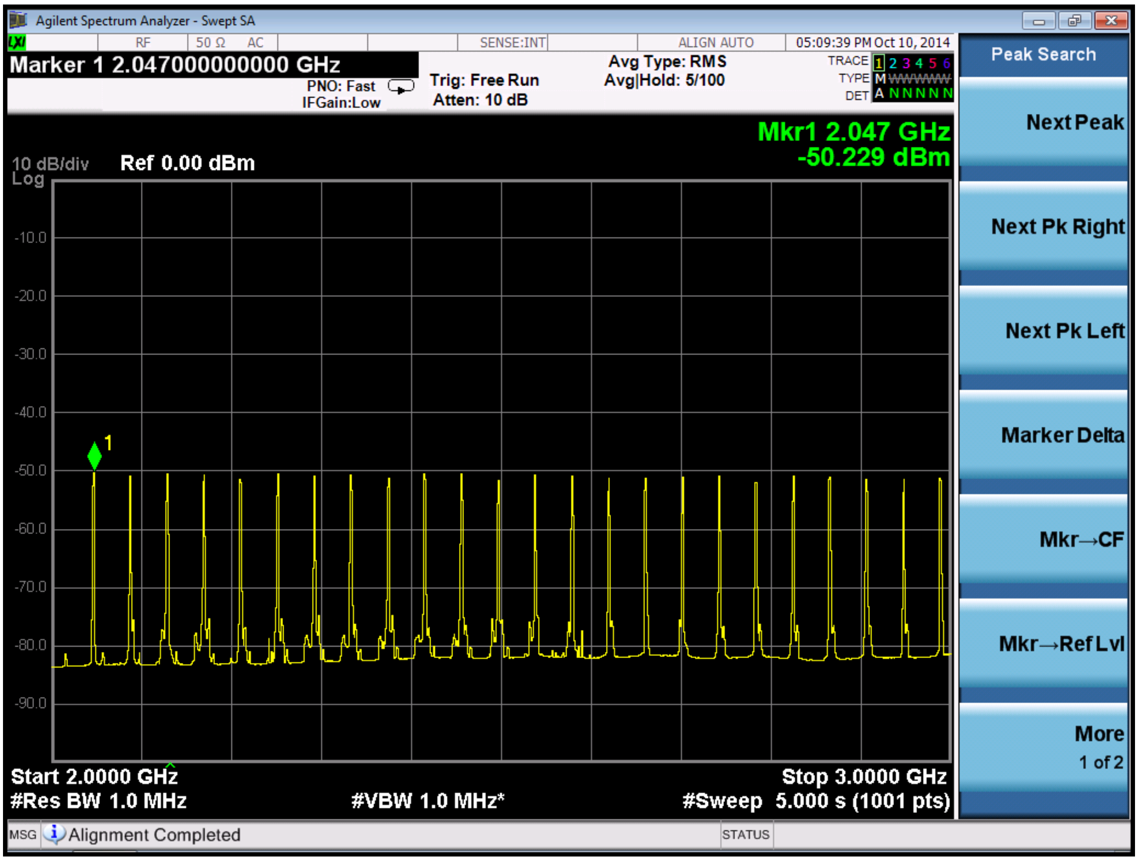


Figure 25: Spectrum of a stepped-frequency signal

5.2.3 Frequency modulated continuous wave

For Frequency Modulated Continuous Wave (FMCW) modulation, the transmitted waveform is frequency modulated over a period of time (P). This period of time may be constant, or may be varied. An example of a typical modulation scheme is shown in figure 26. During the time (P), the frequency may either increase or decrease. The modulation may assume (but is not limited to) the form of a "saw tooth", "triangular" or a "sinusoidal" waveform. Also a constant frequency may be maintained and transmitted during one or more periods of time. Furthermore, the transmitted power may be switched off during one or more periods of time (e.g. Frequency Modulated Interrupted Continuous Wave (FMCW)). The modulation waveform may be repeated or varied over several periods of time, and at the beginning or end of each period of time (P), there may be a time "G" (the "blanking period") where the transmitted waveform is adjusting to the requirements of the beginning of the next period. An example is shown in figure 26.

