ECC Report 278

Specific UWB applications in the bands 3.4-4.8 GHz and 6.0-8.5 GHz: Location tracking and sensor applications (LTA) for vehicular access systems

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0 EXECUTIVE SUMMARY

The Current regulation for UWB devices which are installed in road and rail vehicles with Low Duty Cycle (LDC) mitigation technique limit their e.i.r.p. emission to -53.3 dBm/MHz, based on the application of the exterior limit as defined in 2014/702/EU [4] (Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC). The limit for the power spectral density for Generic UWB applications applying LDC mitigation technique is defined at -41.3 dBm/MHz for indoor as well as for outdoor applications. The corresponding study results are shown in ECC Report 64 [5].

Study results presented in this Report evaluate whether compatibility with incumbent system could be achieved, when UWB devices are operating as car keyless entry systems without the application of the exterior limit, but instead operating like generic LDC UWB devices with an e.i.r.p. of -41.3 dBm and applying the new trigger-before-talk mitigation technique. The new trigger-before-talk mitigation technique results in a very low activity and correspondingly reduced probability of interference aggregation. Two different Ultra Wide Band device categories are studied in this Report: Category A for proximity verification and Category B for proximity monitoring purposes. Both category types work by using different activity factors.

Therefore, results of sharing studies related to aggregate interference or on probability of interference are particularly interesting. For single entry scenarios, the interference behaviour of the considered trigger-before-talk UWB system is the same as that one for generic LDC UWB devices[1]. The intention of the "exterior limit" introduction was to limit interference probability of moving objects which are transmitting periodically UWB signal with a given duty cycle.

A big parking lot with a capacity of 10000 cars was identified as a worst-case scenario for aggregated interference studies. In order to create a realistic propagation model for the particular case of UWB devices radiating from vehicles placed in big parking lots, the results obtained from detailed radio wave propagation measurements have been used as a base for all aggregated interference compatibility studies.

However, it should be noted, that the considered keyless entry system consists of a key fob, which is regulated as a generic UWB device with a maximum e.i.r.p. of - 41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal T_{on} time. Therefore any interference analysis result of single entry scenario is independent of the application of the exterior limit.

Single entry and aggregated interference are considered in the compatibility studies of the following incumbent systems:

Mobile Service

Protection of 5G, considering protection criterion I/N = -20 dB, was assessed.

Mobile station as well as base station receivers are studied as victim systems. As a worst case scenario, this study considers a big parking lot placed around a victim mobile station.

Because the separation distance between the mobile station and the UWB devices on vehicles is longer than the separation distance between the mobile station and the key fob, the impact of the vehicular UWB devices on the interference is for that scenario comparatively negligible.

For 5G active antenna system (AAS) victim receiver, interference caused by category A UWB devices never exceeds the protection criterion I/N =-20 dB with a probability of more than 2% of time in aggregated

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[1] Regulated in 2007/131/EC, Generic UWB devices which are not used at a fixed outdoor location or connected to a fixed outdoor antenna, installed in flying models, aircraft and other aviation as regulated in 2007/131/EC.

scenario. The probability of exceedance caused by UWB category B devices may be up to 22% of time in aggregate scenarios.

Unmanned Aircraft Systems (UAS)

UAS are operating under Mobile allocation in the band 4.4-4.99 GHz.

As their operating parameters have not changed since the studies made in ECC Report 170 [7] separation distances have been updated to protect UAS from LTA. Furthermore, due to the low possibility of simultaneous transmission, the aggregated effect is considered limited. The current regulatory limits of Table 3 in ECC Report 170 for the frequency band 4400-4800 MHz can be considered relevant to protect UAS in 4.4-4.8 GHz.

Unmanned Ground Vehicles (UGVs)

The interference potential of the vehicular access system in the case of Unmanned Ground Vehicles (UGV) is re-evaluated using the activity scenarios related to vehicular access systems. Since the usage of the vehicular access systems is only possible with parked cars, the worst case scenarios given in ECC Report 170 have been adapted and calculations have been re-assessed.

The studies conclude that even with the estimation of 25% for the market penetration factor and the assumption of very big parking lots, the probability of interference is negligible compared with generic UWB devices studied in ECC Report 170.

Fixed Service (FS)

The most critical interference scenario is the one involving the Category B devices operating in the lower UWB band. Simulations show that even if a sufficient level of protection can be reached for victim FS receivers operating in this band as defined by the long-term and the short-term criterion, there is a probability that interference slightly exceeds the protection criteria for a reduced range of power spectral density (PSD) limited to the case of very low antenna gains (i.e. much lower that the range defined by Recommendation ITU-R F.758-6 [8], Table 6).

For all other simulated cases, UWB devices operating in the keyless scenario with trigger-before-talk mitigation but without exterior limit fulfil the protection criterion with enough margins.

It is considered a worst-case scenario, i.e., lower antenna gains and maximum density of interfering devices within a parking lot area that has been positioned at a distance from the FS antenna corresponding to the worst case (i.e. for most of the case including FS antenna main beam and sidelobes). No minimal separation distance except the one provided by the antenna height has been used. Generally, the upper UWB band is much less affecting FS receivers owing to the intrinsically higher losses that occur due to the propagation mechanism (geometric attenuation from the free space propagation assumption). Furthermore, the fact that the same propagation model as the one developed for the low UWB band has also been used for the higher band provides an additional confidence margin on the simulations performed in the 6-8.5 GHz, where no significant impact has been noticed on the incumbent Fixed Service.

Fixed Satellite Service (FSS)

Previous interference studies between UWB and FSS (ECC Reports 64 and 170) have shown that the main scenario of interference is in the space to earth direction (in the 3-4 GHz range), and that the risk of interference to the FSS space station in the earth to space direction is therefore assumed to be negligible. Therefore, studies here focused only on the space to earth links (i.e. interference caused to the earth stations).

By making the necessary modifications to the assumptions used in ECC Report 170, single and aggregate interference from car keyless entry systems to FSS earth stations have been evaluated. In all cases, the lower antenna height and lower activity factor of UWB make the results considerably better than in ECC Report 170.

In the upper band (7250-7750 MHz), required separation distances for the single entry scenario are low. The worst case occurs for low elevation angles (5 degrees) where the maximum required separation distance reaches 66 metres. Both short- and long-term aggregate interference criteria are respected especially regarding the maximum activity factor of 0.005% for UWB category B devices.

In the lower bands (3.4-4.2 GHz and 4.5-4.8 GHz), the required separation distances for the single entry scenario tend to be higher, especially for low elevation angles and lower FSS receiver heights. While in many cases it remains below 20 metres, the worst cases require a separation distances from 102 to 270 metres. Once again, the long-term aggregate interference requirements are met similarly as for the high band case. In the considered scenario of a parking lot with 10000 cars, Category A devices fail to meet the short-term interference criteria for the smaller dishes (1.2 and 1.8 m) and elevation angles up to 15-20 degrees. Category B devices fail to meet the short-term interference criteria in most cases.

However, it should be noted, that the considered keyless entry system consists of a key fob, which is regulated as a generic UWB device with a maximum e.i.r.p. of -41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal T_{on} time. Therefore any interference analysis result of single entry scenario is independent of the application of the exterior limit.

Radio altimeter

Due to the lack of an approved value for minimum aircraft height above ground to be considered for the compatibility studies, two scenarios A and B representing different aircraft height levels are taken into account. Scenario A assumes a minimum aircraft height of 50 m and scenario B assumes a minimum aircraft height of 153 m according to ECC Report 272 [9].

At a minimum aircraft height level of 50 m, assumed by scenario A, the protection level for radio altimeter is exceeded, while at aircraft height level of 153 m assumed by scenario B the protection level is not exceeded.

Based on the results of scenario A, and noting the information from ICAO stipulating a minimum separation distance to vehicles in the order of 5 meters for protection of both fixed-wing and rotary-wing aircraft, it can be concluded that in the frequency band 4.2-4.4 GHz the exterior limit has to be applied to satisfy the protection criterion I/N = -6 dB. It should be further noted that the report does not consider the situation when the radio altimeter receives higher power which may be the case for low flight altitudes.

In the case of Wireless Avionics Intra-Communication (WAIC), separation distances of less than 10 m are calculated and therefore present a low risk of interference in a single entry scenario.

Radio astronomy

The application of the big parking lot scenario to the radio astronomy study is not appropriate because at any place nearby a big parking lot, a high level of man-made noise has to be expected and is therefore not suited for radio astronomy operations. Instead a scenario is considered with a parking lot of 100 cars.

For single entry interference scenarios, the minimum required separation distance between considered Category A UWB devices or Category B UWB devices and the radio astronomy station is 98.3 m or 376.8 m, respectively to protect the radio astronomy service from harmful interference.

For aggregated interference, the minimum separation distances are 602.1 m and 1985 m when assuming a worst case car deployment on the parking and a frequent car usage.

Conclusions on compatibility

In conclusion, the operation of the considered UWB devices in a road vehicle for the application of car keyless entry systems without the application of the exterior limit, but instead operating like a generic LDC UWB devices with an e.i.r.p. of -41.3 dBm/MHz causes no interference or interference with low probability. In general, the aggregated interference levels from UWB devices operating with trigger-before-talk mitigation technique are lower than those from UWB devices operating with LDC mitigation technique. With respect to single entry scenarios, the same separation distance has to be considered as for generic UWB devices operating with LDC mitigation technique. Radio astronomy services can be protected by respecting a reasonable separation distance. Therefore compatibility with the incumbent services in the bands 3.8 - 4.2 6-8.5 GHz can be achieved when trigger-before-talk mitigation is used.

In the band 3.4 - 3.8 GHz, it can be considered that the percentage of time exceeding I/N =-20 dB towards 5G is 2% for category A and 22% for category B devices. Reduction of category B activity factor could cause significant improvement of the interference situation.

In the band 4.2-4.4 GHz, it can be stated that the exterior limit has still to be applied. In the band 4.4-4.8 GHz, it can be stated that the exterior limit has still to be applied

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
AAS	Active Antenna System
cdf	Cumulative distribution function
CEPT	European Conference of Postal and Telecommunications Administrations
e.i.r.p.	equivalent isotropically radiated power
ECC	Electronic Communications Committee
ES	Errored Second
FS	Fixed Service
FSS	Fixed Satellite Service
HALE	High Attitude Long Endurance
ICAO	International civil aviation organization
IMT	International Mobile Telecommunications
LDC	Low Duty Cycle
LOS	Line of Sight
LTA	Location and Tracking Applications
MoM	Method of Moments
NLOS	Non Line of Sight
P-to-MP	Point to Multipoint
PKES	Passive Keyless Entry and Start
PSD	Power Spectral Density
P-to-P	Point to Point
QLOS	Quasi Line of Sight
QNLOS	Quasi Non Line of Sight
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SES	Severely Errored Second
TPC	Transmit Power Control
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UGV	Unmanned Ground Vehicle
UWB	Ultra Wide Band
WAIC	Wireless Avionics Intra-Communication

1 INTRODUCTION

Decision 2014/702/EU [4] (Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC) defines the maximum allowed radiated power from Ultra Wide Band (UWB)devices for different types of applications. In the frequency range 3.4-4.8 GHz, when used by UWB for generic applications, a limit of -41.3 dBm applies, when devices operate with standard LDC mitigation techniques. For the frequency range 6-8.5 GHz a limit of -41.3 dBm for the same type of UWB devices applies, without mitigation technique restrictions. Generic UWB devices are assumed to operate in 20% of the cases outdoor, as concluded in ECC Report 64 [5]. The radiation power density of UWB devices integrated in rail and road vehicles must not exceed the exterior limit, which defines the maximum e.i.r.p. of -53.3 dBm/MHz, when measured outside the car at elevation angles above 0°. As it can be concluded from studies of ECC Report 170 [7], the exterior limit was introduced to limit the interference potential of moving UWB devices. ECC Report 170 provides the results of the compatibility studies regarding specific Ultra-Wideband UWB location tracking applications including applications for automotive and transportation environments (LTA). As stated in CEPT Report 45 [6], ECC Report 170 concludes that an exterior limit of -53.3 dBm/MHz for emissions outside road and rail vehicles would provide a high level of confidence on the protection of most affected radio services.

In May 2016, ETSI approved for publication the SRdoc ETSI TR 103 416. This SRdoc defines three new categories of vehicular UWB devices depending on the vehicular access control application: Category A, Category B and Category C.

These UWB devices are operating as car keyless entry systems without the application of the exterior limit, but instead operating with an e.i.r.p. of -41.3 dBm, as generic LDC UWB do. Differently to generic LDC UWB devices, the considered UWB keyless entry system makes use of a new mitigation technique, called trigger-before-talk, which results in a very low activity. Furthermore, in contrast to UWB devices considered in all previous studies, the considered UWB keyless entry systems is only active when cars are not moving, which reduces the interference potential significantly for most considered interference scenarios.

In this Report, compatibility studies are performed for described Category A and B systems only, to determine whether the proposed changes maintain the protection of incumbent radio services. Category C devices are not considered in this Report.

2 SYSTEM DESCRIPTION

As stated in the introduction, vehicular access systems using UWB devices are clustered into three categories depending on the vehicular access control applications. For the studies considered in this Report, categories as well as the corresponding technical parameters and mitigation factors are as defined in ETSI TR103 416 [1].

Category A: Vehicular access systems using triggered UWB transmission for proximity verification.

- These systems are characterised by short (single) UWB transmissions after a user triggered event.

Category B: Extended vehicular access systems using triggered UWB transmission for proximity monitoring.

- These systems are characterised by periodic UWB transmissions for a limited time. The initialisation is a user triggered event. The duration is either based on a user interaction and/or a pre-defined time-out and/or connection loss.

Category C: Vehicular access systems using periodic UWB beacons for proximity detection.

- These systems are characterised by periodic UWB transmissions ("beacons"), which are sent by the vehicle in order to trigger an ID device action ("Wake-Up"). Typically, no ID device is in range and thus no response is sent after a vehicle beacon;
- Once a response from an ID device is received by the vehicle, the subsequent communication can be viewed as "triggered communication".

UWB devices used by Category A, B and/or C vehicular access systems are referred to as Category A, B or C UWB devices.

The trigger-before-talk mitigation technique is described as follows:

- UWB transmission is only initiated when necessary, in particular only if the system indicates that UWB devices are in range;
- Wake-up mechanism(s) for UWB device detection is not UWB;
- Only the physical proximity of a car key to the car triggers UWB communication.

Below the technical characteristics of each category are defined.

2.1 CATEGORY A DEVICES

Category A UWB devices are UWB devices used for proximity verification. The core characteristic of these devices is that UWB transmission is triggered by the vehicular access system following a user event (e.g. door handle touch, Start button push) and the communication time is very short (e.g. just a single or few UWB transmissions).

2.1.1 Technical parameters

Table 1: Technical parameters for Category A UWB devices

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	3.4 GHz to 4.8 GHz and/or 6 GHz to 8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz (Max), without exterior limit 0 dBm/50 MHz (Max)
Operational Bandwidth	System dependent, typical > 500 MHz

System Parameter	Value/Description
Data Rates	System dependent
Tx to Rx Range	typical 10 m or less
Existing mitigation techniques	TPC and/or LDC
Additional mitigation technique	Trigger-before-talk (see 2.1.2)
Cumulative T_{on}-time (per vehicle device) during bidirectional UWB communication (1 trigger)	typical 10 ms or less, max. 50 ms LDC requirements (see ETSI EN 302 065-3 [10], clause 4.5.3) will be kept in any case: T_{on} max < 5 ms T_{off} mean < 38 ms (averaged over 1 s) $\sum T_{off}$ > 950 ms per second

2.1.2 Mitigation factors

Mitigation factors for Category A UWB device communication for proximity verification:

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

b) Very low activity factor (typical < 0.00035%):
  - Low duty cycle for the communication due to short packages (small amount of data for command, authentication and/or status transfer);
  - Usage profile of functions is low.

c) Once UWB communication is established, transmit power control (TPC) can be used as additional mitigation.

d) Low risk of aggregate transmissions (uncoordinated networks, ad-hoc communication):
  - Door openings are uncoordinated events. Even in parking lots, door openings are single and sporadic events.

2.2 CATEGORY B DEVICES

Category B UWB devices are UWB devices used for proximity monitoring. The core characteristic of these devices is that UWB transmissions are triggered by the system following a user event as in Category A and the communication is repeated for a limited time to check for the user's presence or exact location.

2.2.1 Technical parameters

Table 2: Technical parameters for Category B UWB devices

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	3.4 GHz to 4.8 GHz and/or 6 GHz to 8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz (Max)

	0 dBm/50 MHz (Max) without exterior limit
Operational Bandwidth	System dependent, typical > 500 MHz
Data Rates	System dependent
Tx to Rx Range	typical 10 m or less
Existing Mitigation techniques	TPC and/or LDC
Additional mitigation technique	Trigger-before-talk (see 2.2.2)
Cumulated T_{on}-time (per vehicle device) during bidirectional UWB communication (1 interval)	typical 5 ms or less per interval; max. 50 ms LDC requirements (see ETSI EN 302 065-3 [10], clause 4.5.3) will be kept in any case: T_{on} max < 5 ms T_{off} mean < 38 ms (averaged over 1 s) $\sum T_{off}$ > 950 ms per second
Duration of UWB communication repetitions (for proximity monitoring)	typical < 30 s for functions with user interaction typical < 60 s for functions without user interaction
Repetition interval of vehicle transmissions	typical > 200 ms for functions with user interaction typical > 500 ms for functions without user interaction

2.2.2 Mitigation factors

Mitigation factors for Category B UWB device communication for proximity verification:

a) Trigger-before-talk:
  - UWB transmission is only initiated when necessary, in particular if the system indicates that UWB devices are in range.

b) Very low activity factor (typical < 0.005%) (especially true for functions with user interaction, due to usage profile):
  - Low duty cycle for the communication due to short packages (small amount of data for command, authentication and/or status transfer);
  - Usage profile of functions is low;
  - Wake-up mechanism for polling is not UWB;
  - Only the physical proximity of a key triggers UWB communication.

c) Once UWB communication established, TPC can be used as mitigation (especially true for functions without user interaction, due to lower response time requirements).

d) Low risk of aggregate transmissions (uncoordinated networks, ad-hoc communication):

2.3 GENERIC ASSESSEMENT OF TRIGGER-BEFORE-TALK MITIGATION TECHNIQUE

The considered UWB system makes use of a new mitigation technique, called trigger-before-talk. Since this mitigation technique represents a completely new mitigation approach, a generic assessment of this mitigation technique is carried out and is compared to the currently implemented mitigation technique LDC for LTA devices in combination with exterior limit.

The current regulation limits the e.i.r.p. of LTA UWB devices to -53.3 dBm/MHz when installed in road or rail vehicles. For generic UWB devices the e.i.r.p. is limited to -53.3 dBm/MHz for high duty cycle and -41.3 dBm/MHz for low duty cycle.

The UWB system presented in this report consists of a key fob, which is regulated under the generic LDC UWB devices requirements, with an e.i.r.p. of -41.3 dBm/MHz. The devices integrated in cars are considered as vehicular devices. Each activation induces an emission of the key fob with an e.i.r.p. of -41.3 dBm/MHz, regardless of the emission level of the vehicular devices. The emission time of the key fob is 50% of the entire system emission time.

Therefore, when no distinction is made between short and long-term protection of victim systems, the considered new UWB keyless entry system would require a minimum separation distance for single entry scenarios, which is independent of the emission level of the vehicular devices, i.e. -41.3 or -53.3 dBm/MHz.

The advantage of this new trigger-before-talk mitigation technique is important for aggregated interference scenarios. In that case, the duty cycle, respectively the activity of the devices has major impact on the study results. The duty cycle parameters of the current applied LDC mitigation technique on LTA devices and the corresponding maximum e.i.r.p., are defined in the Decision 2014/702/EU [4] (Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC) respectively in standard ETSI EN 302 065 V1.2.1, and are summarised below:

Table 3: Low duty cycle (LDC) parameters according ETSI EN 302 065 V1.2.1 [10]

LDC parameter	Value
Maximum Tx on	≤ 5 ms
Accumulated minimum Tx off (Σ Tx off)	≥ 950 ms in one (1) second
Maximum accumulated transmission time (Σ Tx on)	18 s in one (1) hour

According to the LDC parameters presented in Table 3, in previous ECC Reports on UWB, a maximum duty cycle of 5% within 1 second and 0.5% within 1 hour is considered. Therefore, when a comparison is made between the new trigger-before-talk UWB devices, a long-term activity of 0.5% for LDC LTA UWB devices is taken into account. The activity of the considered new trigger-before-talk UWB devices are defined in ETSI TR 103 416 V1.1.1 and given below:

- Car keyless entry device Category A : activity factor < 0.00035%;
- Car keyless entry device Category B : activity factor < 0.005%;
- For studying aggregate interference effects, the considered UWB devices are assumed to operate on a parking lot with 2000 equipped cars;
- The probability of simultaneous transmission of multiple Category A or Category B devices is following the Poisson distribution with the following mean values;
- Mean LDC = n *p = 2000 *0.5% = 10 (LTA LDC UWB devices);
- Mean Category A = 2000 *0.00035% = 0.007 (Category A devices);
- Mean Category B = n *p = 2000 *0.005% = 0.1 (Category B devices).

It should be noted, that for mean values below 10 and probabilities of less than 2%, the approximation of the binominal distribution through the Poisson distribution is valid.

The Poisson distributions for the three above mentioned mean values are shown graphically in Figure 1:

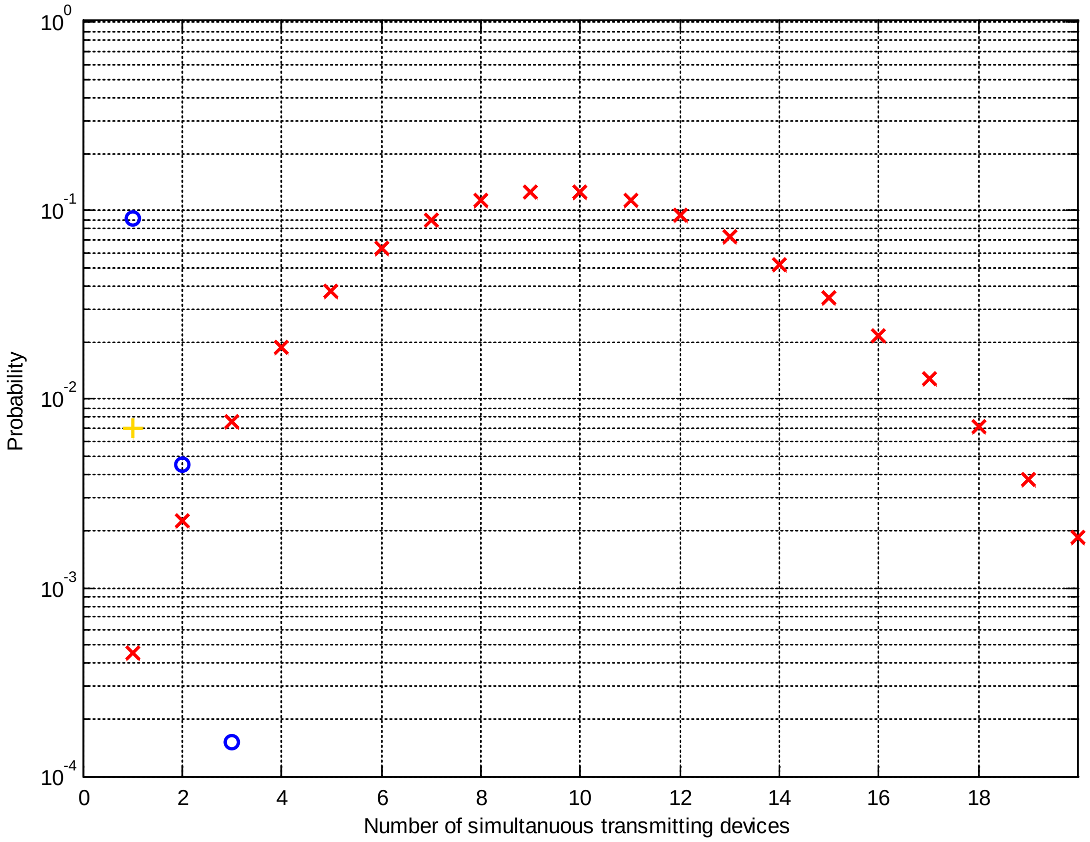

Figure 1: Poisson distribution for three different mean values (mean = 10 (red x), mean = 0.1 (blue o) and mean = 0.007(yellow +))

The probability that one of the 2000 Category A device transmits is equal to 0.7%. For the same probability, an interference aggregation of 3 and 18 LDC UWB devices occurs. The probability that one of the 2000 Category B device is transmitting, is equal to 9%. With the same probability an interference aggregation of 7 and 12 LDC UWB devices occurs. It is obvious, that the low activity of the new trigger-before-talk mitigation technique highly reduces the risk of aggregated interference. Therefore, there is no need to apply the more stringent exterior limit for the new trigger-before-talk UWB system.

To clearly demonstrate the effectiveness of the new trigger-before-talk mitigation technique, the cumulative distribution function (cdf) for the interference level probability for the mobile service small base station is analysed as an example. The scenario is described in detail in Section 4.3, where studies for the mobile service are presented. The small cell base station as victim is selected, because it turns out to be the most critical case. In this scenario, standard LDC LTA UWB devices with e.i.r.p. of -53.3 dBm/MHz and a DC = 0.5% are compared with the new trigger-before-talk devices with an e.i.r.p. of -41.3 dBm/MHz. For both devices a T_{on} of 50 ms is assumed.

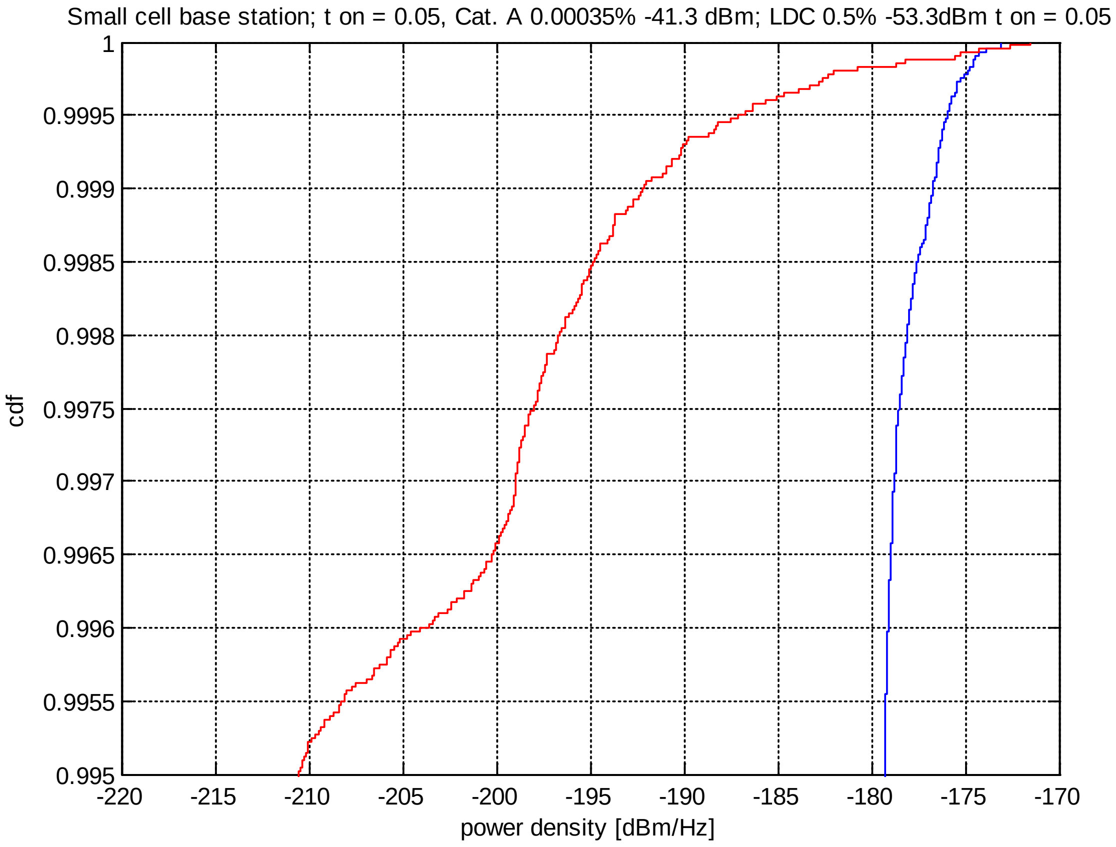

Figure 2: cdf for new Category A trigger-before-talk UWB devices (red curve) and for LDC UWB devices (blue curve)

Figure 2 shows the results for the cumulative distribution function for the interference level probability into the small base station. For 99.996 % of interference situations, the UWB devices with e.i.r.p. of -41.3 dBm/MHz and the new trigger-before-talk mitigation technique cause less interference than standard LDC UWB devices with e.i.r.p. of -53.3 dBm. For more than 99.9% of interference cases, the interference level from the new trigger-before-talk UWB devices is more than 15 dB lower that the interference level from standard LDC UWB devices. For 0.004% of the interference situations the standard LDC UWB devices causes less interference, where the level of interference is 1.4 dB lower.

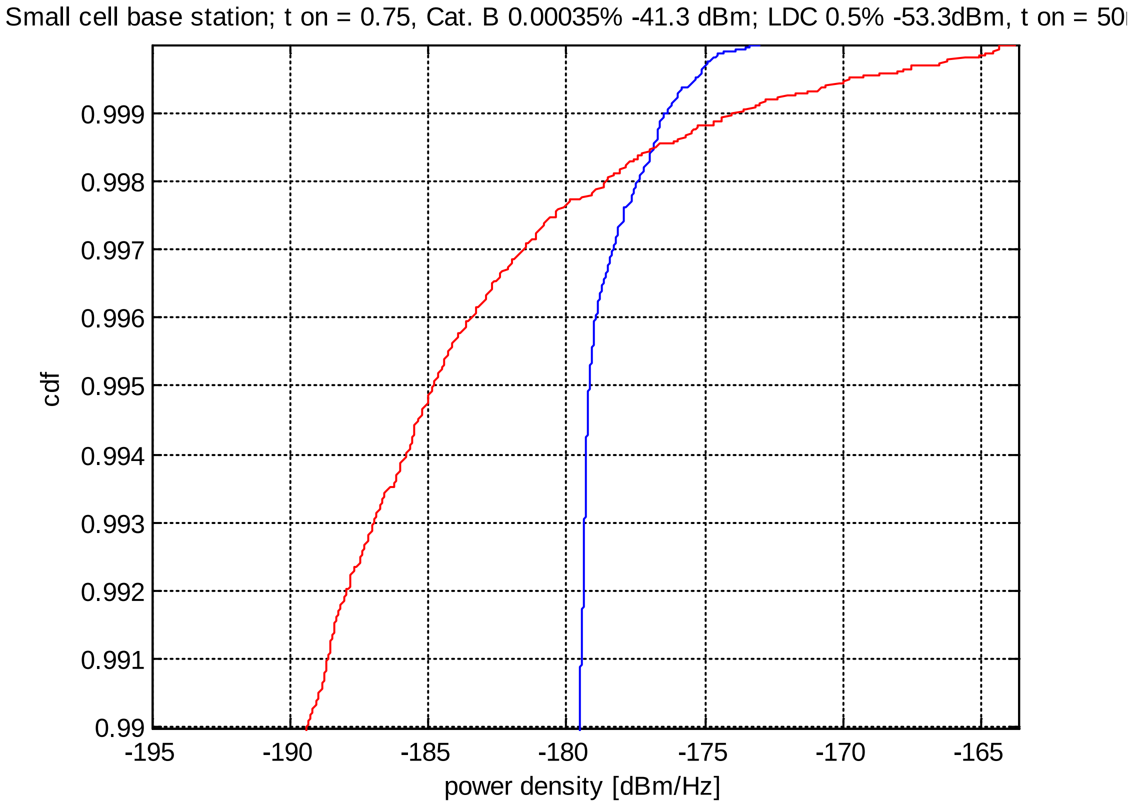

Figure 3: cdf for new Category A trigger-before-talk UWB devices (red curve) and for LDC UWB devices (blue curve)

Figure 3 shows the results for the cumulative distribution function for the interference level probability into the small base station. For 99.84 % of interference situations, the UWB devices with e.i.r.p. of -41.3 dBm/MHz and the new trigger-before-talk mitigation technique cause less interference than standard LDC UWB devices with e.i.r.p. of -53.3 dBm. For more 99% of interference cases, the interference level from the new trigger-before-talk UWB devices is more than 10 dB lower that the interference level from standard LDC UWB devices. For 0.16% of the interference situations the LDC UWB devices cause less interference, where the level of interference is 9.3 dB lower.

From the above simulations, it can be concluded that the new trigger-before-talk mitigation technique is a very effective measure to reduce the interference level and interference probability in real deployment scenarios. With the development of the considered keyless entry system, the industry is offering a technology for a particular type of vehicular LTA application, which causes less interference for considered deployment scenarios than the existing LTA technology applying standard LDC mitigation technique with exterior limit. For the single entry scenario the minimum separation distance is the same as for the standard LDC LTA. But the application of the new technology reduces significantly the probability of interference.

The use of the new mitigation technique for this UWB application causes significantly less interference than the same application would cause, based on the standard LDC LTA mitigation technology with exterior limit.

The conclusions made above are generally valid, regardless of potential parameter evolution for the considered victim systems.

3 PARAMETERS, DEPLOYMENT AND REFERENCE SCENARIOS FOR STUDIES

The UWB system parameters presented in Table 4 are considered for the studies in this Report.

Table 4: UWB system parameters used for the studies

Parameter	Value
Frequency range 1	3.4 to 4.8 GHz
Frequency range 2	6.0 to 8.5 GHz
Cumulated T_{on} - time (Category A devices) per Trigger event	50 ms
Cumulated T_{on} - time (Category B devices) per trigger event	750 ms
Antenna heights	1.5 m, 0.4 m
Radiation pattern	Omnidirectional
Transmit Power density	-41.3 dBm/MHz
Trigger events per day	Scenario dependent Equally distributed over time

The considered keyless access system consists of UWB transceivers installed in a car and a key fob equipped with a UWB transceiver. The UWB transceiver of the key fob is a generic UWB device and follows the regulation of ERC Recommendation 70-03 [11]. For the considered UWB system, there is a time division duplex communication between key fob and UWB devices installed in the car with equal T_{on} - time in "up- and down link" direction. Accordingly, the maximum short term cumulated T_{on} time of all UWB devices installed on a single car is limited by the maximum permitted T_{on} time of the corresponding key fob. Therefore, the number of installed UWB devices per car does not change the maximum possible cumulated T_{on} - time of UWB transmissions per car.

3.1 DEPLOYMENT

Regarding aggregated interference studies, scenarios are considered where the cars are parked in a dense parking lot (e.g. shopping mall, airport). It is assumed that the density of cars can reach 33000 vehicles/km^2. This would correspond roughly to an average of 30 m^2 for one parking spot (a large car including the access for moving into and out of spaces).

There are typically 4 UWB devices installed in a car. No simultaneous transmissions of UWB devices installed in the same car can happen. Therefore aggregation effects are possible only from UWB devices installed in different cars. In order to improve the range of the radio communication, there are multiple UWB devices installed at a different position of the car body. This allows achieving line of sight radio wave propagation conditions between any car UWB devices and the key fob, for as many positions around the car as possible. Accordingly, there is normally no possible situation, where all UWB devices on a car have line of sight propagation condition in a single direction. For example, considered UWB devices are usually installed in the bumpers or left and right side mirror. Because of those types of UWB device positions on the car, the radio wave signals of some UWB devices get attenuated due to car body losses of the same as well as of neighbouring cars. This fact applies also for radio wave propagation from signals of the UWB devices to a victim receiver. For the interference studies, this effect may be taken into account by a particular path loss model (for details refer to Section 3.2). In

Figure 4, an illustration of possible car screening effects for UWB signal wave propagation is given. Red dotted lines represent wave path obstructed by car bodies and black dotted lines represent propagation path with line of sight conditions.

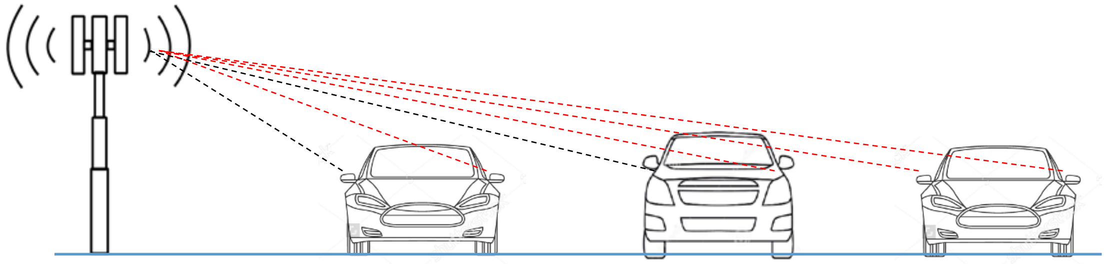

Figure 4: Illustration of radio wave propagation path between UWB devices installed in car rear mirror and a victim radio receiving antenna

For all studies in this Report, a 25% market penetration of the considered UWB keyless access systems is assumed, including Category A and Category B devices.

The number of trigger events depends on the scenario whether the parking lot is nearby an airport, shopping mall, etc.

3.2 CAR SCREENING

The issue of car screening attenuation was considered in CEPT Report 17 [12] for UWB devices situated inside cars. For screening effects according deployments as described in Section 3.1, a dedicated path loss model is developed, based on results of a measurement campaign. The model is applicable for the 3.4-4.8 GHz and 6-8.5 GHz frequency range and is based on two classes of propagation effects: free space path loss and an additional loss, which is due to car screening attenuation. The car screening attenuation considers different propagation phenomena like diffraction loss, multipath propagation and attenuation of wave propagation trough car body windows.

There are three different models for the additional loss to be considered for aggregated studies. Model A for UWB transmitters placed in side mirrors, model B1 and model B2 for UWB transmitters placed in the bumpers. The models B1 and B2, used in Monte-Carlo type simulations, have equal probability of occurrence. The models for the additional loss are described by the following formulas:

- Model A : $A = 89.36\,(\frac{6X}{h_{RX}})^{-1.747}$
- Model B1: $A = 185.0(\frac{6X}{h_{RX}})^{-2.317}$
- Model B2: $A = 9.837\,(\frac{6X}{h_{RX}})^{-0.904}$

where:

- A: additional loss (linear scale);
- x: separation distance between UWB transmitter and victim receiver antenna (m);
- h_{RX}: Victim receiver antenna height (m).

Details on the propagation model are given in ANNEX 2:.

4 STUDIES

4.1 FIXED SERVICE

4.1.1 Introduction

This section describes a method for assessing the interference on Fixed Service (FS) systems from Ultra Wide Band (UWB) access control systems used in cars the range 3.4-4.8 GHz and 6-8.5 GHz. This section describes the simulation method and the results obtained in estimating the percentage of time that a defined protection criterion (expressed in terms interference to receiver's noise, I/N) is exceeded in a victim FS receiver.

4.1.2 Protection Criteria

A long-term protection criterion of I/N = -20 dB should not be exceeded for more than 20% of time as advised by Recommendation ITU-R. F 758-6 Table 4 [8] for UWB.

A short-term criterion, in Recommendation ITU-R SF.1650-1 (Table 1) [13], for sharing with a co-primary service, the following value of I/N of 19 dB not to be exceeded for more than 4.5x10-4% of the time in any month (for errored seconds (ES) objective). However, standing the “not co-primary” status of UWB, that value should be reduced by a factor of 10. Therefore a value of I/N of +19 dB is not to be exceeded for more than 4.5x10-5% of the time.

It should also be noted that in case of the protection criteria, the % of time should be intended as "% of seconds affected by interference" rather than "any % of time". This is because the Error Performance Objective (EPO) allowance for interference given in ITU-R Recommendation F.1094 [25] is based on % of ES or SES and not to "any % of time”.

The impact of UWB on FS victim receivers have already been studied and reported in ECC Report 64 (Section 7.1) [5]. However, the given limits only apply to UWB systems that are intended for continuous (or systematic throughout most part of the day) emissions. This Report investigates the impact on FS from UWB systems with very low activity factors (defined as trigger-before-talk mitigation) as defined in SR doc ETSI TR 103 416 V1.1.1 (2016-07) [1].

4.1.3 Parameter for Fixed Service

4.1.3.1 Selected Victim Fixed Service (FS)

The selection of victim FS has been primarily based on their frequency of operation. The considered frequency bands are those used by PKES, i.e. covering 3.4 to 4.8 GHz and 6 to 8.5 GHz, according to ETSI TR 103 416 [1]. Key parameters of FS can be found in ITU-R F.758-6 (Tables 6-7 and 11 in Annex 2 and Table 15 in Annex 3) [8].

For these bands, potential victim FS are:

- Digital point-to-point in the frequency bands between
  - 3.4 to 4.8 GHz;
  - 6.0 to 8.5 GHz;
- Digital point-to-multipoint frequency bands between 3.4 and 4.8 GHz.

The key parameters for simulations are:

- typical and worst case antenna gain (antenna gain range) in dBi;
- feeder losses in dB;

- receiver noise power density (typical) expressed in dBW/MHz.

A complete table showing the selected FS and their key parameters is given below. Note that for each FS, the lowest frequencies have been simulated (worst case propagation attenuation).

The antenna height of the FS receiver is not reported in in ITU-R F.758-6. FS antenna height above ground used in simulations are h_{RX}=20 m, 40 m and 60 m (these heights cover most of the case listed in Recommendation ITU-R F.2086 [14]).

Additional worst case antenna gains (corresponding to low-cost “60 cm” antenna) with gains of about 30 dBi in 4/5/6 GHz and 7/8 GHz bands have also been considered.

Table 5: Fixed Service parameters for band 3.4 to 4.8 GHz (lower UWB band)

		BAND 3.4-4.8 GHz						
				PP			PMP	
Victim FS parameters	**case no.**	1	2	3	4	5	6	7
description/modulation		64-QAM	512-QAM	QPSK	16-QAM	256-QAM	64-QAM	QPSK
ref. (ITU-R)		F.635	F.635	F.382	F.1099	F.1099	F.1488	F.1488
min. freq.	**GHz**	3.6	3.6	3.7	4.4	4.4	3.4	3.4
max. freq.	**GHz**	4.2	4.2	4.2	5	5	3.8	3.8
max. ant. gain (typ)	**dBi**	42	40	37	22.5	22.5	18	18
ant. gain,worst	**dBi**	30	30	30	21.5	22.5	10	8
antenna pattern (ITU-R F.xxx)	**-**	**699/1245**	**699/1245**	**699/1245**	**699/1245**	**699/1245**	**1336**	**1336**
antenna height	**m**	**20/40/60**	**20/40/60**	**20/40/60**	**20/40/60**	**20/40/60**	**20/40/60**	**20/40/60**
Rx feeder loss (min.)	**dB**	0	3	3	0	3	2	0
Noise PSD	**dBm/MHz**	-111	-112	-112	-107.5	-107.5	-111	-111

Table 6: Fixed Service parameters for band 6.0 to 8.5 GHz (higher UWB band)

		BAND 6-8.5 GHz							
					PP				
Victim FS parameters	**case no.**	8	9	10	11	12	13	14	15
description/modulation		64-QAM	128-QAM	QPSK	64-QAM	16-QAM	128-QAM	16-QAM	128-QAM
reference (ITU-R)		F.383	F.383	F.384	F.384	F.385	F.385	F.386	F.386
min. freq.	**GHz**	5.925	5.925	6.425	6.425	7.11	7.11	7.725	7.725
max. freq.	**GHz**	6.425	6.425	7.125	7.125	7.9	7.9	8.5	8.5
max. ant. gain (typ)	**dBi**	45	46.6	43.9	47.4	48.6	48.6	48.6	48.6
ant. gain (worst)	**dBi**	38.1	38.7	35.3	32.6	30	30	30	30
antenna pattern (ITU-R F.xxx)	**-**	**1245**	**1245**	**1245**	**1245**	**1245**	**1245**	**1245**	**1245**
antenna height	**m**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**
Rx feeder loss (min.)	**dB**	2.5	1.1	1.2	0	0	0	0	0
Noise PSD	**dBm/MHz**	-109	-110	-109	-109.5	-111.5	-111.5	-111.5	-111.5

4.1.4 Fixed Service antenna model

4.1.4.1 *Point-to-point FS case*

Antenna model for point-to-point FS are described in Recommendations ITU-R F.699 [15] and ITU-R F.1245 [16]. The latter document is an update of the ITU-R F.699 which is based on the peak envelope of side-lobe patterns and therefore provides more pessimistic estimations for the effect of interference entries in aggregated scenarios. Note that in the case of single entry scenario, models from ITU-R F.699 shall be used since the pattern represents a good estimation of the peak sidelobe value (worst case when a single interferers radiating into one of the sidelobe).