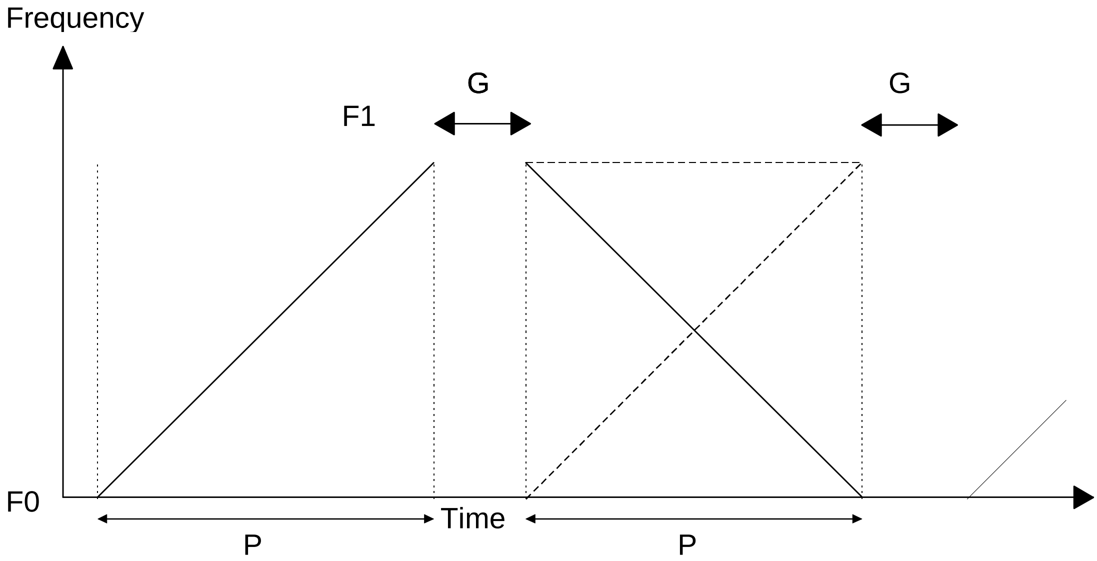


Figure 26: Typical FMCW modulation scheme

5.2.4 Multiband UWB signals

5.2.4.1 Introduction

The specific class of multiband UWB systems splits the overall available UWB bandwidth into sub-bands with a typical bandwidth of 500 MHz. The sub-band can either be used as independent communication channels or can be combined together. These signals have been proposed mainly for communication systems based on UWB. The split of the overall bandwidth into sub-band allows for a simpler signal processing by parallel operation in the receiver.

5.2.4.2 Multi-band pseudo -carrier modulated signal

"Multi-band pseudo-carrier" modulation was an approach to UWB proposed in the IEEE Multi-band pseudo-carrier UWB modulation is a method where the 7,5 GHz of permitted spectrum is split into multiple smaller frequency bands. The number of bands varies in the various proposals, with bandwidth usually in the 500 MHz to 800 MHz range.

Impulse shape is the primary characteristic that determines the distribution of energy within the frequency domain, and properly shaping the impulse will concentrate more of the energy in the centre lobe of the energy band, reducing side lobe energy and reducing chances for adjacent band interference.

To effectively fill the specified spectrum, multiple frequency bands of energy should be generated with different centre frequencies spaced across the spectrum. A method for shaping an impulse that enables centre frequency definition is shown in figure 27. The centre frequency selection is accomplished using a pseudo-carrier oscillation in generating and shaping the required UWB impulse. The frequency of the pseudo-carrier oscillation determines the centre frequency of the band, while the impulse shape defines the bandwidth.