Smaller gain antenna has also been added to the parameters of Table 5 and Table 6. For costs reasons, small gain antennas are widely used in practice, especially where hop lengths are short. Because of their wide deployment and the importance of side-lobe interference, small gain antennas have also been included in this study.

4.1.4.2 *Point-to-multipoint FS case*

In this scenario, P-to-MP FS systems use sectorial antennas with wider main beam and smaller gains as described in Recommendation ITU-R F.1336 [17]. In this study, no differences have been made between single entry and aggregate cases. The fact that P-to-MP antenna gains are significantly lower than in the P-to-P case makes the latter a clear worst case in the interference studies.

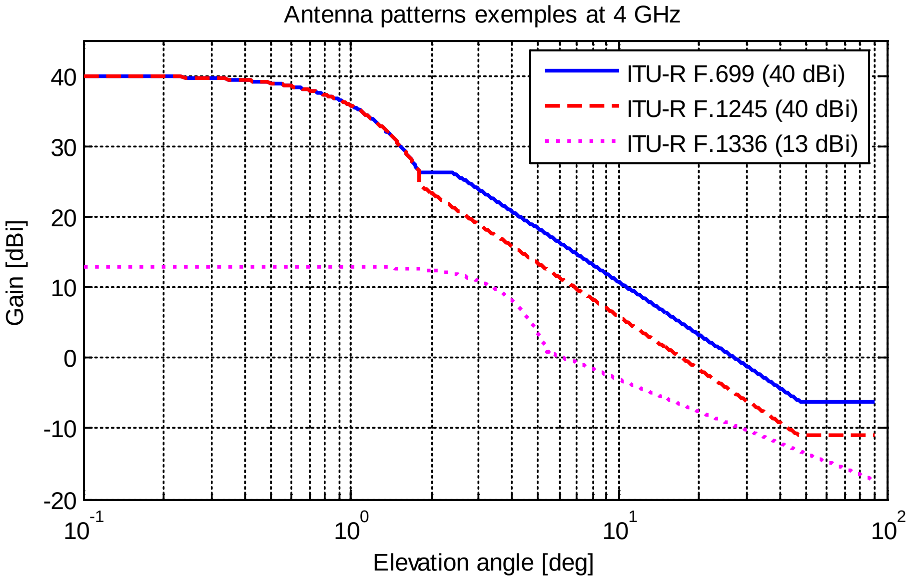

Figure 5: Different antenna patterns used in this study

4.1.5 Simulation

4.1.5.1 Assumptions

The evaluation of the interference impact with respect to the aforementioned protection criteria is performed via simulations by calculating how often the interference level at the victim receiver exceeds the defined protection criteria. The latter is expressed in errored seconds, i.e. the number of seconds within which an interference event (even much shorter than a second) is exceeding a certain ratio of interference to noise (I/N).

For the vehicular access systems deployment scenario, a big parking lot placed around a victim FS receiver is considered as a worst case scenario. Biggest parking lots around airports have a capacity of around 10000 cars (e.g. Detroit Metropolitan Wayne County Airport). The car density of such a typical parking lot is 33000 cars/km^2. The parking lot area used for the simulation is 600m × 600m and contains 10000 cars. The parking lot area under simulation is always placed for the worst case interference situation (see section 4.1.5.2).

Numerical assumptions are summarised as follows:

- Parking lot area with a dimension of approx. 600m × 600m, i.e. containing approximately 10000 cars. A quarter of them are equipped with UWB keyless, i.e. UWB market penetration $k_{market} = 0.25$;
- An open/close activity rate corresponding to a parking lot of a shopping mall is assumed. For this scenario, the mean activity rate during opening hours (10/24h, 7/7 days) is:
  - two UWB communications per hour (r_A/h_r) for a single UWB device Category A and
  - one UWB communication in per hour (r_B/h_r) for a single UWB device Category B.
- The effect of shadowing of nearby cars is considered according the propagation model shown in ANNEX 2:;
- -41.3 dBm/MHz e.i.r.p Tx power density (12 dB exterior limit removed in this study);
- Maximum cumulated on-time for an open or close activity is T_{on} = 50 ms for Category A and 750 ms for Category B devices;

- The UWB antenna on the car is assumed omnidirectional (0dBi), i.e. energy is also radiated toward high elevation angles (worst case).

For multiple entries scenario, the victim FS receiver antenna gain pattern follows ITU-R F.1245 guidelines that enable a less pessimistic influence from sidelobes; however, worst antenna gains are also considered as an input for antenna model derived from ITU-R F.699 (single entry).

4.1.5.2 Additional remarks on the propagation model

The effect of shadowing of nearby cars is considered according the propagation model shown in ANNEX 2:.

It is important to note that for each scenario, the location of the parking lot under the main beam of the FS antenna has also been selected to generate a worst case situation. The selection criteria have been based on maximising the average PSD from all locations throughout the area. As shown from antenna simulations in ANNEX 3: the path loss to victim FS antenna can exhibit a minimum values at distances between a few tens of meter up to more than 3 km.

Figure 6 illustrates such a case for which the worst case distance to the FS antenna is dependent on the antenna height. For FS antenna height the worst case distance is 200 m, whereas for a height of 20 m, the worst case location for the parking lot is at 1 km. The right plot is showing the PSD intensity (in dBm/MHz) from interferers to the victim receiver for such a situation.

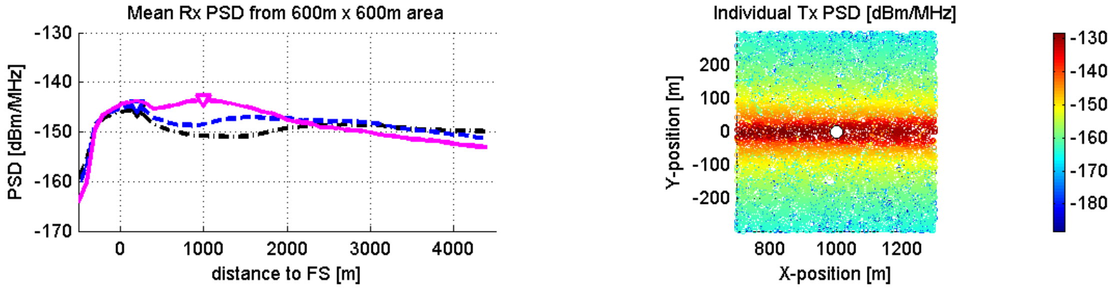

Figure 6: Influence of the FS antenna height on the worst case distance from the parking lot to the victim receiver (scenario no. 8, Category A with worst case FS gain)

4.1.5.3 Simulation challenge

The very low percentage of errored seconds that needs to be computed for the short-term protection level is challenging. Obtaining a significant number of errored seconds requires the equivalent computation of a large amount of seconds. Typically, the number of simulated seconds should be taken 10 times larger than the inverse of the targeted short-term protection criteria, which corresponds to approx. 257 days (≈22 millions of seconds).

Moreover, UWB events are very short bursts with maximum total duration of 50 ms per second and also contribute to extend the computation time due to their low probability of aggregation.

Therefore a mixed mode methodology is proposed here, based on:

- Event-based simulations for estimating the long-term protection level which requires smaller amount of errored seconds;
- Semi-analytical simulation for assessing the interference under the short-term protection criteria.

4.1.6 Methodology

4.1.6.1 Introduction

The simulation methodology consists in simulating the effect of many devices transmitting over a defined area close to (or surrounding) the FS victim receiver. Figure 7 shows an example on how the victim receiver (triangle marker at coordinates [x,y]=[0,0]) is affected by multiple devices randomly located over the parking area. For each position, there is an interference level to the victim FS that is identified by the contour lines (values are given here in –dBm/MHz).

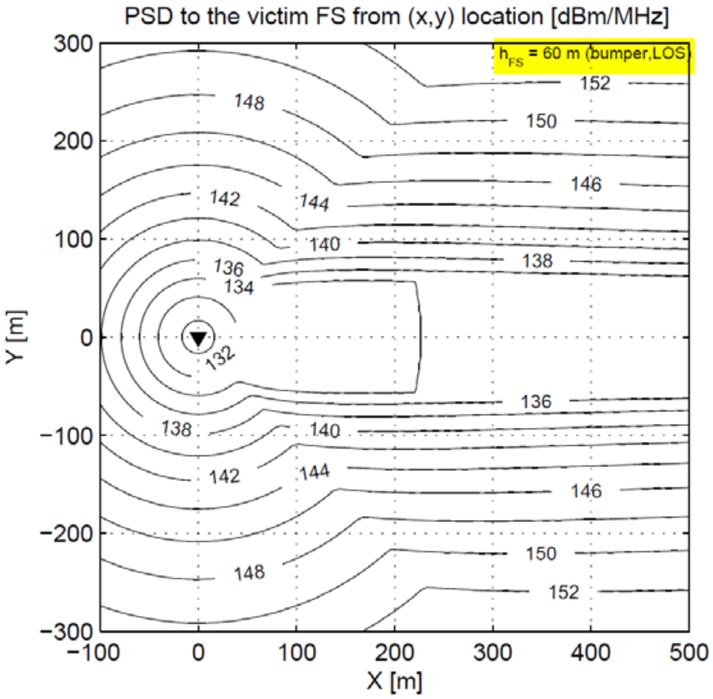

Figure 7: Interfering PSD levels from an area surrounding a victim FS antenna (black triangle)

In this example the victim antenna tilt angle is set to 90 degrees and oriented toward the right part of the figure. The FS antenna height in this example is 60 m and the UWB transmitter is located on the car's bumper with line-of-sight (LOS) conditions. The main lobe of the FS antenna can be easily identified by observing the asymmetry in the distribution of the contour lines. For an UWB device located at coordinates [x,y]=[200,100], the PSD that is sent to the victim receiver by the UWB Tx emitting at a PSD of -41.3 dBm/MHz is -140 dBm/MHz.

4.1.6.2 Assessment of the aggregation effect

Although the activity factor for each interfering device is rather low (owing to the trigger-before-talk mitigation) the large number of device over the considered area leads to a non-negligible aggregation effect.

The aggregation is computed by applying a Poisson distribution with the mean activity per T_{on} over the parking lot as a parameter. The mean activity per T_{on} for Category A is therefore

- $\frac{r_A}{T_{on}} = \frac{R_A}{hour}\frac{1}{3600}N_{cars}T_{on} = \frac{2}{3600}2500 \cdot 0.05 = 0.0694$
- where r_A/hour is the activity factor per hour, N_{cars} the number of cars (10000 x·kmarket) and cumulated T_{on} the duration of the UWB event for one open/close activity, in second.

For Category B, the rate of activity is multiplied by 15 as there might be a cumulative T_{on} time up to 750 ms, but with an average of one action per hour (r_B/hour = 1):

- $\frac{r_B}{T_{on}} = \frac{R_B}{hour}\frac{1}{3600}N_{cars}T_{on} = \frac{2}{3600}2500 \cdot 0.05 \cdot 15 = 1.0417$

The probability of aggregation is given by the output of the Poisson probability density function that expresses the probability that there is 0, 1, 2,… additional UWB events during an event of duration T_{on}.

The probability that there is no aggregation for Category A is therefore Poisson(0,r_A/T_{on})≈93% and for Category B Poisson(0,r_B/T_{on})≈35%.

As a conclusion, the aggregation effect for Category A is small; for each Tx UWB event, there is a 7% probability that another event is occurring simultaneously. For Category B this probability increases to 65%. However this does not mean that the result of the aggregation leads to a total I/N that will exceed the protection criteria. These probabilities must be biased by the effect of choosing randomly the location of the interference over the parking lot area (see Figure 7). The location of the UWB transmitter on the car also contributes to reduce the effect of the aggregation depending on the LOS or NLOS conditions.

This biasing due to the random location of the interfering device over the area and due to the position on the car is explained hereafter. For the example scenario given in Figure 7, the probability that the PSD emitted from a certain location is larger than protection level PSD_{prot} can be computed as the ratio of the area surrounded by the contour PSD_{prot} compared to the total parking area (the locations of the UWB event are picked randomly with uniform distribution over the area).

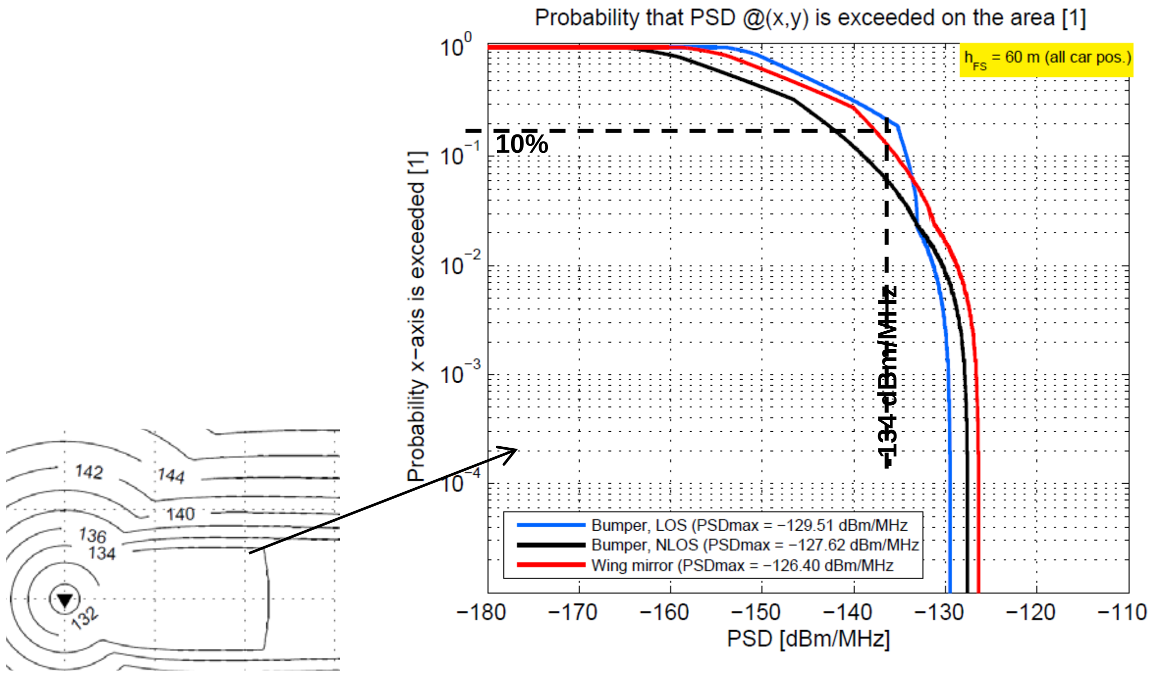

Figure 8: Probability that an UWB event located at a random position produces a PSD level that is exceeding the value indicated in x-axis (curves gives probability for different positions on the car)

Figure 8 describes the probability that an UWB event located at a random position in the considered area exceeds the PSD level indicated in x-axis. This probability is computed for each position defined for the UWB transmitted placed on the car (i.e. bumper LOS and NLOS and wing mirror position).

4.1.6.3 Long-term simulation

For simulating the long-term interference, the low protection level I/N_{prot}=-20 dB makes the number of UWB events above that protection level rather frequent. The simulation tool developed for this study can thus obtain a sufficient number of events exceeding the protection level to compute reliably the number of errored seconds.

The tool simulates repetitively over duration of one second and records all the interfering PSD contributions from the different Tx locations, including the simultaneous contributions that might potentially aggregate to exceed the protection level. It then counts the number of seconds experiencing a PSD above the protection level. The aggregation is considered here as producing a worst case additive interference (i.e. full coherence between two or more simultaneous Tx events).

4.1.6.4 Short-term calculation

The short-term calculation is difficult due to the extremely low number of errored seconds that has to be obtained. The method here proposes a semi-analytical approach based on the following assumptions.

As the protection level is increased from -20 dB (for the long-term criterion) to +19 dB (for short-term criterion), the probability that an event exceeds the protection level decreases very quickly. This is illustrated in Figure 8 showing that there is no “single entry” interference above a certain PSD level. Beyond that point, only the aggregation of two or more devices can lead to a PSD level that is exceeding the protection level. However, the probability of aggregation also quickly reduces with the increase of the protection level.

For the short-term calculation, a semi-analytical model is derived that is neglecting the aggregation effect and this model is compared to the events-based simulations used for the long-term scenario. From the PSD contour lines, it is easy to calculate the amount of UWB events that potentially exceed the protection level.

Figure 9 shows the comparison between events-based simulations and the semi-analytical method for typical case 1 (Category A, case no. 1 with typical FS antenna gain) with different antenna height. The “x” markers are obtained from the event-based simulation; the minimum probability that can be computed in a reasonable CPU time is approximately 0.005%. The lines are obtained from the semi-analytical model which is not taking into account aggregation effect. As expected, for low I/N (i.e. smaller than -15 dB), the discrepancy between the event-based model and the semi-analytical model increases due to the aggregation effect. On the other hand, a good match is obtained for higher I/N and a maximum I/N value can be extracted. For this scenario, the PSD level never reaches the short-term protection level and the maximum I/N to the victim FS receiver is -5 dB.

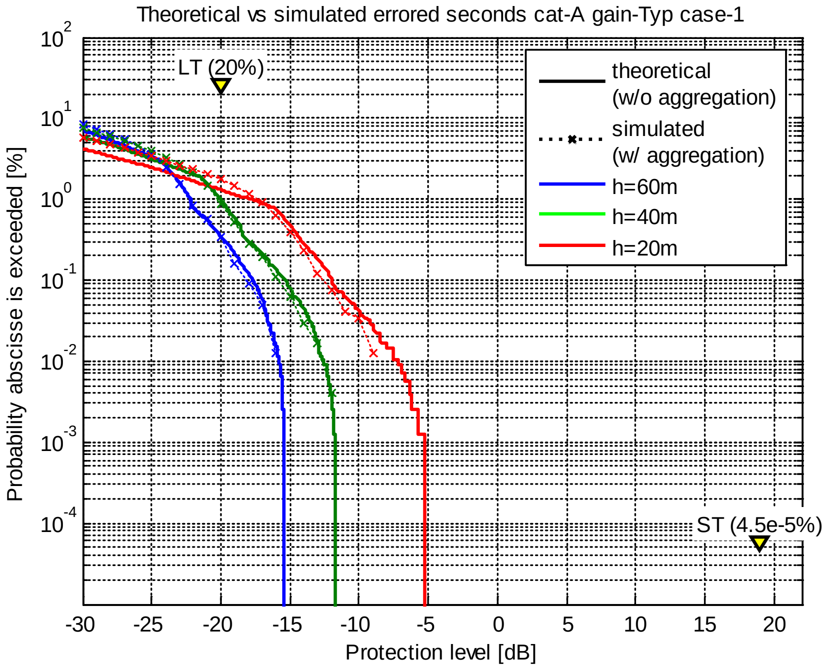

Figure 9: Comparison of the simulation with aggregation (“x” markers) and the proposed semi-analytical method without aggregation (continuous lines)

4.1.7 Simulation Results

For each of the cases listed in Table 5 and Table 6, a simulation for errored seconds has been conducted. The simulation outputs are illustrated in the figures below. The simulation results are showing the average percentage of errored seconds over 1 month with peak activity of 10 hours per day (typical shopping mall opening hours).

4.1.7.1 Lower UWB band

Worst case (Category B, worst case FS antenna gains)

The simulation outputs are illustrated in Figure 10 for the scenario showing the worst case results in the low UWB band and Category B with worst case antenna gains. The maximum ratio of long-term errored second is 12.6% and fulfils the 20% protection criteria. Case 1 corresponds to a FS operating at 3.6-4.2 GHz with antenna gain of 30 dBi (worst) and height of 20 m.

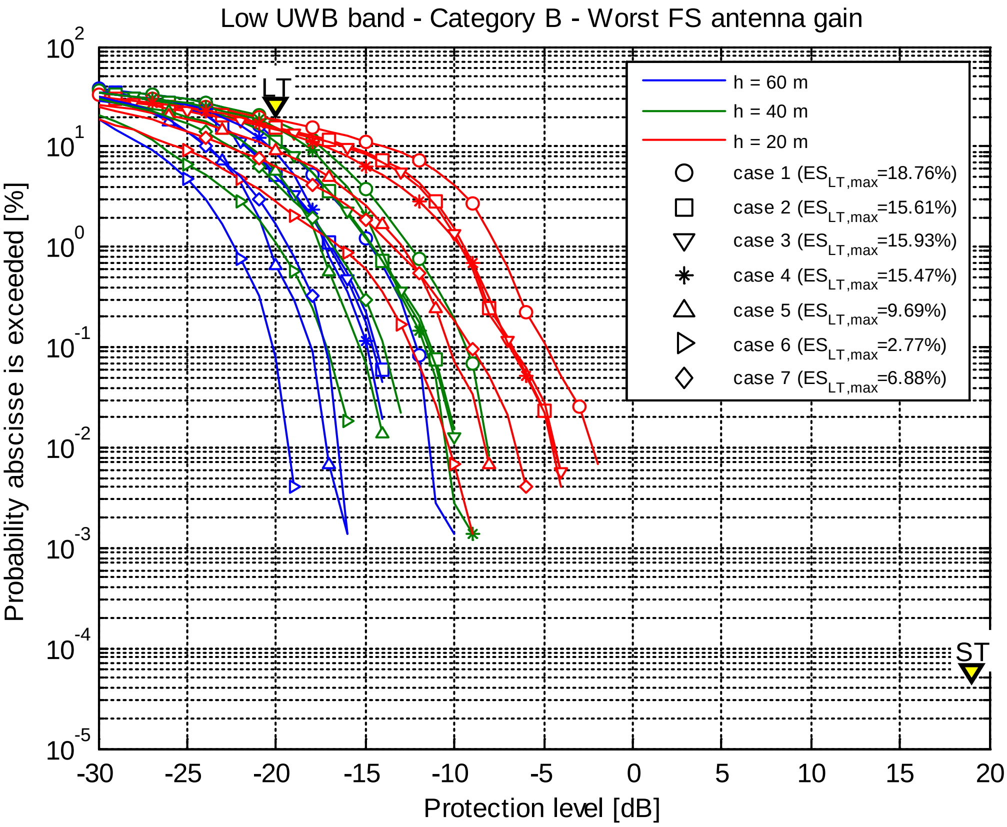

Figure 10: Cumulative distribution of interference PSD from Category B devices in the low UWB band to a victim FS receiver with worst antenna gain

Typical cases (Category A, typical FS antenna gain)

For Category A with typical antenna gains, the ratio of errored seconds is not exceeded by more than 1.7% (case 4).

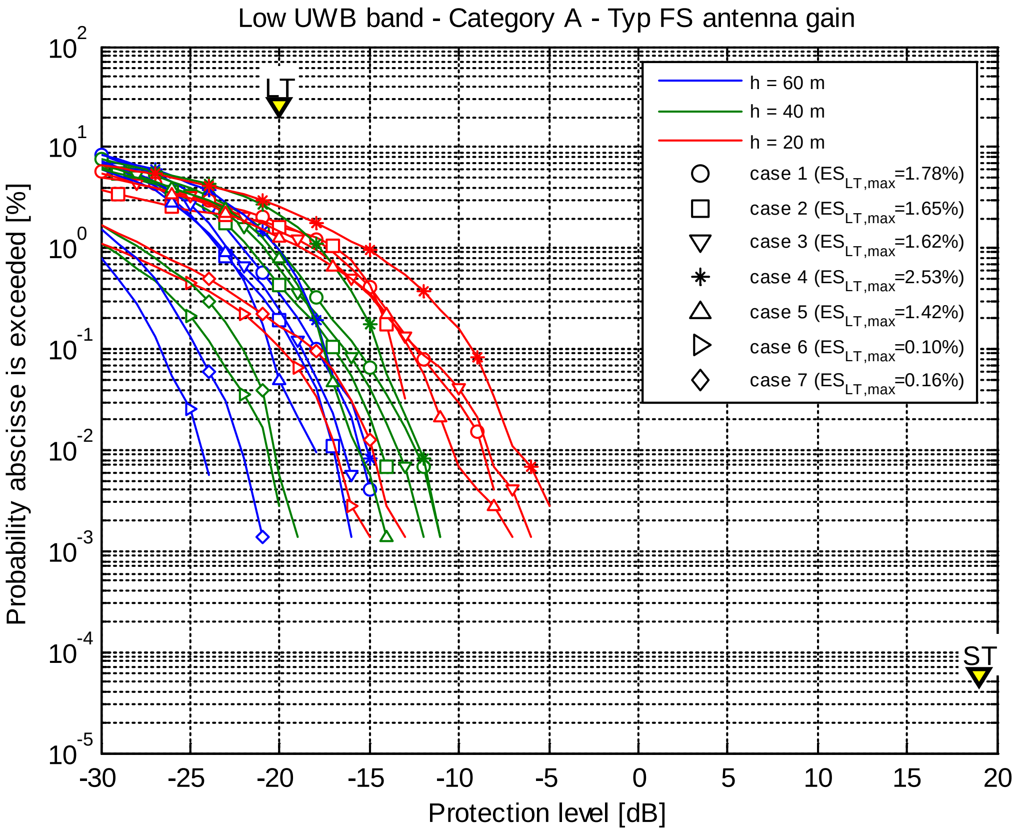

Figure 11: Cumulative distribution of interference PSD from Category A device in the low UWB band to a victim FS receiver with typical antenna gain

4.1.7.2 Upper UWB band

Similar results are given for the upper UWB band show that the protection criteria are fulfilled for all cases.

Worst case (Category B, worst case FS antenna gains)

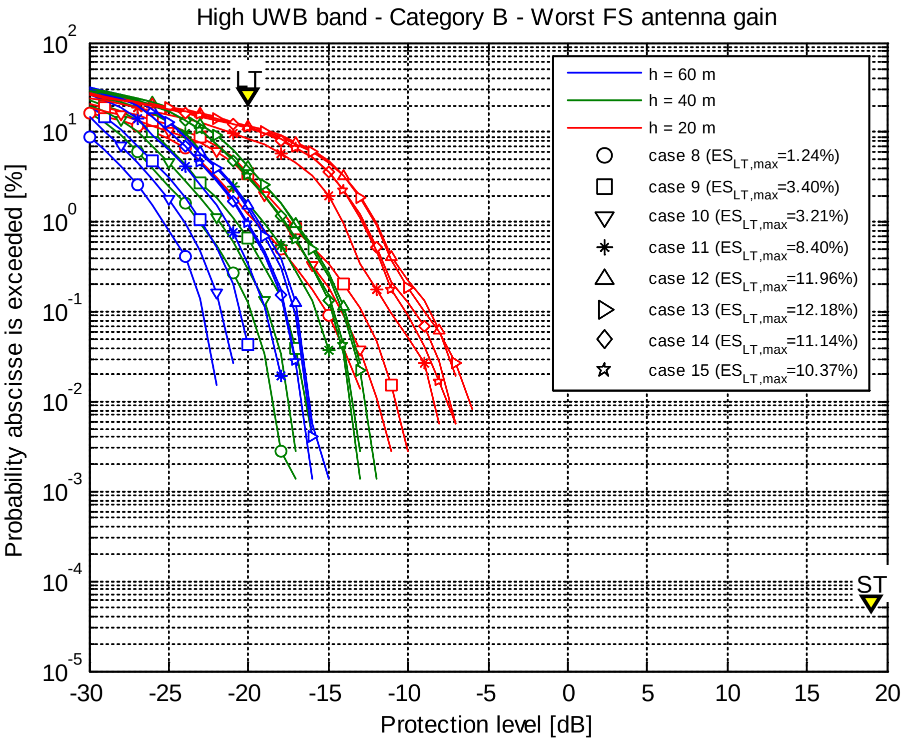

Figure 12: Cumulative distribution of interference PSD from Category B device in the high UWB band to a victim FS receiver with worst antenna gain

Typical cases (Category A, typical FS antenna gain)

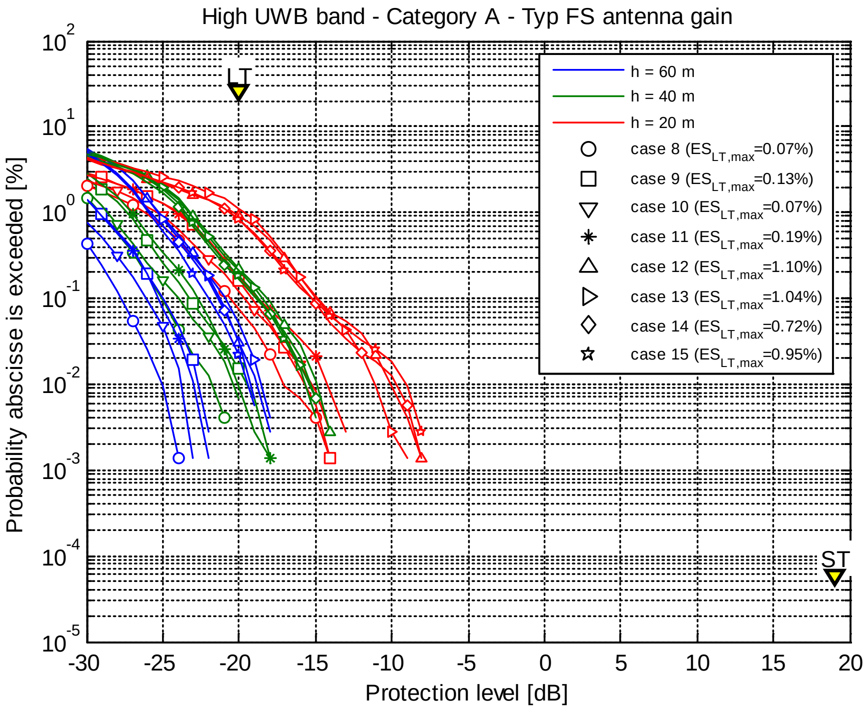

Figure 13: Cumulative distribution of interference PSD from Category A device in the high UWB band to a victim FS receiver with typical antenna gain

4.1.7.3 Summary Tables

Long-term protection

The ratio of errored seconds for long term is obtained by simulations taking into account the aggregation effect multiple UWB devices simultaneously transmitting from different locations of the parking lot.

Table 7: Ratio of errored seconds in the low band for long-term protection

Max % Errored Seconds (I/N > -20 dB)	BAND 3.4-4.8 GHz						
	PP					PMP	
Victim FS parameters case no.	1	2	3	4	5	6	7
Cat. A, Typ. FS antenna gain	1.78	1.65	1.62	2.53	1.42	0.10	0.16
Cat. A, Worst FS antenna gain	2.85	2.78	2.35	2.61	1.42	0.33	0.79
Cat. B, Typ. FS antenna gain	12.39	10.18	11.50	15.40	9.69	0.86	1.60
Cat. B, Worst FS antenna gain	18.76	15.61	15.93	15.47	9.69	2.77	6.88

Table 8: Ratio of errored seconds in the high band for long-term protection

Max % Errored Seconds (I/N > -20 dB)	BAND 6-8.5 GHz							
	PP							
Victim FS parameters case no.	8	9	10	11	12	13	14	15
Cat. A, Typ. FS antenna gain	0.07	0.13	0.08	0.19	1.10	1.04	0.72	0.95
Cat. A, Worst FS antenna gain	0.20	0.40	0.40	1.30	1.72	1.72	1.48	1.78
Cat. B, Typ. FS antenna gain	0.55	1.30	0.73	1.30	7.56	7.83	6.47	6.20
Cat. B, Worst FS antenna gain	1.24	3.40	3.21	8.40	11.96	12.18	11.14	10.37

Short-term protection

As the short-term protection level in term of errored second can never be approached by simulation, the table below provides the maximum I/N for each scenario based on the semi-analytical method described above. Note that the maximum I/N is not exceeding -2 dB for all simulated cases.

Table 9: Ratio of errored seconds in the low band for short-term protection

Max. I/N in [dB]	BAND 3.4-4.8 GHz						
	PP					PMP	
Victim FS parameters case no.	1	2	3	4	5	6	7
Cat. A, Typ. FS antenna gain	-5	-13	-6	-5	-8	-14	-12
Cat. A, Worst FS antenna gain	-2	-4	-4	-5	-8	-10	-7
Cat. B, Typ. FS antenna gain	-5	-7	-6	-5	-8	-14	-12
Cat. B, Worst FS antenna gain	-2	-4	-4	-5	-8	-10	-7

Table 10: Ratio of errored seconds in the high band for short-term protection

Max. I/N in [dB]	BAND 6-8.5 GHz							
	PP							
Victim FS parameters case no.	8	9	10	11	12	13	14	15
Cat. A, Typ. FS antenna gain	-14	-12	-14	-13	-9	-9	-9	-9
Cat. A, Worst FS antenna gain	-13	-10	-12	-9	-7	-7	-8	-8
Cat. B, Typ. FS antenna gain	-14	-12	-14	-13	-9	-9	-9	-9
Cat. B, Worst FS antenna gain	-13	-10	-12	-9	-7	-7	-8	-8

4.1.8 Conclusions for the Fixed Service

The most critical interference scenario is the one involving the devices operating in the lower UWB band operated under Category B. Simulations show that even if a sufficient level of protection can be reached for victim FS receivers operating in this band as defined by the long-term and the short-term criterion, there is probability that the interference come close to the protection criteria for a reduced range of limit PSD in the case of very low antenna gains (i.e. much lower that the range defined by ITU-R F.758-6, Table 6 [8]), as shown in Figure 12.

For all other simulated cases, UWB devices operating in the keyless scenario with trigger-before-talk mitigation but without exterior limit fulfil the protection criterion with enough margins.

This study considered worst case parameters (i.e. lower antenna gains) and maximum density of interfering devices within a parking lot area that has been positioned at a distance from the FS antenna corresponding to the worst case (i.e. for most of the case including FS antenna main beam and sidelobes). No minimal separation distance except the one provided by the antenna height has been used. Generally, the upper UWB band is much less affecting FS receivers owing to the intrinsically higher losses that occur from the propagation mechanism (geometric attenuation from the free space propagation assumption). Furthermore, the fact that the same propagation model than the one developed for the low UWB band has also been used for the higher band provides an additional confidence margin on the simulations performed in the 6-8.5 GHz, where no significant impact has been simulated on the incumbent Fixed Service.

4.2 PROTECTION OF RADIO ALTIMETERS AND WIRELESS AVIONICS INTRA - COMMUNICATION (WAIC)

4.2.1 Introduction

This study provides compatibility results on the coexistence between the proposed new UWB systems and aeronautical systems in the band 4200-4400 MHz.

It presents a preliminary assessment of the impact of UWB keys on radio altimeters and WAIC systems, if the external limit was relaxed in order to allow an e.i.r.p. density of -41.3 dBm/MHz.

The study does not consider the aggregated effect of multiple UWB keys active at the same time, nor it does the question of the aggregated impact of all UWB systems (previous and UWB keys).

4.2.2 Scenario for compatibility

In order to assess the compatibility, a simple scenario has been considered. A single UWB key is considered and it is checked whether the protection criteria are met for an airplane flying at different heights above the key. Figure 14 shows the geometry of the scenario.

The rationale of considering one single interferer is to make a sanity check to verify whether this scenario can pose a threat to the aeronautical systems in the band. If not, the analysis could proceed to consider the aggregation of multiple interferers.

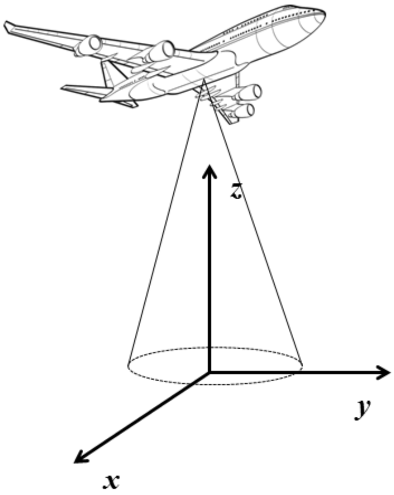

Figure 14: Scenario of the simulation

With reference to the coordinate systems in Figure 14:

- The key is located at (0,0,0);
- The aircraft is flying along a horizontal path defined by the coordinates (0,ya,ha). The altitude ha of the aircraft is fixed, so that his position varies along the axis y only;
- For simplicity the aircraft has zero roll and pitch;
- The radio-altimeter antenna beam is modelled with a cone whose aperture is defined in Recommendation ITU-R M. 2059 [18]. Inside the cone, the gain of the antenna is considered, as prescribed by the Recommendation, equal to its maximum gain. Outside the aperture, it is attenuated by 20 dB.

The propagation model is free space and no polarisation mismatch is considered between the key and the radio-altimeter.

Due to the lack of an approved value for minimum aircraft height above ground to be considered for the compatibility studies, two scenarios A and B representing different aircraft height levels are taken into account. Scenario A assumes a minimum aircraft height of 50 m and scenario B assumes a minimum aircraft height of 153 m according to ECC Report 272 [9].

4.2.3 Protection for radio altimeters

Technical characteristics and protection criteria are given in ITU-R M. 2059. It has to be noted that the latest version of this Recommendation approved in 2014 entered into force after the approval of ECC Report 170 [7]. Therefore, the Recommendation shall prevail over the Report.

Table 11 gives a summary of the types of radio-altimeters in the Recommendation and the relevant protection criteria:

Table 11: Summary of protection criteria for radio altimeters in Recommendation ITU-R M.2059 [18]

Denomination	Type	Desensitisation (*)	False altitude threshold	Receiver overload threshold
A1	Analog	I/N=-6	-143 dBm/100 Hz	-30 dBm
A2	Analog	I/N=-6	-143 dBm/100 Hz	-53 dBm
A3	Analog	I/N=-6	-143 dBm/100 Hz	-56 dBm
A4	Analog	I/N=-6	NA	-40 dBm
A5	Analog	I/N=-6	NA	-40 dBm
A6	Analog	I/N=-6	NA	-40 dBm
D1	Digital	I/N=-6	NA	-30 dBm
D2	Digital	I/N=-6	NA	-43 dBm
D3	Digital	I/N=-6	NA	-53 dBm
D4	Digital	I/N=-6	NA	-40 dBm

(*) Regarding the desensitisation criterion, it has to be noted that ITU-R M. 2059 indicates that, given the critical mission performed by the aeronautical radio altimeters, it might be appropriate to adopt a more stringent protection criterion (I/N=-12 dB instead of I/N=-6 dB).

It should be noted that this criteria protects radio altimeter also during operation at high flying altitudes, here the radio altimeter receiving signal is very weak. At low flight altitudes, the radio altimeter receiving signal power may be higher. In that case the probability of false radio altimeters operation due to low power spectral density interference signals, such as UWB emissions or spurious emissions from services operating in the adjacent band, may be negligible under certain circumstances.

4.2.4 Result of single entry studies for radio altimeters

Table 12 summarises the results.

Table 12: Summary of results (flight altitude at which the criterion is met)

Denomination	Type	Desensitisation	False altitude threshold	Receiver overload threshold
A1	Analog	24.5 m	11 m	Never attained
A2	Analog	39 m	11 m	Never attained
A3	Analog	62 m	17.5 m	Never attained
A4	Analog	35 m	NA	Never attained
A5	Analog	27.5 m	NA	Never attained
A6	Analog	27.5 m	NA	Never attained
D1	Digital	35 m	NA	Never attained
D2	Digital	55 m	NA	Never attained
D3	Digital	55 m	NA	Never attained
D4	Digital	69 m	NA	Never attained

As it may be seen in Table 12, the constraining criterion for radio altimeters is the desensitisation.

The following figures give the results of the simulations for each combination of system/criterion for different flight altitudes.