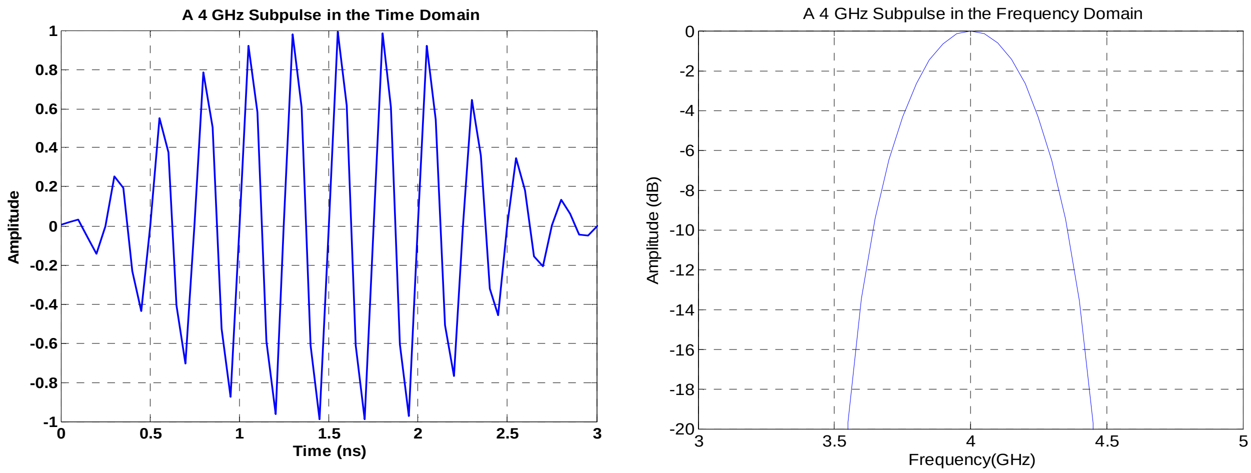


Figure 27: Amplitude and frequency spectrum characteristics for a pseudo-carrier oscillation

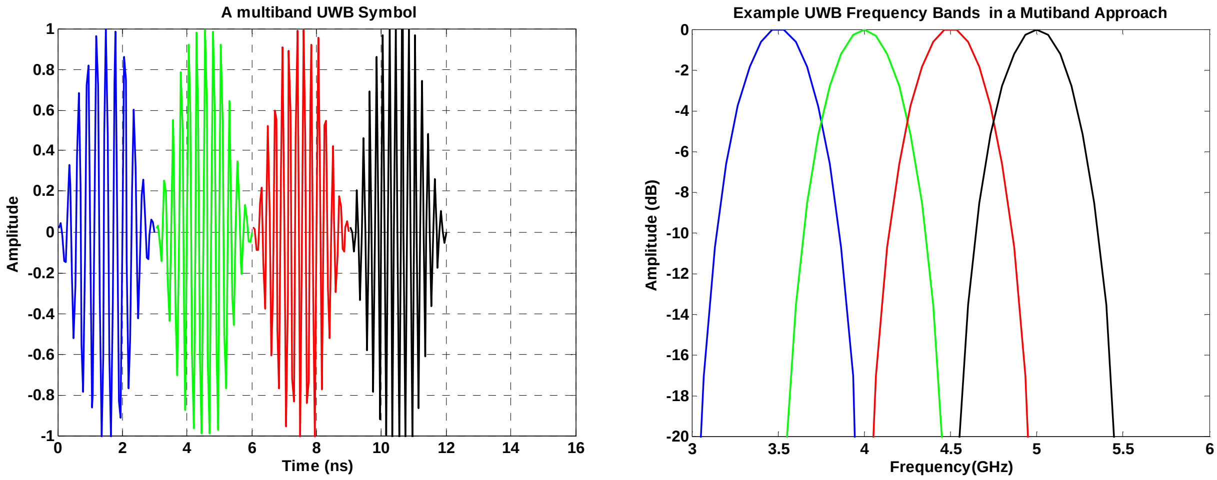


Figure 28: Amplitude and frequency spectrum characteristics for a multi-band symbol