4.2.4.1 Results for I/N

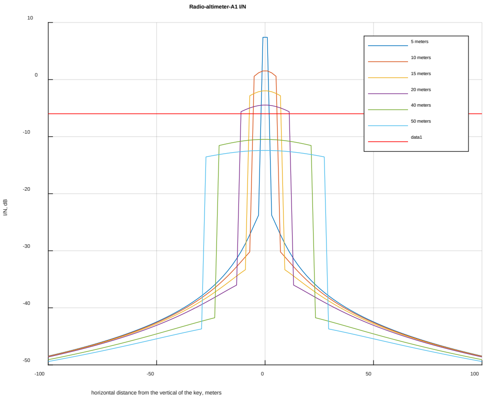

Figure 15

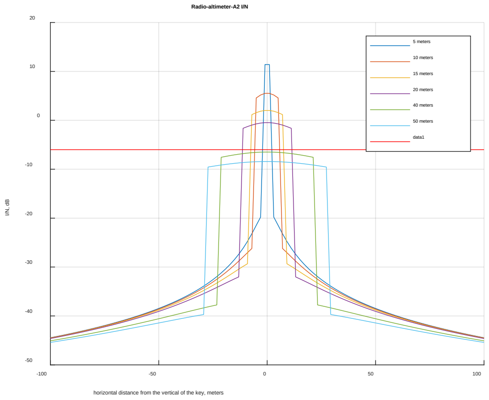

Figure 16

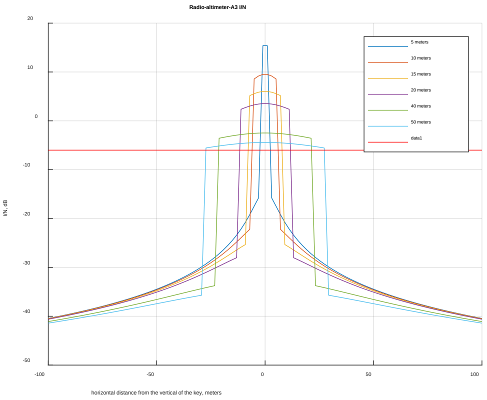

Figure 17

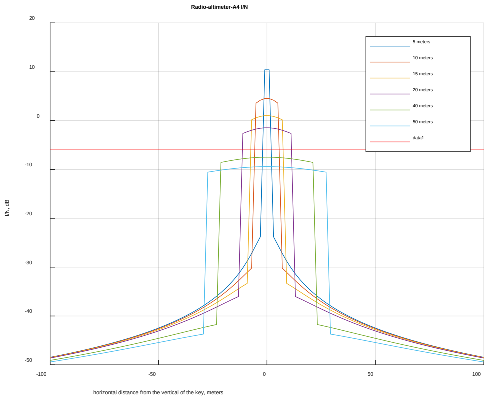

Figure 18

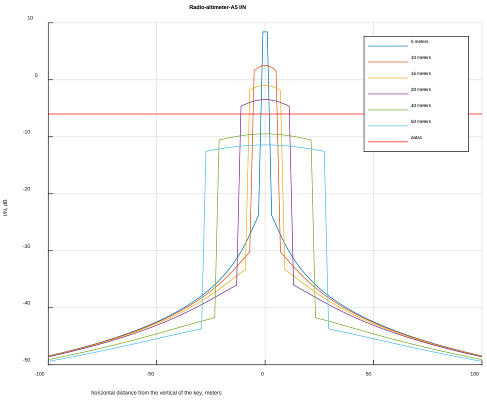

Figure 19

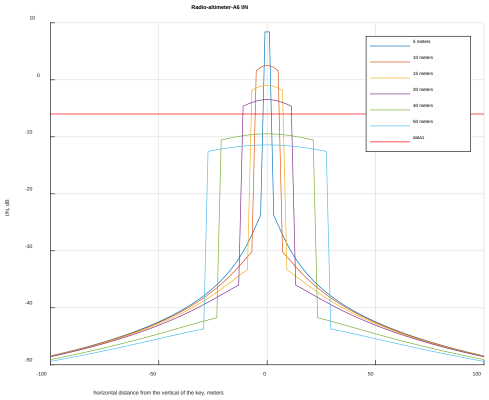

Figure 20

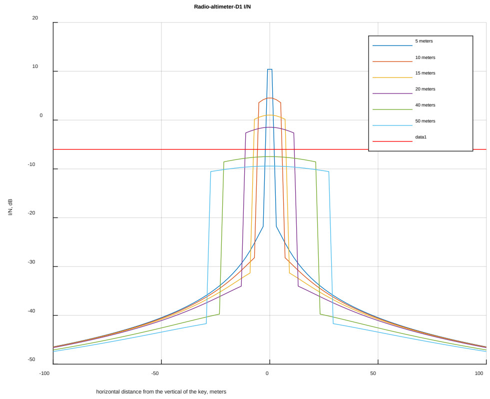

Figure 21

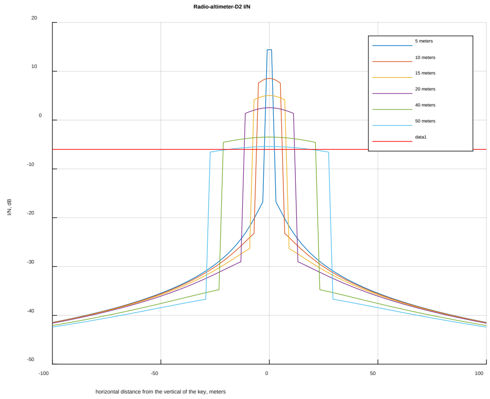

Figure 22

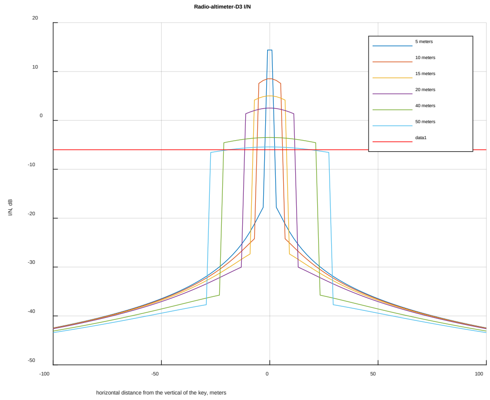

Figure 23

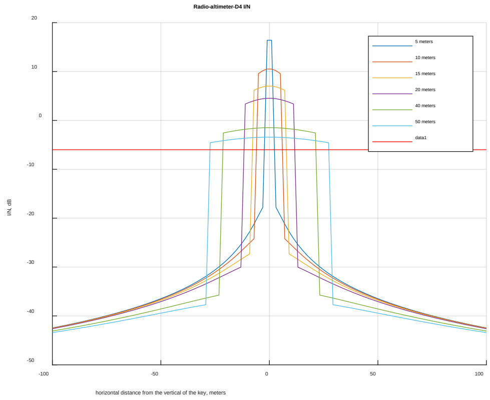

Figure 24

4.2.4.2 Results for False Altitude Reports

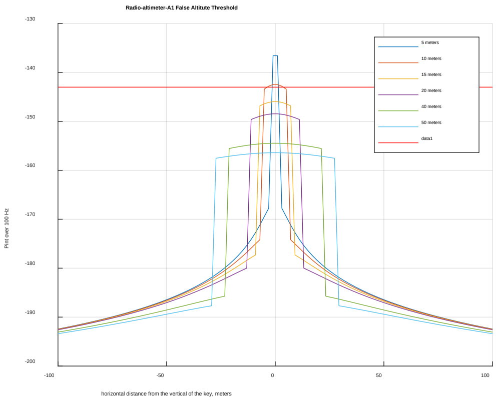

Figure 25

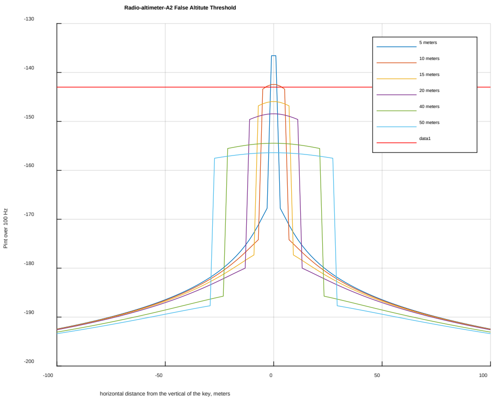

Figure 26

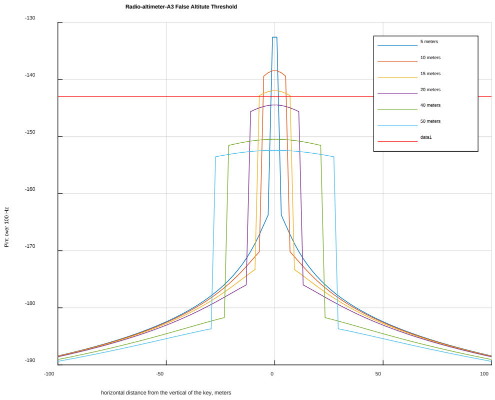

Figure 27

4.2.4.3 Results for Overloading

The analysis shows that overloading is never a problem.

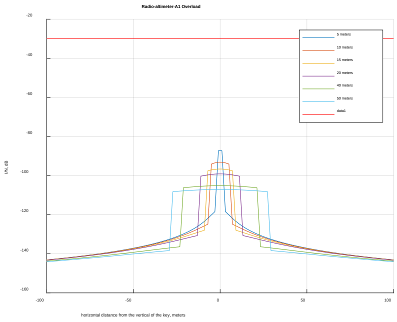

Figure 28

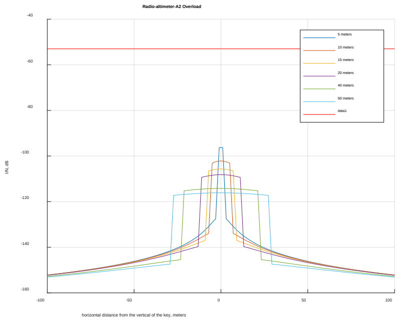

Figure 29

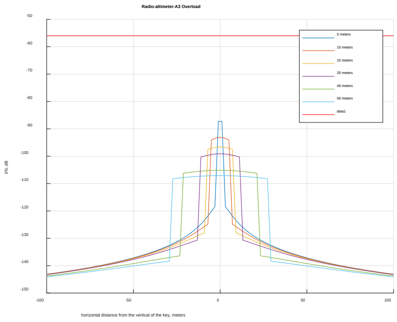

Figure 30

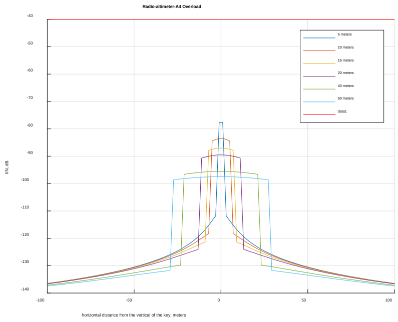

Figure 31

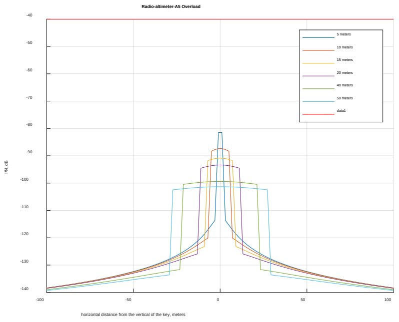

Figure 32

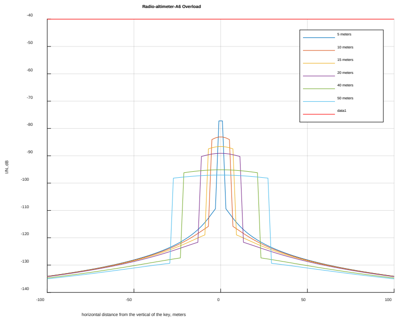

Figure 33

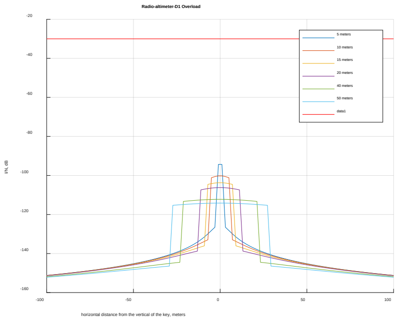

Figure 34

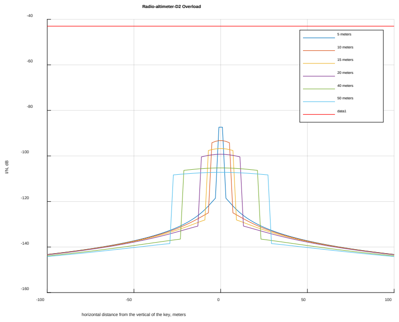

Figure 35

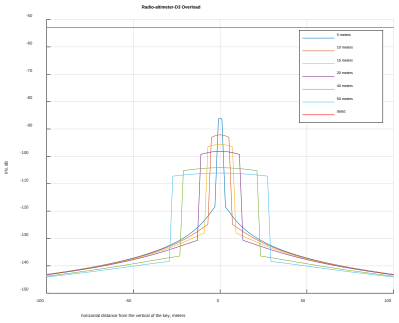

Figure 36

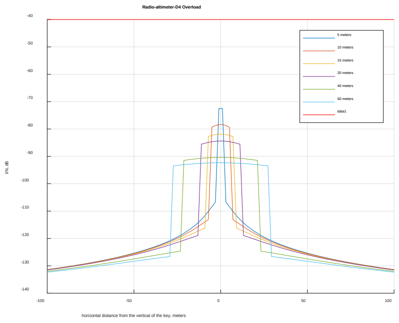

Figure 37

4.2.4.4 Protection criteria for WAIC

WRC-15 introduced wireless avionics intra-communication systems in the band 4200-4400 MHz. Their characteristics and protection criteria are given in Recommendation ITU-R M. 2067 [19].

The Recommendation specifies two types of Wireless Avionics Intra-Communication (WAIC) systems. Table 13 summarises the protection criteria:

Table 13: Protection criteria for WAIC

System	I/S (sensitivity to interference ratio)	Threshold of RX overload
Low data rate system	-9 dB	-14 dB
High data rate system	-30 dBm	-30 dBm

4.2.5 Result of single entry studies for WAIC

The simulations indicate that the criteria are met at the flight altitudes reported in Table 14:

Table 14: Flight altitudes where protection criteria are met

System	I/S (sensitivity to interference ratio)	Threshold of Rx overload
Low data rate system	8 m	Never attained
High data rate system	7.8 m	Never attained

The following figures provide the results of the simulations for the two systems. The results indicate that overloading is not a problem but the required protection criteria for sensitivity are not met.

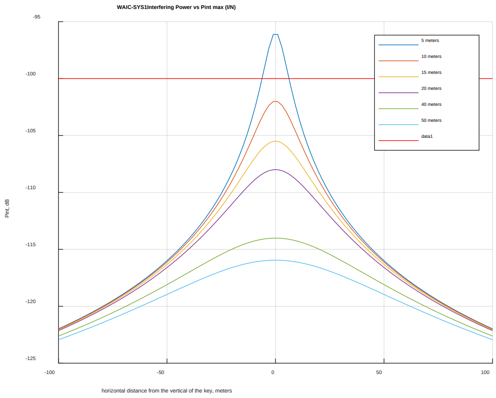

Figure 38

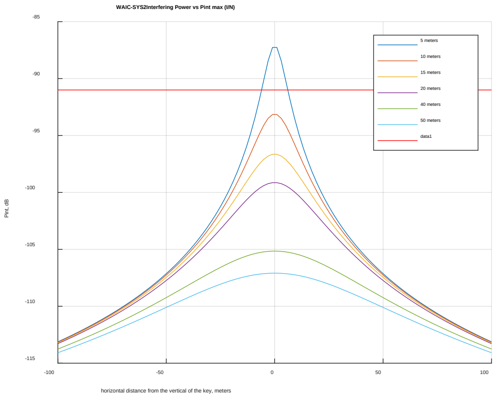

Figure 39

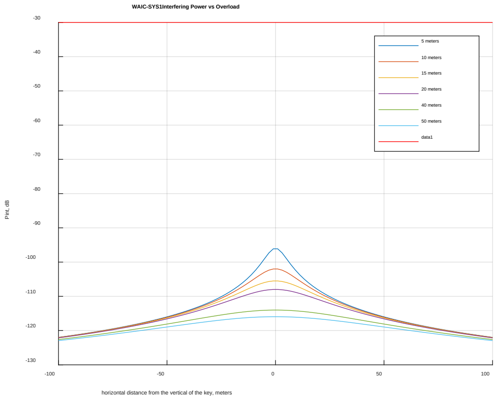

Figure 40

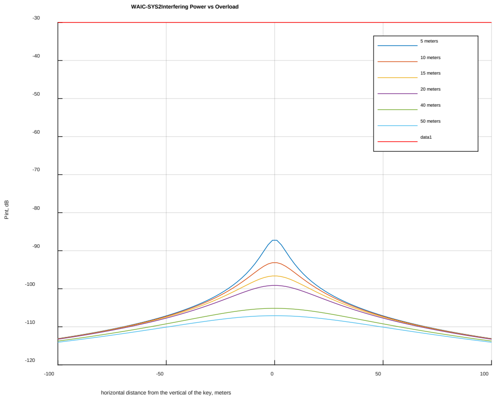

Figure 41

4.2.5.1 Aggregated interference for WAIC

For studying aggregate interference effects for WAIC, the considered UWB devices are assumed to operate on airport parking at very low activity factor - typically 1 open and 1 close access within 24 hours (86400 s). Further considering deployment and operational parameters described as 25% market penetration and10000 cars in a parking lot, 5 000 transmit periods with each cumulated length of 50 ms for Category A or 750 ms for Category B devices within 24 hours are possible.

The probability of simultaneous transmission of multiple Category B or Category A devices is following the Poisson distribution with the following mean values:

- Mean Category B = 5 000 · 0.750s / 86400s = 4.340 · 10^{-2} (Category B devices);
- Mean Category A = 5 000 · 0.050s / 86400s = 2.894 · 10^{-3} (Category A devices).

The Poisson distributions for both above mentioned mean values are shown graphically in Figure 42.

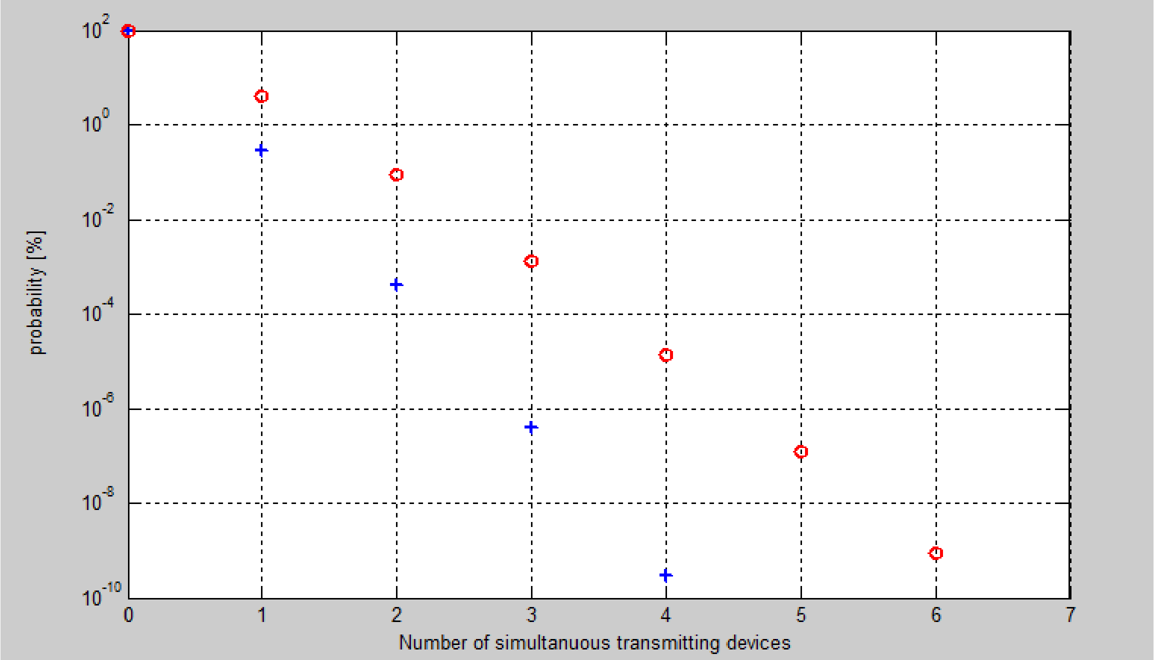

Figure 42: Poisson distribution for two different mean values (mean = $4.340 \cdot 10^{-2}$ (+) and mean = $2.894 \cdot 10^{-3}$ (o))

Accordingly, the probability for simultaneous transmission of more than 2 devices and the probability for simultaneous transmission of exactly 8 devices are calculated as shown below:

- $P_{0.04340}(X > 2) = 1 - P_{0.0434}(0) - P_{0.0434}(1) - P_{0.0434}(2)$;
- = 1 – 95.75283% – 4.155673% – 0.0901781% = 0.0013189%;
- $P_{0.04340}(X = 8) = 5.51 \cdot 10^{-12}$ %;
- $P_{0.002894}(X > 2) = 1 - P_{0.002894}(0) - P_{0.002894}(1) - P_{0.002894}(2)$;
- = 1 – 99.71102% – 0.288564% – 0.0004175517% = 0.0000004031%;
- $P_{0.04340}(X = 8) = 3.634 \cdot 10^{-20}$ %.

The probability of simultaneous transmission of more than 2 devices is 0.001319 % for Category B and 0.0000004031% for Category A. The probability of simultaneous transmission of 8 devices is 3.634 10-20 %.

In case of 3 simultaneous transmitting devices, the interference power is increased by 4.8 dB when the very improbable case is considered that all three devices are placed at the minimum separation distance to the victim receiver. In that case, the minimum separation distance is below 15 m, as can be deduced by means of Figure 38 and Figure 39.

In case of 8 simultaneous transmitting devices, the interference power is increased by 9 dB when the very improbable case is considered that all three devices are placed at the minimum separation distance to the victim receiver. In that case, the minimum separation distance is below 30 m, as can be deduced by means of Figure 38 and Figure 39.

4.2.5.2 Conclusions

Due to the lack of an approved value for minimum aircraft height above ground to be considered for the compatibility studies, two scenarios A and B representing different aircraft height levels are taken into account. Scenario A assumes a minimum aircraft height of 50 m and scenario B assumes a minimum aircraft height of 153 m according to ECC Report 272 [9].

At a minimum aircraft height level of 50 m, assumed by scenario A, the protection level for radio altimeter is exceeded, while at aircraft height level of 153 m assumed by scenario B the protection level is not exceeded.

Based on studies in ICAO it is estimated that the minimum vertical distance of a fixed-wing aircraft above vehicle outside airport area or a vehicle operated for airport service is about 19m. Helicopters (rotary-wing aircraft) can operate in much closer proximity to vehicles both near airports and elsewhere. For example, emergency aeromedicine helicopters are critical for emergency medical care and operate wherever they can, , it is quite common for helicopters to be operating within a few meters of vehicles both vertically and laterally. . As a result, for protection of both fixed-wing and rotary-wing aircraft, ICAO preconizes a minimum separation distance to vehicles on the order of 5 meters should be assumed.

According to scenario A it can be stated that in the frequency band 4.2-4.4 GHz the exterior limit has to be applied. On the other side, the much shorter separation distance for WAIC, seems to pose a risk of interference in a single entry scenario.

In the case of WAIC, separation distances of less than 10 m are calculated and therefore present a low risk of interference in a single entry scenario.

4.2.6 Aggregated effect on radio-altimeters

4.2.6.1 Output power, and operating frequency

An UWB access control system in the band 3.4-4.8 GHz and 6 – 8.5 GHz consists of a key fob equipped with an UWB transceiver and a vehicle equipped with 4 UWB transceivers. The key fob device and the devices in the vehicle are considered to operate with the maximum allowed PSD -41.3 dBm/MHz.

4.2.6.2 Aggregation scenarios

A UWB-based access control system presents negligible aggregation effects due to both the ultra-low duty cycle as well as the additional mitigation by trigger-before-talk. Given that trigger-before-talk is a user action (e.g. touching the door handle, pushing start button), the probability of simultaneously operating access control systems is considered extremely unlikely.

In order to reuse the studies on aggregation effects on radio altimeters performed in ECC Report 170 [7], two aggregation scenarios are considered where the cars are parked. In a UWB-access control system, the secure UWB bi-directional communication between the key fob and the car takes only place when i) the car is parked ii) upon user trigger operation in the car close proximity.

In all other cases there is no UWB communication.

Scenario 1 (Same as in ECC Report 170 adapted to UWB-based vehicular access systems)

The cars are considered parked outdoor with the urban density 330 cars/km^2.

- 330 vehicles/km^2 (as in ECC Report 170);
- 4 devices/vehicle (ref. ETSI TR 103 416 V1.1.1 (2016-07) [1]);

- Max. DC of 5 %/s (as in ECC Report 170);
- Long-term activity factor taken as in ETSI TR 103 416 V1.1.1 (2016-07) for Category A, Category B and Category C UWB access systems.

Scenario 2 (Big outdoor parking lot)

For the vehicular access systems deployment scenario, a big parking place next to an airport is considered as a most conservative worst case scenario. In this scenario, the car density to 33000 cars/km^2 is artificially increased.

Parking decks are not in the scope of this study, as they do not represent worst case aggregation scenario. It is noted that the biggest parking lots around airports are actually park decks with around 10000 cars (e.g. Detroit Metropolitan Wayne County Airport).

- 33000 vehicles/km^2;
- 4 devices/vehicle (Ref. ETSI TR 103 416 V1.1.1 (2016-07)]);
- Max. DC of 5 %/s (as in ECC Report 170);
- Long-term activity factor (1 open and 1 close access operation in 24 hours).

Mitigation factors and activity

Mitigation technique are i) LDC mitigation and ii) trigger-before-talk mitigation in the car UWB devices.

The short-term activity factor is provided by LDC mitigation and is Max DC of 5%/s/device as in ECC Report 170.

The long-term activity factor is according to the considered scenario (see above).

4.2.6.3 Aggregation effect

Scenario 1

Tables 38 and 39 of ECC Report 170 show aggregated interference levels compared to the protection level of radio altimeter. Taking the case with the generic -41.3 dBm/MHz mean PSD per device, without car shielding but with long-term protection of 0.5 %/hour, it is observed that a maximum of 6 dB is missing for the required protection.

By taking the long-term activity of an UWB-based vehicular access control system together with trigger-before-talk, Table 15 shows the achieved protection for the radio-altimeter and compares the results of ECC Report 170 with the calculations for vehicular access systems.

Table 15: Comparison of ECC Report 170 [7], Table 38 with trigger-before-talk mitigation for Category A, B and C (without exterior limit)

Aggregated interference level compared to the protection level of radio-altimeters				
Scenario/ Altitude of the aircraft	100 m	500 m	1000 m	1500 m
Generic LTA applications (from ECC Report 170) -41.3 dBm/MHz/LTA - no car shielding 330 vehicles/km^2 10 LTA/vehicle Max DC of 5 %/s LTA Max DC of 0.5 %/hour/LTA → 18 000 ms/hour	6 dB	5 dB	4 dB	4 dB
Generic LTA applications (from ECC Report 170) -53.3 dBm/MHz/LTA for elevation higher than 0°	-6 dB	-7 dB	-8 dB	-8 dB

Aggregated interference level compared to the protection level of radio-altimeters				
(i.e. power reduction or car shielding) 330 vehicles/ km^2 10 LTA/vehicle Max DC of 5 %/s LTA Max DC of 0.5 %/hour/LTA → 18 000 ms/hour				
Category A Proximity verification -41.3 dBm/MHz/Vehicle Access - no car shielding 330 vehicles/ km^2 4 devices/vehicle Max DC of 5 %/s Proximity verification activity factor (incl. DC) max. 0.00174 % →62.64 ms/hour	-22.6 dB	-23.6 dB	-24.6 dB	-24.6 dB
Category B Proximity monitoring -41.3 dBm/MHz/Vehicle Access - no car shielding 330 vehicles/ km^2 4 devices/vehicle Max DC of 5 %/s Proximity monitoring activity factor (incl. DC) max. 0.033 % →1188 ms/hour	-9.8 dB	-10.8 dB	-11.8 dB	-11.8 dB
Category C Proximity detection -41.3 dBm/MHz/Vehicle Access - no car shielding 330 vehicles/ km^2 4 devices/vehicle Max DC of 5 %/s Proximity monitoring Max DC of 0.5 %/hour/LTA → 18000 ms/hour	6 dB	5 dB	4 dB	4 dB

As a matter of comparison, it is noted that the aggregation scenario in ECC Report 170 requires a total UWB activity of 10 UWB devices x 330 cars/ km^2 x 18 seconds/hour = 59400 seconds per hour per km^2 of UWB communication to reach +6 dB at 100 meters with -41.3 dBm/MHz, i.e., 14750 seconds per hour per km^2 to get 0 dB at 100 meters with -41.3 dBm/MHz.

In case of an UWB-based vehicular access control system, reaching UWB activity of 14750 seconds per hour per km^2 would require more than 235000 system triggers per hour per km^2 of Category A and more than 12000 system triggers per hour per km^2 of Category B.

Scenario 2

Considering 1 car open/start and 1 car close in 24 hours, 1375 triggered cars per km^2 per hour are obtained. Under the communication activity per car according to Category A and Category B systems, this makes a total UWB activity of 1375*3*0.05s = 206.25 seconds per hour per km^2 (Category A) and 1375*2*0.75s = 2062.5 seconds per hour per km^2 (Category B with 1 Comfort Open, Remote (Control) Parking).

The total UWB active time in both Category A and Category B is significantly lower than the total active times per hour per km^2 considered in Table 15 to produce an aggregated interference level problematic for the radio-altimeters.

4.2.6.4 Conclusion for aggregated interference

Based on the methodology of ECC Report 170, UWB-based access control systems of type Category A: "Proximity verification" and Category B: "Proximity monitoring applications" provide a significantly higher degree of protection to the radio altimeters, even when operating at a maximum mean e.i.r.p. spectral density requirement of -41.3 dBm/MHz outside the vehicle, i.e. without an exterior limit (as defined in ETSI EN 302 065-3 [10]) than vehicular or generic UWB devices applying LDC..

4.2.7 Aggregated interference form WAIC and UWB on radio altimeter

Sharing of the frequency band 4 200 – 4 400 MHz between radio altimeters and WAIC is studied in Report ITU-R M.2319-0 [20]. This Report concludes, that sharing is not possible as long as no directional antennas for WAIC are used.

Recommendation ITU-R M.2067-0 [19] provides technical characteristics and protection criteria for wireless avionics intra-communication (WAIC) systems. Inconsistent to the Report ITU-R M.2319-0 [20], this recommendation does not require the use of directional antennas for WAIC, but specifies 0 dBi antenna gain for both, WAIC transmitter and receiver. In footnote 1 of table 1 however, the possible use of directional antennas with the aim to reduce the overall emission from the aircraft is mentioned, on condition that the main beam has to point towards the centre of the aircraft.

Recommendation ITU-R M.2085-0 [35] defines the maximum permitted transmit spectral power density for WAIC systems of 5dBm /MHz when high data rate applications are used and 6 dBm/ MHz when high and low data rate applications are used.

For studying aggregate interference effects with WAIC to radio altimeter, scenarios are considered where aircrafts on the airport ground (e.g. when taxiing with operating WAIC transmitters) interfere with aircrafts in the final stage of landing. When assuming such scenarios, the range of distances from airport car parking to the victim radio altimeter receiver is the same as the range of distances from aircrafts on airport ground to the victim radio altimeter receiver. Considering aggregated interference from WAIC and UWB devices (with transmit power spectral density of -41.3 dBm/MHz), the interference level at the radio altimeter receiver input is dominated by WAIC signals: Assuming scenarios as used in Section 4.2.5.1, the following probabilities for simultaneous transmission of more than 2 devices and the probability for simultaneous transmission of exactly 8 devices are obtained:

- $P_{0.04340}(X > 2) = 1 - P_{0.0434}(0) - P_{0.0434}(1) - P_{0.0434}(2)$;
- $= 1 – 95.75283\% – 4.155673\% – 0.0901781\% = 0.0013189\%$;
- $P_{0.04340}(X = 8) = 5.51 \cdot 10^{-12}$ %;
- $P_{0.002894}(X > 2) = 1 - P_{0.002894}\ (0) - P_{0.002894}(1) - P_{0.002894}\ (2)$;
- $= 1 – 99.71102\% – 0.288564\% – 0.0004175517\% = 0.0000004031\%$;
- $P_{0.002894}\ (X = 8) = 3.634 \cdot 10^{-20}$ %.

The probability of simultaneous transmission is 0.001319% for Category B and 0.0000004031% for Category A devices. Because according to ITU-R Recommendations, the emission power of WAIC transmitters is maximum 5 dBm/MHz or 6 dBm/MHz respectively - radiating isotopically -, the addition of the aggregated emission of simultaneous transmitting UWB devices causes a potential e.i.r.p. interference level of:

- $P_{UWB}(3)$ = -41.3 dBm/ MHz + 10Log(3) = -36.5 dBm/ MHz (for 3 simultaneous transmitting devices);
- $P_{UWB}(8)$ = -41.3 dBm/ MHz + 10Log(8) = -32.3 dBm/ MHz (for 8 simultaneous transmitting devices);
- Both emission levels cause very weak increase of the overall interference (dominated by WAIC device emissions = 5 dBm/MHz) at the radio altimeter receiver of;
- $P_{increase}((3), 5\ dBm/MHz) = 10 * \log(10^{0.5} + 10^{-3.65}) – 5dBm = 3 \cdot 10^{-4}$ dBm;
- $P_{increase}((8), 5\ dBm/MHz) = 10 * \log(10^{0.5} + 10^{-3.23}) – 5dBm = 8 \cdot 10^{-4}$ dBm.

4.3 MOBILE SERVICE IN THE 3400-3800 MHZ FREQUENCY BAND

4.3.1 Introduction

The frequency band 3.4-3.8 GHz is assigned for future 5G system deployment. Therefore sharing between 5G (IMT-2020) and UWB needs to be studied in this Report. The protection criterion according to Report

ITU-R M.2039-3 is applied for scenario where 5G base station parameters are considered according to ECC Report 281 [34].

4.3.2 UWB Vehicular access system usage scenarios

In contrast to other vehicular UWB devices, the considered one does not radiate during driving under normal conditions. Accordingly, the worst case deployment scenario for aggregated as well as for single entry interference is a large parking lot. Again, a density of 33000 cars/km^2 is assumed as worst case. It is assumed, that there is one UWB communication in 30 minutes for a single UWB device Category A, and one UWB communication in 60 minutes for a single UWB device Category B device. There are maximum 4 non simultaneously operating UWB devices per car. Within one communication period with the duration T_{on}, the UWB radiation of all 4 devices is terminated.

4.3.3 UWB channel model

In scenarios involving small separation distances d < 50m between devices using UWB technology and IMT terminals and base stations the free-space loss model is used.

Aggregated interference scenarios are studied only for macro and micro environments. For those scenarios, a specific path loss model is applied as shown in ANNEX 2:.

In this section, a scenario for protecting 5G, considering protecting criterion I/N = -20 dB, is assessed.

4.3.4 5G mobile station parameters

The parameters for the 5G mobile station applied for the analysis are according definitions of ECC Report 281 and are shown in Table 16.

Table 16: 5G mobile station parameters

System Parameter	Value/Description
Noise Figure	9 dB
Antenna Gain	-4 dBi
Body loss	4 dB
Protection Criterion I/N	-20 dB

4.3.5 5G base station parameters

The parameters for the 5G base station applied for the analysis are according to definitions of ECC Report 281 Annex 1 [34]. The antenna specifications are shown in Table 17.

Table 17: 5G antenna element and array parameters

Parameter	Value
Antenna element directional pattern $a_E(\theta,\varphi)$	According to 3GPP TR 37.840 (section 5.4.4.2) [36]: $a_{E\,\mathrm{dB}}\,(\theta,\varphi) = -\min\{-[A_{E,V\,\mathrm{dB}}(\theta) + A_{E,H\,\mathrm{dB}}(\varphi)],\ A_{m\,\mathrm{dB}}\} + G_{E\,\mathrm{dB}},$ $A_{E,H\,\mathrm{dB}}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3\mathrm{dB}}}\right)^2, A_{m\,\mathrm{dB}}\right\},$ $A_{E,V\,\mathrm{dB}}(\theta) = -\min\left\{12\left(\frac{\theta - 90°}{\theta_{3\mathrm{dB}}}\right)^2, SLA_{V\,\mathrm{dB}}\right\},$

Parameter	Value
	where 3 dB elevation beamwidth $\theta_{3dB} = 65°$, 3 dB azimuth beamwidth $\varphi_{3dB} = 80°$, Front-to-back ratio $A_m = 30$ dB, Side-lobe ratio $SLA_V = 30$ dB. $G_{E\,\mathrm{dB}} = 5dB$
Number of base station beam forming elements (N_V, N_H)	8,8 and 16,16
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation.
Mechanical downtilt	Macro-cell: 10° Micro-cell: 10°
Array beam forming directional pattern $a_A(\theta,\varphi)$	According to 3GPP TR 37.840 (section 5.4.4.2): $a_{\mathrm{A}}(\theta,\varphi) = 1 + \rho\left[\left\lvert\sum_{m=1}^{N_{\mathrm{H}}}\sum_{n=1}^{N_{\mathrm{V}}} w_{m,n}v_{m,n}\right\rvert^2 - 1\right]$ where $v_{m,n} = \exp\left[j\frac{2\pi}{\lambda}\{(m-1)d_{\mathrm{H}}\sin(\varphi)\sin(\theta) + (n-1)d_{\mathrm{V}}\cos(\theta)\}\right]$, $w_{m,n} = \frac{1}{\sqrt{N_{\mathrm{H}}N_{\mathrm{V}}}}\exp\left[-j\frac{2\pi}{\lambda}\{(m-1)d_{\mathrm{H}}\sin(\varphi_{\mathrm{SCAN}})\cos(\theta_{\mathrm{TILT}}) - (n-1)d_{\mathrm{V}}\sin(\theta_{\mathrm{TILT}})\}\right]$, and ρ is the signal correlation across the antenna elements, $N_{\mathrm{V}}, N_{\mathrm{H}}$ are the number of vertical and horizontal antenna elements, $d_{\mathrm{V}}, d_{\mathrm{H}}$ are the vertical and horizontal antenna element spacings, $-\pi/2 \le \theta_{\mathrm{TILT}} \le \pi/2$ is the downward beam steering tilt angle relative to boresight, and $-\pi \le \varphi_{\mathrm{SCAN}} \le \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight.
Correlation	$\rho = 1$.
Array beam forming directional (power) gain $g(\theta,\varphi)$	Power $P(\theta,\varphi)$ radiated by antenna array system in direction (θ,φ) is $P(\theta,\varphi) = P_{\mathrm{TX}}\, g(\theta,\varphi)$ where P_{TX} is the conducted power, and $g(\theta,\varphi) = G\, a(\theta,\varphi) = G\, a_{\mathrm{E}}(\theta,\varphi)\, a_{\mathrm{A}}(\theta,\varphi)$ Where G is the normalization factor and L is the antenna loss. The normalization factor is 4.8 dB
Element gain	5 dB
Antenna loss, L	L = 0 dB
Beam forming	At each Monte Carlo trial, in each sector a single beam is steered in azimuth and elevation toward a mobile station which is dropped randomly within the sector. Mobile stations are considered to be outdoor in all cases and to

Parameter	Value
	be at a height of 1.5 m above the ground.
Antenna height [m]	Macro-cells: 20 metres. See ITU-R M.2292 [22]. Micro-cells: 6 metres. See ITU-R M.2292.
Sectorization	Each macro base station would have three independent sectors (120° each). See 3GPP TR 37.840. The orientation of the sectors does not change from one Monte Carlo trial to the next. Micro base stations are not sectorised.
Noise figure F_{RX}	5 dB
Protection criterion I/N	-20 dB
Feeder loss A_{Feeder}	0 dB
Base station range	200 m

The following four different types of active antenna systems (AAS) base stations are considered for the interference analysis:

- Macro base station with 16 x 16 beam forming elements deployed for three sectors;
- Micro base station with 8 x 8 beam forming elements deployed with a single sector.

The normalised patterns of 8 x 8 AAS and 16 x 16 AAS are shown in Figure 43 and Figure 44.

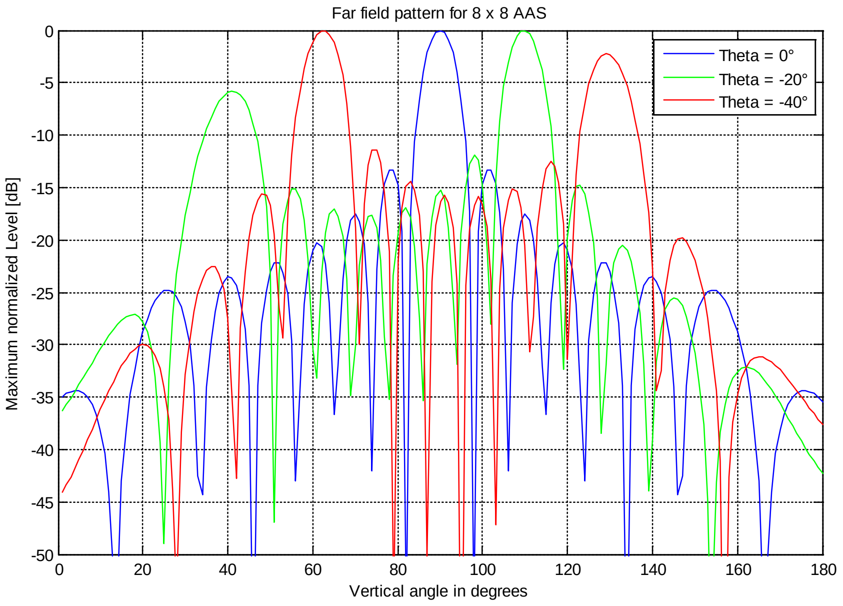

Figure 43: Normalised far field pattern for 8 x 8 AAS for 0°, 20° and 40° tilt angles

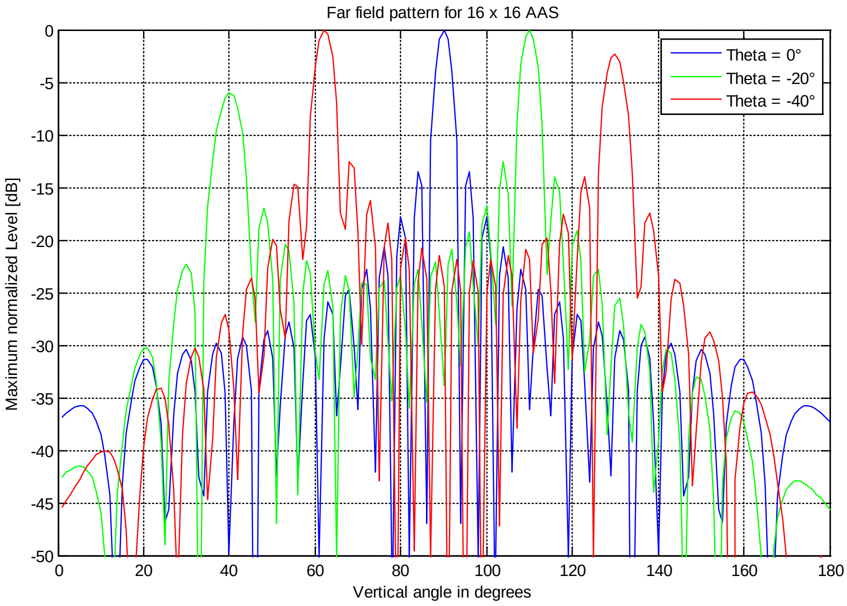

Figure 44: Normalised far field pattern for 16 x 16 AAS for 0°, 20° and 40° tilt angles

As also highlighted in document 3GPP TR 37.840 [36], the vertical separation distance of 0.9λ makes the antenna more susceptible to generate grating lobes when tilt angles are applied.

Because the application of the normalisation factor for AAS is still under debate, the interference evaluation is done considering the two options: with and without applied normalisation. For the antenna gain patter plots, shown in Figure 45 to Figure 48, no normalisation factor is considered.

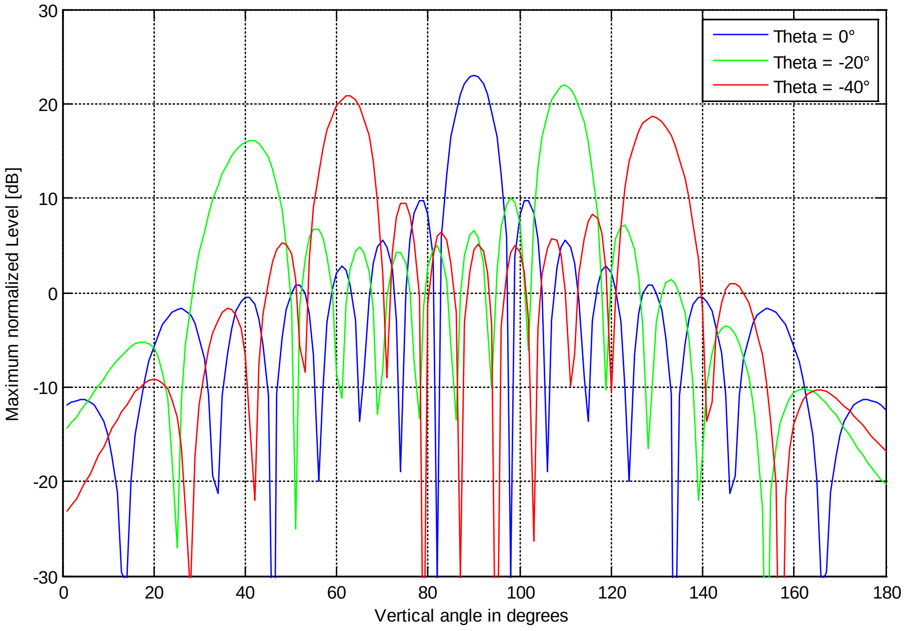

Figure 45: Array vertical gain patterns for 8 x 8 array used for macro and micro base stations

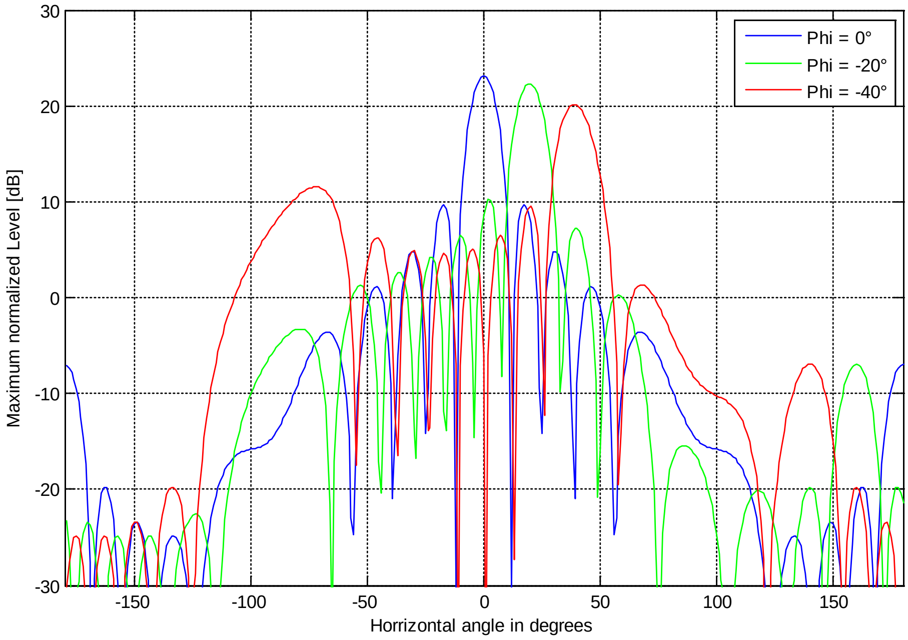

Figure 46: Array horizontal gain patterns for 8 x 8 array used for macro and micro base stations

The relatively large separation distance of 0.6 wavelengths between horizontal radiating elements generates side lobes at a horizontal scanning angle of 40° with a gain of just 8 dB below the main lobe. Lower separation distances, as frequently used 0.5 wavelengths, would reduce the gain of the considered side lobe by 14 dB.