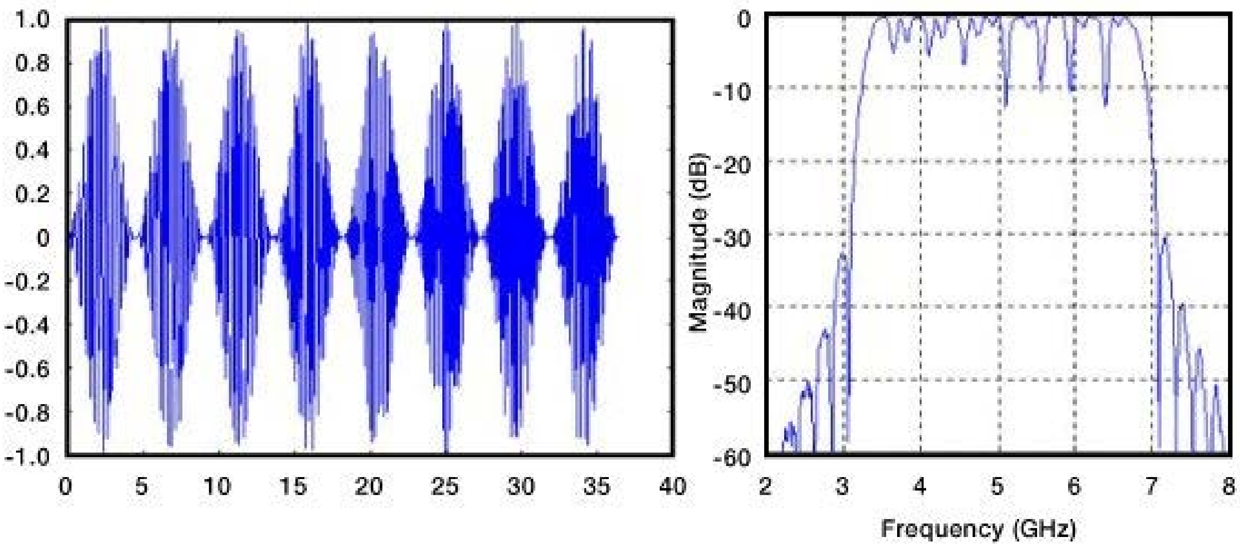


Figure 29: Amplitude and frequency spectrum characteristics for an overall multi-band implementation

5.2.4.3 OFDM and Multiband OFDM

Another method to generate a multiband UWB signal is the construction of the signal based on OFDM symbols and to add a frequency hopping operation. On example for this kind of UWB signals is the WiMedia UWB short range communication standard in defined in ECMA-368 [i.60]. This ECMA standard specifies a MultiBand Orthogonal Frequency Division Modulation (MB- OFDM) scheme to transmit information. A total of 110 sub-carriers (100 data carriers and 10 guard carriers) are used per band to transmit the information. In addition, 12 pilot subcarriers allow for coherent detection.

The basic OFDM symbol with a bandwidth of around 500 MHz will then be spread over a large bandwidth by using a frequency hopping on a OFMD symbol base over three or more bands. This is depicted in figure 30 for the case of three band hopping in the lower UWB band from 3,1 GHz to 4,8 GHz.

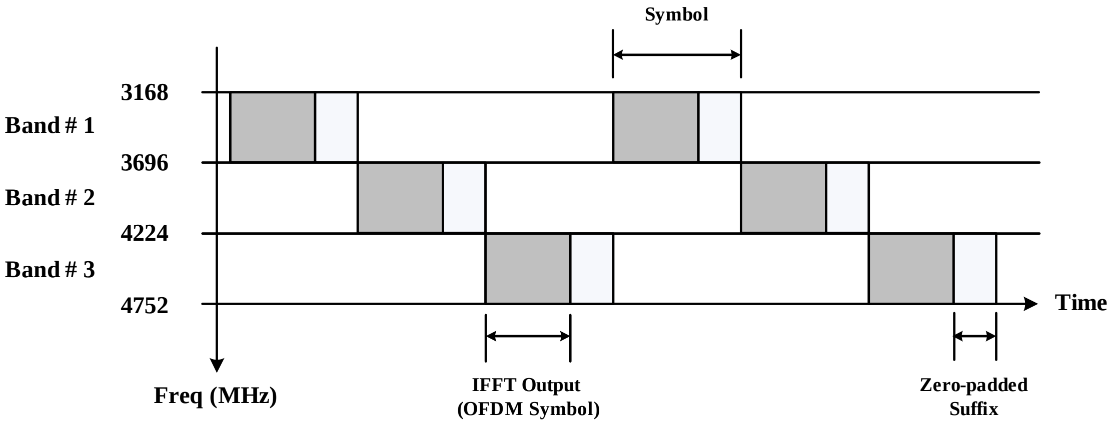


Figure 30: ECMA-368 [i.60] OFDM symbol hopping using three bands

A more detailed signal representation is depicted in figure 31. Here it can also be seen that the hopping can be switched of leading to an OFDM only system.