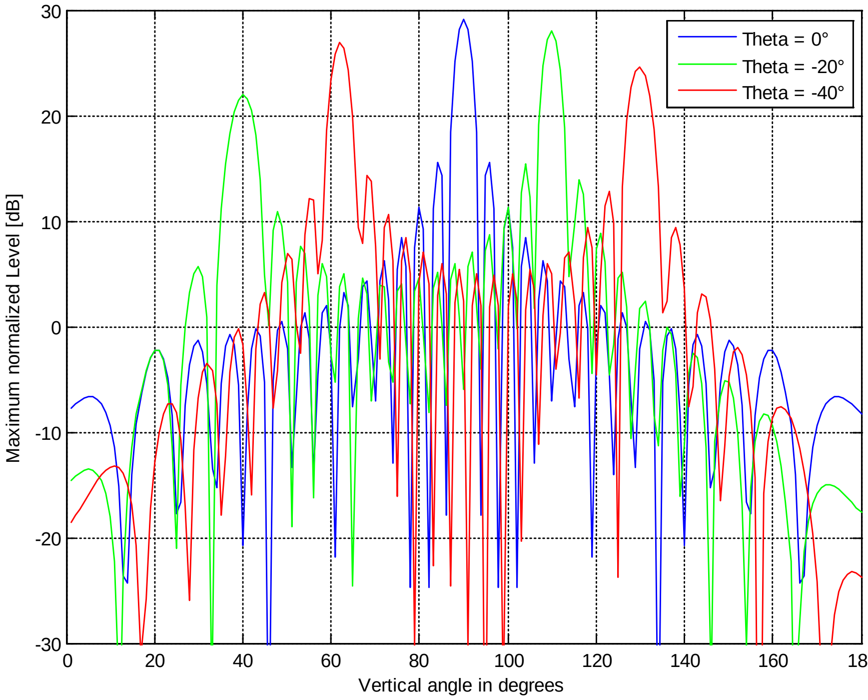

Figure 47: Array vertical gain patterns for 16 x 16 array used for macro and micro base stations

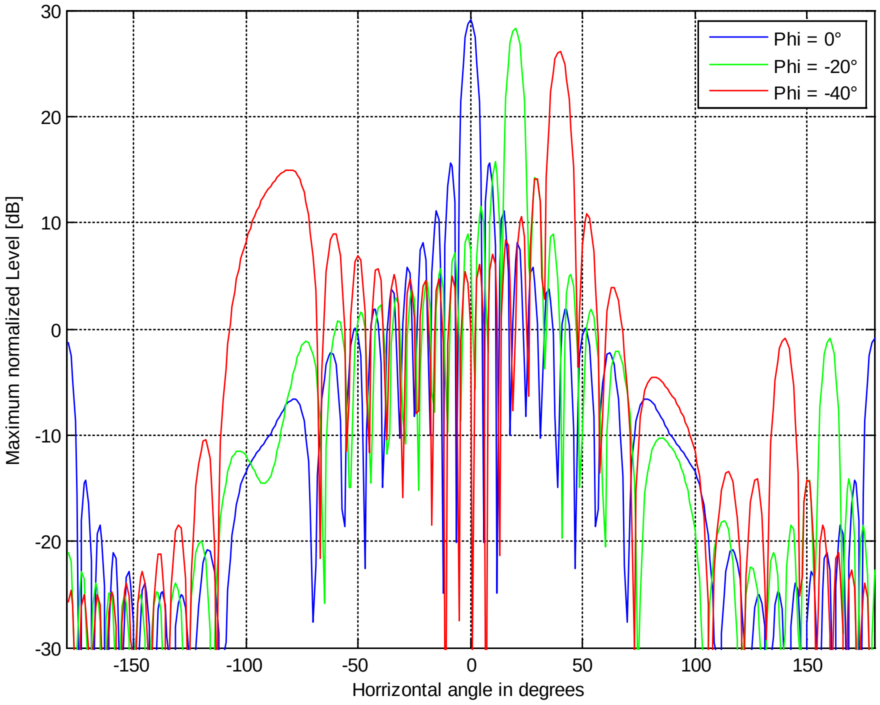

Figure 48: Array horizontal gain patterns for 16 x 16 array used for macro and micro base stations

The protection levels for the two deployment cases (micro and macro cell) are calculated as follows:

$$P_P = N_0 + I/N + \mathrm{F}_{RX} + \mathrm{A}_{\mathrm{Feeder}}$$

where

- P_P: Protection level of the victim receiver (dBm/Hz);
- N_0: Thermal noise level = -174 dBm/Hz;
- I/N: Protection criterion of the victim receiver (dB);
- F_{RX}: Noise Figure of the victim receiver (dB);
- A_{Feeder}: Antenna feeder loss of the victim receiver (dB).

The protection levels in Table 18 are calculated based on the parameters based on figures of ECC Report 281 [34] and the protection criterion I/N of -20 dB.

Table 18: Protection levels for 5G base stations

Station type	Protection level
Macro base station	-189 dBm/Hz
Micro base station	-189 dBm/Hz

The two considered deployment scenarios for micro and macro base stations are shown in Figure 49 and in Figure 50. In Figure 49 the blue circles represent the 5G mobile station communicating with the 5G micro base station which is placed in the centre at the distances 0 km / 0 km. The red circles represent UWB devices, placed in cars which are parked on the parking lot. The black dot represents the placement of the base station.

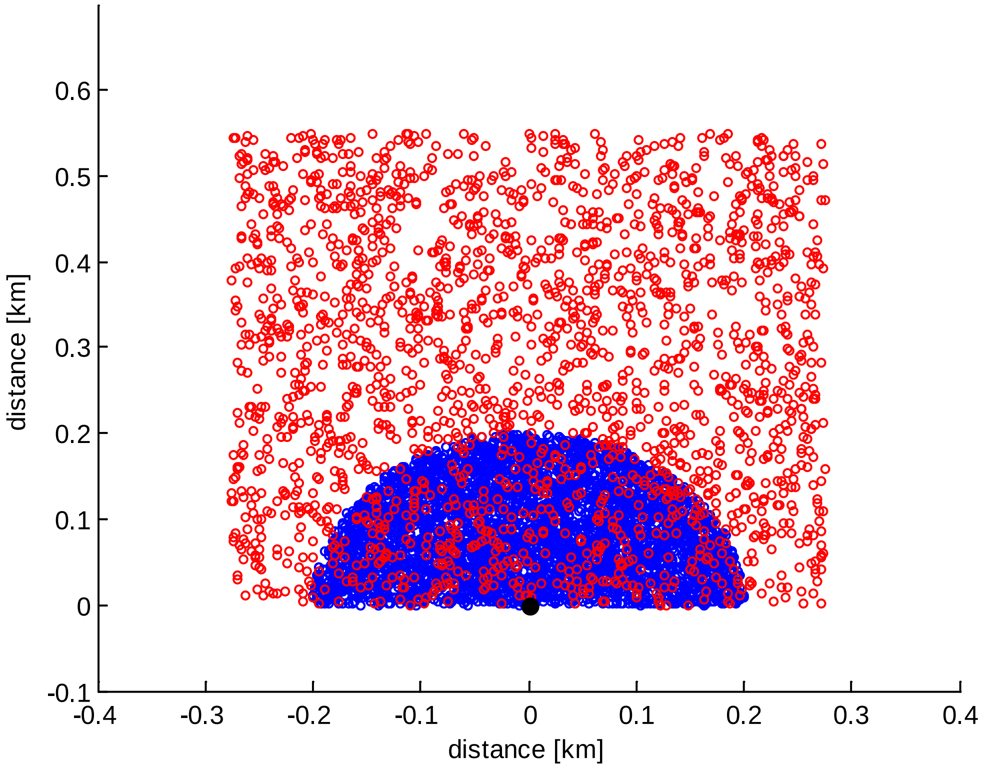

Figure 49: 5G mobile station and UWB device deployment scenario for micro base station

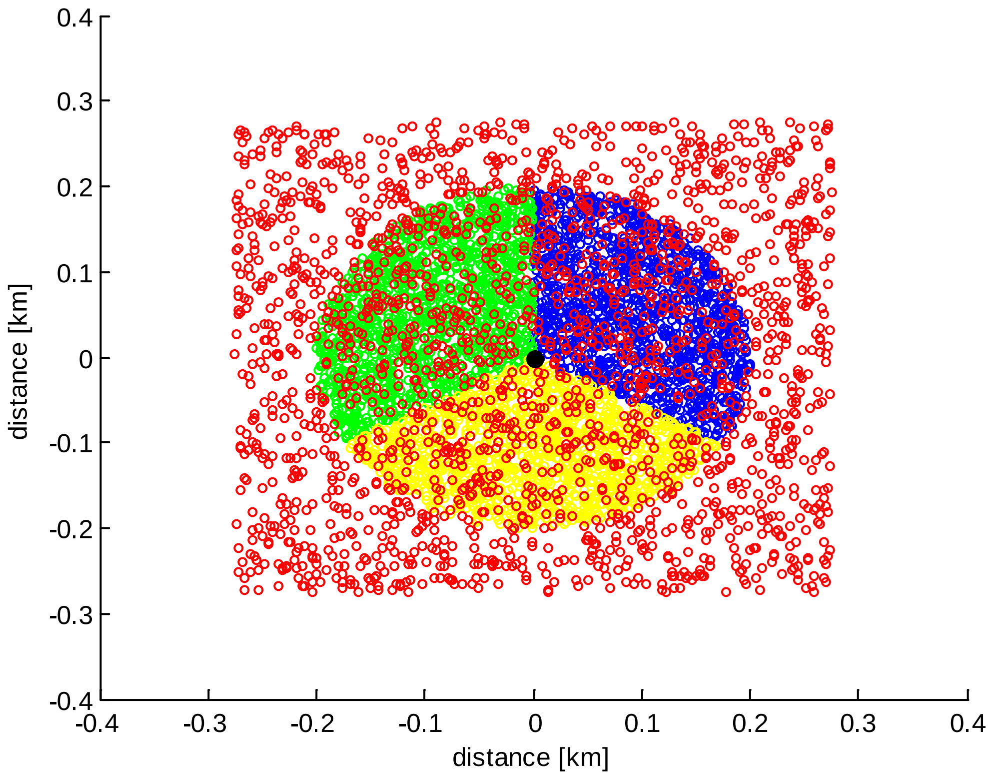

Figure 50 5G mobile station and UWB device deployment scenario for macro base station

In Figure 50 the deployment scenario for 5G macro base station is shown. The blue, green and yellow sectors represent the deployment of 5G mobile station for each of the three base station sector antennas, which are placed in the centre of the parking lot at the distances 0 km / 0 km. The red circles represent UWB devices, placed in cars which are parked on the parking lot. The black dot represents the placement of the base station.

4.3.6 Interference scenarios and methodologies

4.3.6.1 Single entry scenarios

5G interference studies are based on parameters according to ECC Report 281, Annex 1 [34]. Accordingly AAS are considered as antennas for the 5G base stations. Because the main beam direction of 5G AAS is tuned dynamically, any single entry study would need to consider all possible main beam directions for every interferer position. Hence there is not a single interference calculation result for a single interferer position, but results representing the influence of the antenna pattern on the received interference power. When considering different main beam directions for single interferer analysis, the results will be very similar to those of aggregated studies, when very low UWB activity would be considered. Therefore only studies for aggregated interference scenarios are considered in this Report.

4.3.6.2 Multiple interferers into a single 5G base station

The methodology for this section provides probabilistic results of the aggregated interference level at the victim receiver antenna terminals. The mobile macro base station is equipped with AAS for three sectors and is surrounded by UWB transmitters which are randomly and uniformly distributed. The macro base station is equipped with a three sector antenna. Therefore the absolute value for the interference signal angle of arrival at the base station is always smaller than 60°. The micro base station is equipped with just a single sector antenna. In this case the base station is placed at a side of the parking lot. All UWB devices transmit with the same e.i.r.p. The cumulative interference power is calculated by simulation. The main lobe direction of the victim antenna is evaluated by randomly placed mobile stations within the mobile station coverage area. The simulation runs different events, where each event calculates the interference level at the victim receiver antenna terminals taking into account the transmission probability of each UWB device, the receiver antenna pattern and the appropriate path loss. The transmission probability is calculated by the ratio of the cumulative T_{on} - time over the activity period. After a number of simulation events, a cumulative distribution function is formed based on the calculated interference level results. This function is used to evaluate the probability of interference level, which exceeds a given value. The received aggregated interference power is calculated according the formula below

$$p_{UWB\_C_k} = p_{UWB\_eirp} + 10\log(\sum_{i=1}^{z_k} 10^{\frac{(A_{path}(m_{k,i})+G_A(\varphi(m_{k,i}),\theta(m_{k,i}))-60))}{10}})$$

Where:

- p_{UWB_C}: cumulated power density at victim receiver (dBm/Hz) for a single simulation event;
- $p_{UWB\_e.i.r.p.}$: transmit power density of a UWB device (dBm/MHz);
- $m_{k,i}$: device place number which is chosen out of all possible device place numbers for the kth simulation event;
- A_{path}: attenuation (dB) for a given device place;
- G_A: antenna gain (dBi) considered for a given device place after random, independent for interferer location, main beam direction selection;
- Θ: elevation angle;
- φ: azimuth angle;
- n: total number of UWB devices;
- z_k: number of simultaneously radiating UWB devices, Z ~ P(λ) for kth simulation event;
- λ: mean value of Poisson distribution → λ = T_{on} – time / activity period * n.

A maximum number of 10000 vehicles on a large parking lot is considered. With an assumed market penetration of 25% there are 2500 cars equipped with UWB vehicular access systems considered for the studies.

In the following, the main steps of the calculation methodology applied for the simulations are summarized.

For the parking lot with 10000 cars, a model is made by an array of 100 x 100 elements P_{xy_UWB}, each one characterised with a distance D_{xy_UWB} and an elevation and azimuth angle (φ_{xy_UWB} and Θ_{xy_UWB}) with respect to the parking lot centre and 5G base station antenna height.

As explained above, the simulation runs different events. In a single event, the following operations are performed:

- The number of simultaneous transmitting UWB devices N_s is evaluated based on Poisson distribution statistics.
- The P_{xy_UWB} are selected randomly at the number of N_s.
- The coordinates of the 5G mobile station (P_{xy_5G}) are evaluated randomly.
- The path distance between 5G mobile station and 5G base station (D_5G) is calculated.
- The path loss for the 5G signal A_5G is calculated considering the propagation model shown in ANNEX 2:.
- The antenna main beam direction (Θ_AAS , φ_AAS) is calculated based on the P_{xy_5G}.
- The antenna main beam gain G_mb based on Θ_AAS, φ_AAS is evaluated.
- The antenna gain G_i to be considered for the interference reception is calculated based on Θ_AAS, φ_AAS, φ_{xy_UWB} and Θ_{xy_UWB} for each of the selected P_{xy_UWB}.

- The aggregated interference power (p_agg) is calculated considering the antenna gain G_i, the propagation loss calculated based on the propagation model shown in ANNEX 2: and the distances D_{xy_UWB}.
- The received 5G signal power p_5G is calculated based on the main beam antenna gain, and the path loss A_5G
- The antenna gain ratio G_mb / G_i is calculated.

After a large number of simulation events, the cumulative distribution function (cdf) for the aggregated interference power p_agg is calculated and the probability of exceeding the protection level is evaluated. Further, for information purposes, the cdf for C/I = p_5G / p_agg is calculated.

4.3.7 Results

4.3.7.1 Single interferer into a single 5G mobile station

$$A_{Min} = P_{UWB} - 10\log(BW_{UWB}) - P_P + \mathrm{G}_{RX} - \mathrm{A}_{\mathrm{Body}} = 75.7dB$$

Where:

- A_{Min}: Minimum coupling loss = 75.7 dB;
- P_{UWB}: Transmit power density of a UWB device (dBm/MHz e.i.r.p.) = -41.3;
- BW_{UWB}: Reference Bandwidth of the UWB signal power density (Hz) = $10^{6;}$
- P_P: Protection level of the victim receiver (dBm/Hz) = -183;
- G_{RX}: Gain of the victim receiver antenna (dBi) = -4;
- A_{Body}: Body loss (dB) = 4.

Assuming free space attenuation, the minimum separation distance is calculated as shown below:

$$d_{Min} = 10^{\frac{A_{Min} - 32.4 - 20\log(f)}{20}} = 0.0406\,km$$

Where:

- d_{Min}: Minimum separation distance (km);
- A_{Min}: Minimum coupling loss (dB) = 75.7;
- f: frequency (MHz) = 3600.

The minimum required separation distance between the vehicular UWB device and mobile user equipment is 40.6 m. It should be noted, that the co-location of mobile user equipment and the key fob of the vehicular access system is quite probable.

However, the key fob is regulated as a generic UWB device with a maximum e.i.r.p. of - 41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal T_{on} time.

Further, the activity factor of the key fob is much lower than for the generic UWB operating with the new trigger before talk mitigation technique, which improves the interference situation compared to generic UWB interference.

4.3.7.2 Multiple interferer into a single 5G macro base station with 16 x 16 AAS

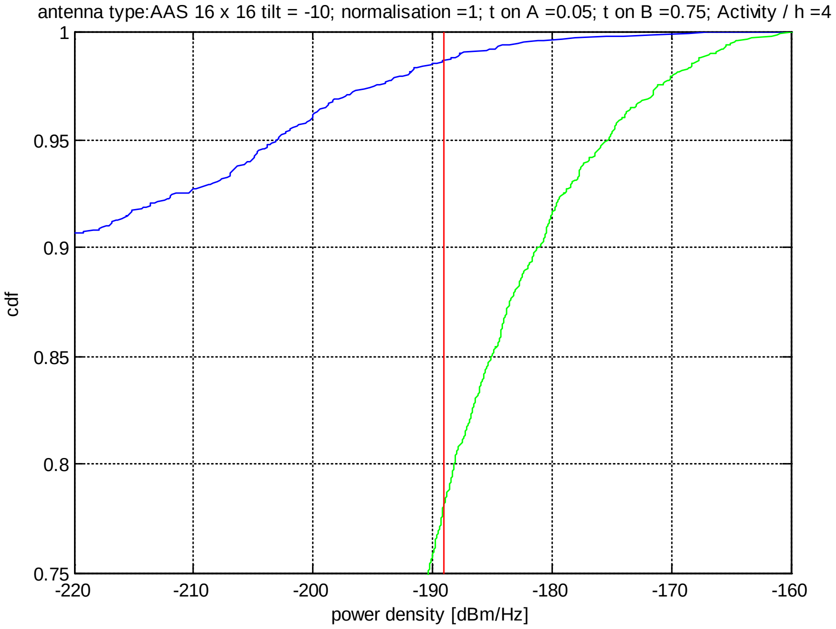

Figure 51: cdf of UWB Category A and B devices aggregated interference level into 16 x 16 AAS 5G antenna with antenna normalisation

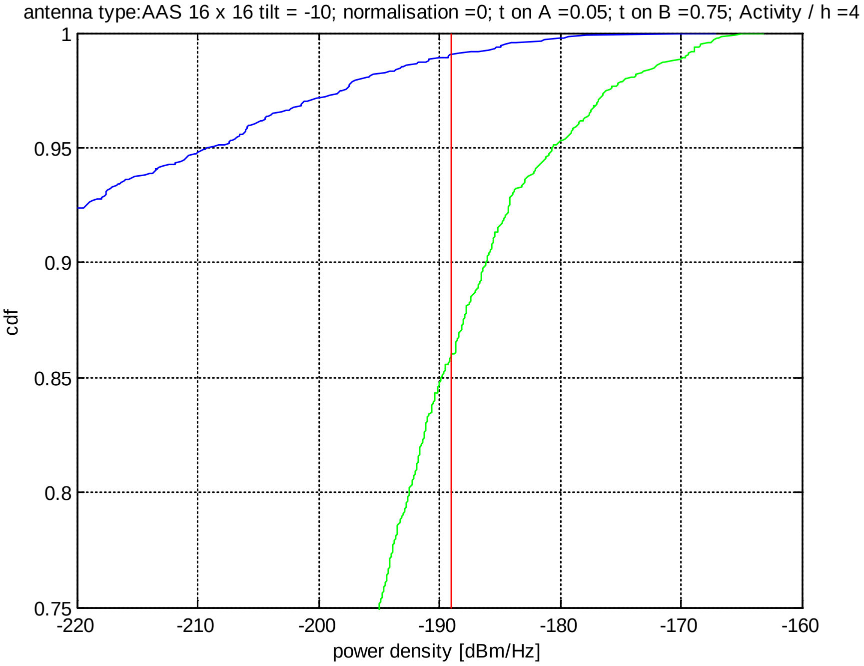

Figure 52: cdf of UWB Category A and B devices aggregated interference level into 16 x 16 AAS 5G antenna without antenna normalisation

In Figure 51 and Figure 52, the aggregated interference levels cdf into 16 x 16 5G AAS antenna are shown for Category A devices (blue line), Category B devices (green line). Results for AAS with normalisation are shown in Figure 51, while results for AAS without normalisation are shown in Figure 52. The results are based on free space propagation model considering shadowing effects, according to the propagation model shown in ANNEX 2:. The red line represents the protection level.

4.3.7.3 Multiple interferer into a single 5G micro base station with 8 x 8 AAS

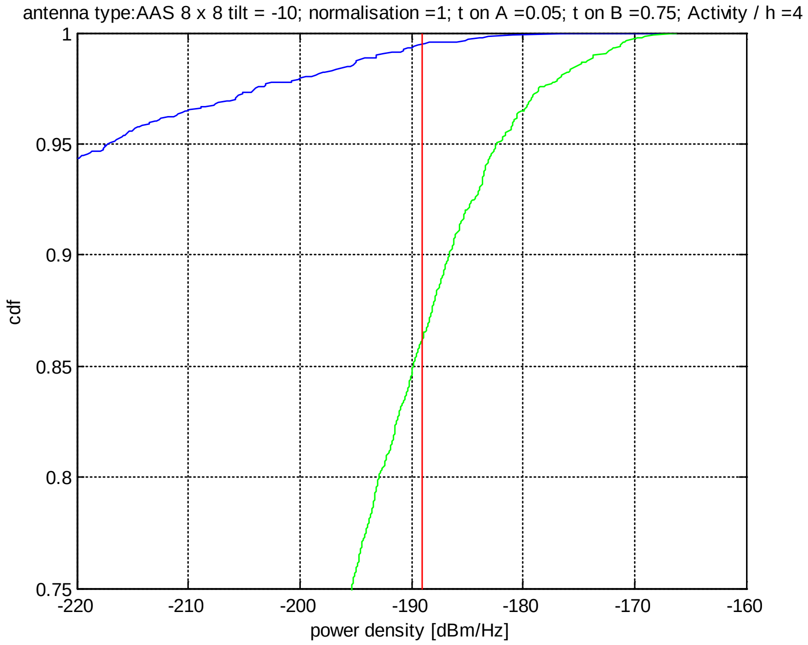

Figure 53: cdf of UWB Category A and B devices aggregated interference level into 8 x 8 AAS 5G antenna with antenna normalisation

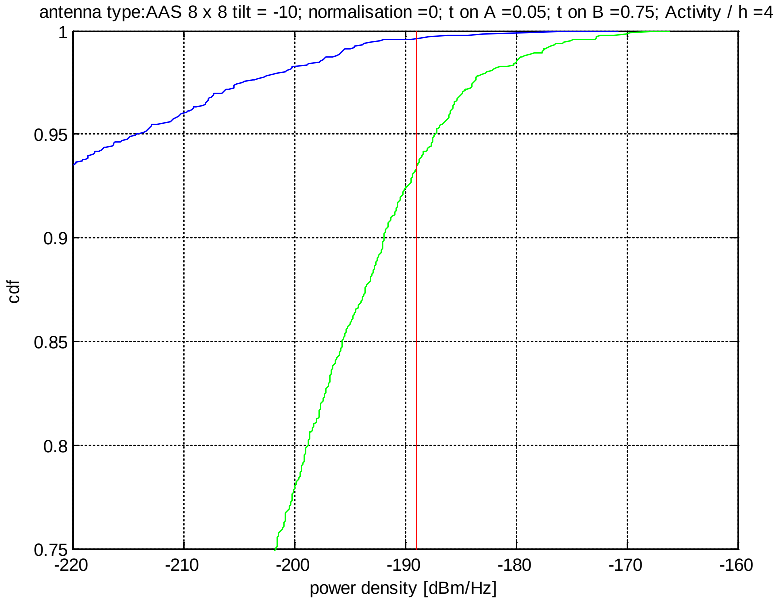

Figure 54: cdf of UWB Category A and B devices aggregated interference level into 8 x 8 AAS 5G antenna without antenna normalisation

In Figure 53, and Figure 54, the aggregated interference levels cdf into 8x8 5G AAS antenna are shown for Category A devices (blue line), Category B devices (green line). Results for AAS with normalisation are shown in Figure 53, while results for AAS without normalisation are shown in Figure 54. The results are based on free space propagation model considering shadowing effects, according to the propagation model shown in ANNEX 2:. The red line represents the protection level.