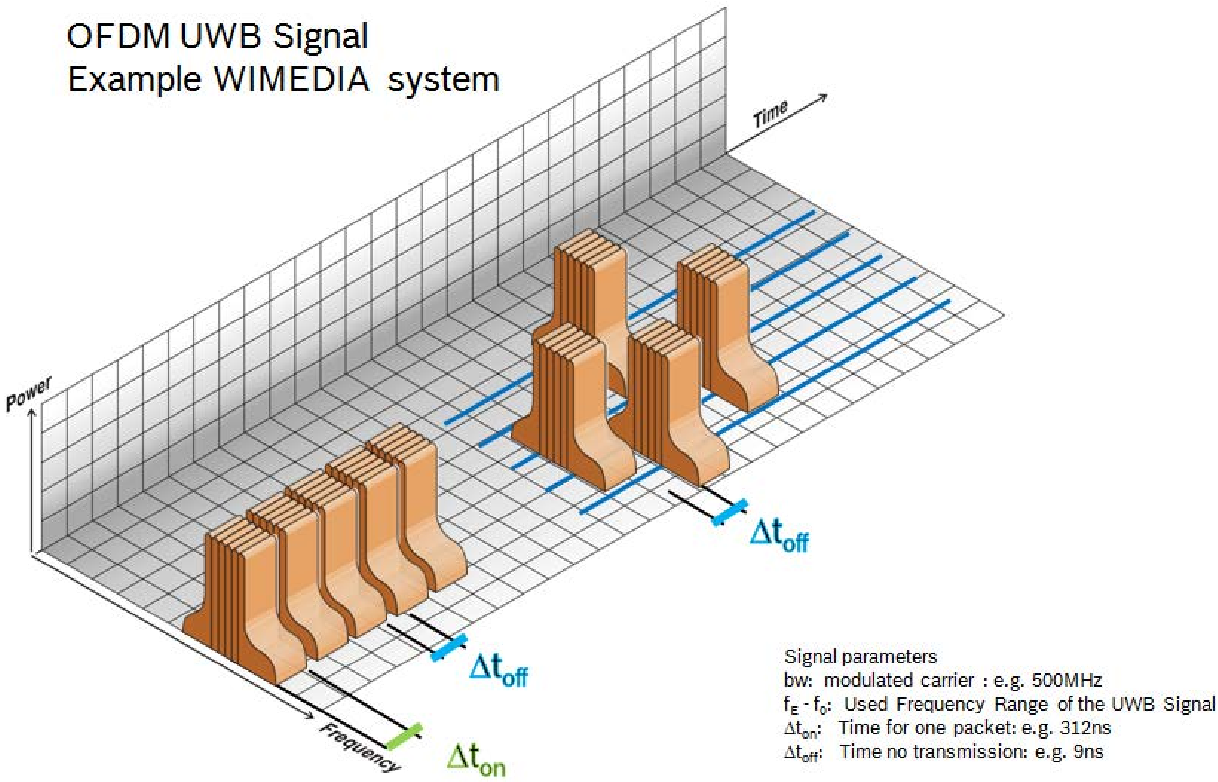


Figure 31: MD- OFDM symbol hopping using a single band or three bands

6 UWB measurements

This clause is planned to be updated during a future revision of the present document.

Reason for this planned amendment:

- ETSI TG UWB currently revise the existing UWB measurement procedures and work out specific measurement procedures for UWB signals described in the present document.
- Add NEW Work item proposals 3 time TR (peak, LDC and TR RE-D).

This work will be reflected in the finalization of ETSI EN 303 883 [i.65] "UWB measurement" which includes a justification of all measurement procedures/methods. Based on the gained results, this clause will be updated.

History

Document history		
V1.1.1	July 2015	Publication