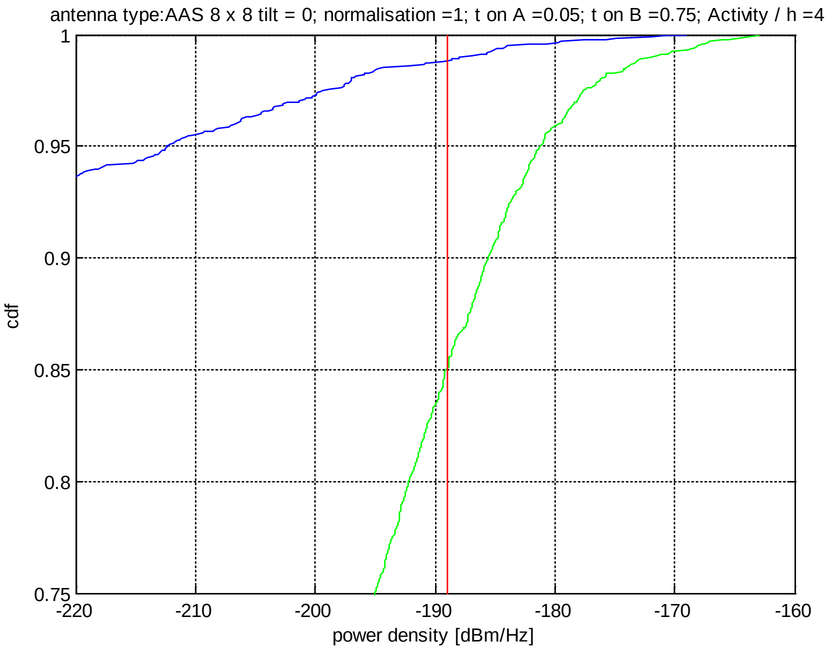

Figure 55: cdf of UWB Category A and B devices aggregated interference level into 8 x 8 AAS 5G antenna with antenna normalisation and 0° tilt.

In Figure 55 the aggregated interference levels cdf into 8x8 5G AAS antenna are shown for Category A devices (blue line), Category B devices (green line). Antenna normalisation and 0° tilt is considered. The results are based on free space propagation model considering shadowing effects, according to the propagation model shown in ANNEX 2:. The red line represents the protection level.

4.3.8 Conclusion for 5G (IMT-2020)

Regarding aggregated interference for 5G AAS base stations, the protection criterion I/N of -20 dB is exceeded as shown in Table 19.

Table 19: Probability of protection criterion exceedance

AAS type	Mechanical tilt	AAS normalisation	UWB Device Cat	Probability of protection criterion exceedance
16 x 16	-10°	Yes	A	0.018
16 x 16	-10°	no	A	0.009
16 x 16	-10°	Yes	B	0.22
16 x 16	-10°	no	B	0.14
8 x 8	-10°	Yes	A	0.007
8 x 8	-10°	no	A	0.004
8 x 8	-10°	Yes	B	0.14
8 x 8	-10°	no	B	0.065
8 x 8	0°	Yes	A	0.02
8 x 8	0°	Yes	B	0.15

4.3.9 Sharing between UAS and UWB

In segregated air space, mainly military UAS are presently operated in the frequency band 4.4-4.99 GHz. These UAS are even permitted for flights above populated areas. Particularly, when operating in support of national security missions. In the future, a more converging use of UAS between governmental actors could be expected in order to cope with the growing demand for police coastguard, border patrol, public security missions and surveillance of important areas. With this regard, sharing between UAS and UWB has to be carefully considered.

ECC Report 170 [7] in its section 3.3.5 provided technical characteristics in the frequency band 4.4-4.8 GHz of UAS.

The characteristics of UAS used in ECC Report 170 are still representative of small UAS as well as high altitude UAS. It also should be noted that ITU is developing a draft new Recommendation [AMS 4.4-5 GHz] [32] that provides the technical characteristics of high altitude capability UAS which are globally consistent with the ones use in ECC Report 170.

However, ECC Report 170 does not provide results of sharing between location tracking applications for automotive and transportation environments (LTA) with UAV. The following section provides similar analysis with LTA parameters.

Based on range and endurance, the Unmanned Aircraft Systems are subdivided into approximately four families, each is subdivided in different categories. It is assumed, that for interference aspects the most challenging families are the “Mini UAS” and the High Attitude Long Endurance (HALE) UAS. In this section, only these two cases covered in ECC Report 170 are covered.

4.3.9.1 Case 1: High attitude long endurance ground station

These are generally installed at airports with restricted areas of about 500m

Figure 56: HALE UAS ground station.

The following Table 20 gives the separation distance for a simple MCL calculation without and with 10 dB mitigation to protect ground station of HALE.

Table 20: LTA impact, HALE ground station protection distance with and without additional 10 dB mitigation.

	LTA	LTA	LTA
Frequency / GHz	4,4	4,4	4,4
mean power level dBm/MHz e.i.r.p.	**-41,3**	**-41,3**	**-41,3**
receiver noise floor dBm/MHz	**-110**	**-110**	**-110**
protection criterion I/N dB	**-6**	**-10**	**-20**
max acceptable power level dBm/MHz	-116	-120	-130
Antenna gain dBi	25	25	25
MCL dB	99,7	103,7	113,7
Protection distance free space loss m	**521**	**825**	**2609**

Protection distance free space loss with additional 10 dB mitigation	**165**	**261**	**825**

4.3.9.2 Case 2: Mini UAS

This kind of UAS has a 2dBi antenna gain with restricted areas of about 50 m.

Figure 57 Mini UAS ground control unit

Table 21 gives the separation distance for a simple MCL calculation to protect ground station of mini UAS.

Table 21: Protection distance for ground station mini UA

	LTA	LTA	LTA	LTA
Frequency / GHz	4,4	4,4	4,4	4,4
mean power level dBm/MHz e.i.r.p.	**-41,3**	**-41,3**	**-41,3**	**-41,3**
peak power mitigation dB	**10**	**10**		
receiver noise floor dBm/MHz	**-110**	**-110**	**-110**	**-110**
protection criterion I/N dB	**-20**	**-6**	**-20**	**-6**
max acceptable power level dBm/MHz	-130	-116	-130	-116
Antenna gain dBi	2	2	2	2
MCL dB	80,7	66,7	90,7	76,7
Protection distance free space loss m	**58**	**12**	**185**	**37**

For the protection of UAS receiver on board the aircraft, Table 22 gives the separation distance for a simple MCL calculation.

Table 22: Separation distance for a simple MCL calculation to protect UA receiver

		UAV	UAV
Interferer			
Frequency	GHz	4,4	4,4
mean power level e.i.r.p.	**dBm/MHz**	**-41,3**	**-51,3**
Receiver			
Antenna gain	dBi	2	2
bandwidth	MHz	5	5
receiver noise floor	dBm	-105	-105
	dBm/MHz	-112,0	-112,0
protection criterion I/N dB	dB	-10	-10
max acceptable power level	dBm/MHz	-122,0	-122,0
MCL	dB	83	73
Protection distance FSL	m	**73**	**23**

4.3.9.3 Discussion on the results

HALE ground station:

- Without additional mitigation, the separation distance for I/N -6 dB is about 520 m and for -20 dB about 2.6 km,
- Assuming a 10 dB mitigation for the high attitude long endurance ground station in worst case (main beam direction) the separation distance for I/N -6 dB is about 150 m and for -20 dB about 820 m;

Mini UAS ground station:

- Without additional mitigation, the protection distance of the UAS-receiver for an I/N -6 dB is about 37 m and for an I/N=-20 dB about 185 m
- Assuming a 10 dB mitigation for the mini UAS in worst-case the separation distance (aircraft altitude) is between 12 m for an I/N of -6 dB and 5 8m for I/N -20 dB.

For UA receiver aboard aircraft:

- Without additional mitigation, the separation distance for I/N -10 dB is about 70 m, which is above the operating flight attitude of 30 m.
- Assuming a 10 dB mitigation the separation distance is about 23 m for an I/N of -10 dB.

4.3.9.4 *Conclusions for UAS*

The current regulatory limits of Table 3 in ECC Report 170 for the frequency band 4400-4800 MHz can be considered relevant to protect UAS in 4.4-4.8 GHz..

4.4 UNMANNED GROUND VEHICLE (UGV) VS LTA IN THE BAND 4.4. TO 4.8 GHZ

4.4.1 Victim Parameters for the Unmanned Ground Vehicle (UGV)

The victim parameters for the UGV taken from the ECC Report 170:

- Distance: less than 1 km;
- Transmit Power: 1-100mW (power control);
- Gain of antennas: 5 to 15 dBi (quasi omnidirectional or section antenna dependent on system);
- Height of antennas: ~3 m;
- Bandwidth: 56 MHz;
- Availability: 99.99(9)%;
- BER: 10-6;
- Feeder Loss: 2 dB;
- S/Nmin: 6 dB.

4.4.2 Interferer assumptions

The potential interference of the vehicular access system in the study for the UGV is evaluated, comparing it to the potential interference of "Generic UWB" devices. The potential interference of "Generic UWB" devices is calculated based on given density figures and activity factors, which can be found in ECC Report 64, page 39 [5]. A density of 33000 cars per km^2 is identified as worst case figure. Because of close proximity of the UWB interferer to the UGV victim, a line of 3 cars parked in parallel to the direction of UGV movement are dominant in contributing to the interference. One open close every 20 minutes is considered as worst case activity for the vehicular access system in that short time parking situation. It is recalled that the vehicular access system consists of a "Generic UWB" device (key → portable device) and UWB devices integrated in the vehicle. Every communication on UWB technology is initiated by the "Generic UWB Device". The vehicular access system can be seen as a UWB hybrid "Generic / vehicular".

4.4.3 Interferer (UWB) assumptions

For vehicular access systems:

- Market penetration = 25%;
- Antenna height = 1.5 m;
- Omnidirectional antenna pattern;
- Cumulated T_{on}-time per activity = 50 ms (Category A) worst case;
- Cumulated T_{on}-time per activity = 750 ms (Category B) worst case;
- Density = 33000 cars / km^2 (randomly distributed);
- Shielding loss due to neighbouring cars 6 dB worst case;
- Devices per car = 10 worst case.

For generic devices:

- Density = 10000 km$^{2;}$
- Outdoor usage = 20%.

4.4.4 Self-Interference of two UGV driving on opposite lanes in opposite directions

Assuming a maximum allowed speed of 80 km/h for each UGV convoy a relative speed of 160 km/h (~44m/s) is taken into account.

Assuming a length of the convoy of minimum 2 vehicles with a length of 6 m and a small safety distance of 5 m between two vehicles, a convoy length of 17 m is obtained.

Taking into account the 17 m length and the traveling speed of the convoy of 44 m/s, the two convoys see each other during around 380 ms, with a power of up to 100 mW, for which the system is designed to be robust against.

This computation was solely done for later robustness assumptions of the victim service.

4.4.5 Worst-case scenario

As the usage of the vehicular access systems is only possible at the parked car, the worst-case scenario given in Report ECC 170 needs to be adapted. Given the dedicated use case for new vehicular access UWB, a scenario of a parking lot with three lines of cars parked next to a road is considered. Those cars are activated simultaneously by the users accessing them while the convoy passes by.

One open/close each 20 minutes is considered as an activity rate for the vehicular access system in that parking lot scenario. All the devices in the same car need to talk to the same key, therefore the 50 ms/s limit for the key is also applicable for the sum of all car devices. This way UWB devices mounted in the same car don’t aggregate.

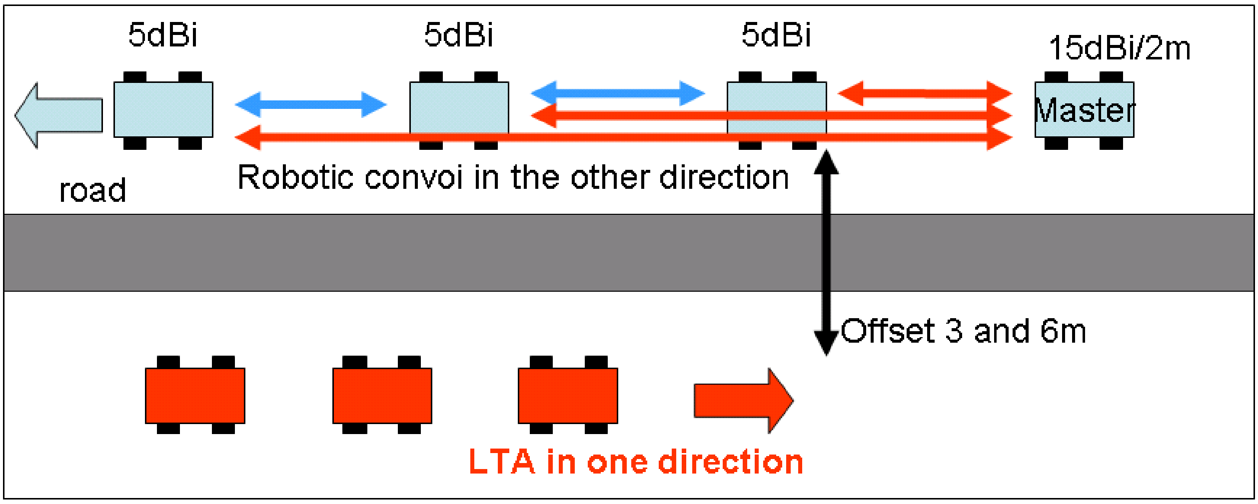

Figure 58: Old UGV scenario

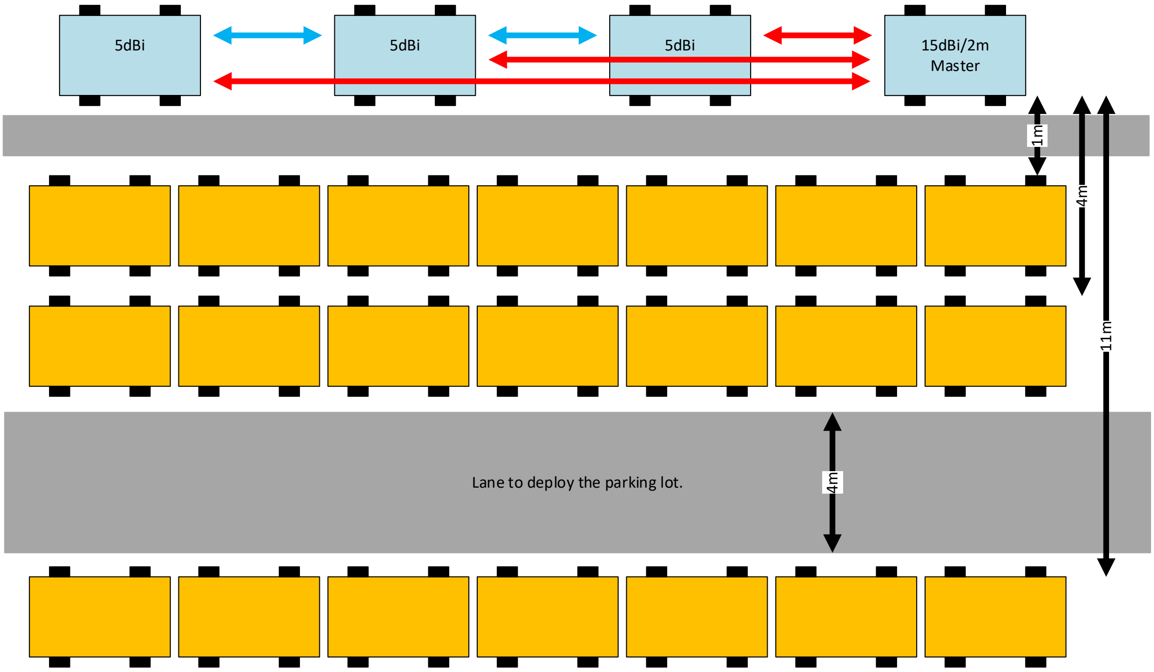

Figure 59: New UGV scenario

The offsets between the victim and the interferer are now given through the standing stripes and a possible available second lane. The cars are parked along the street. Each car is equipped with 10 UWB modules. The timing of all the modules in each car is coordinated not to interfere which each other. The modules are in Category A or B defined in ETSI TR 103 416 [1].

A car density of 33000 devices per km² is further considered in the calculation as well.

4.4.6 Interference Scenario and Calculation Model

The calculations from ECC Report 170 still apply. The difference in this scenario resides in the activation time and triggering of the devices. All 10 devices in the car are assumed to have direct line of sight to the victim’s antenna, which is not possible in reality due to car body shielding at least for half of the devices.

As stated in ETSI TR 103 416 the system (A and B) is only activated through a manual user interaction with the car (trigger-before-talk). There are no simultaneous transmissions going on at one car, but the next car could possibly interfere with the first one. Especially in Category B, which is for example used for piloted parking systems. On the other hand, it is not possible to park two cars simultaneously next to each other in this automated way due to simple space considerations.

The investigation assumes that all cars parked at the parking lane are equipped with an UWB system. This will not be the case (~25% is realistic) but eases the assumption and worsens the results.

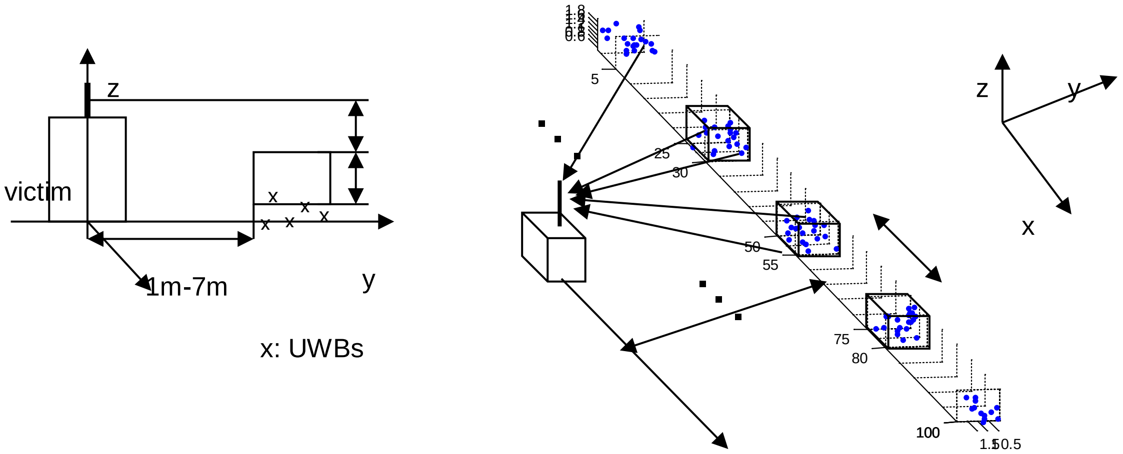

Figure 60: Scenario with UWB-distribution along a street

The space between two adjacent cars in the parking lot is reduced to 0.5 m. Therefore, two cars being parked next to each other using the car parking modules simultaneously is the worst-case scenario regarding the level.

Therefore, in even worst case one has positive interference and aggregation of the RF signals leading to 3 dB more power at the receiver, and no cancelling out of the signals. The victim receiver is then disturbed for a period of 1-2 ms in a current system, before both interfering systems switch to the next car modules which are possibly aligned regarding their timing again, but not located next to each other anymore, therefore producing lower interference levels than before.

In the worst case scenario for which car modules are emitting simultaneously and are at the same distance from the victim receiver, the latter is interfered with power level of 3dB above the single entry scenario. However this situation occurs only during a period of maximum 1 - 2 ms, therefore the probability of interference is very low.

4.4.7 Generic UWB device to Vehicular UWB device

The radiated spectrum of generic UWB devices, for example the key fob, is currently regulated through EN 302 065-1.

It is therefore allowed to send UWB Signals with -41.3 dBm/MHz. Depending on the Band with the mitigation techniques LDC and DAA.

Given the maximum LDC limits from EN 302 065-1 table 7, generic UWB devices are allowed to send 18 s per hour with a maximum T_{on} time of 5 ms per transmission. Within one second there are 50 ms of transmission time allowed.

This leads to the following UWB density per day given the 10000 devices per km² stated in ECC Report 64 [5]. Taken into account, that only 20% of them are outside the following activity time per device is obtained.

$$Active\ Time_{UWB} = \frac{18 * s_{txtime}}{3600s} * 100\% = 0.5\%\ txtime\ per\ device$$

$$Activity\ Density\ per\ km^2 = 0.5\ \%\ txtime * 2000\ devices = 50\ \frac{active\ devices}{km^2}$$

Therefore, there could be 10 active generic UWB devices/km² at any given point in time.

Now doing the same calculation for the vehicular access systems (adding car modules only), the following numbers are obtained, taking the activity times out of ETSI TR 103 416 for Category A and B.

Category A

$$Active\ Time_{UWB} = \frac{0.05\ *\ s_{txtime}}{3600s} * 100\% = 0.0001388\%\ txtime\ per\ device$$

$$Activity\ Density\ per\ km^2 = 0.0001388\% * 33000\ cars * 25\% = 1{,}1\ \frac{active\ devices}{km^2}$$

at any given point in time.

In addition, there is only an UWB activity if the key belonging to the car is found next to the car before. This behaviour is currently achieved through non UWB communication links.

Category B

$$Active\ Time_{UWB} = \frac{0.75\ *\ s_{txtime}}{3600s} * 100\% = 0.002083\%\ txtime\ per\ device$$

$$Activity\ Density\ per\ km^2 = 0.002083\% * 33000\ cars * 25\% = 17\ \frac{active\ devices}{km^2}$$

at any given point in time.

In addition, there is only an UWB activity if the key belonging to the car is found next to the car before. This behaviour is currently achieved through non UWB communication links.

4.4.8 Conclusion for UGV

The proposed change in regulation from ETSI TR 103 416 will not add a significant amount of UWB communication which will disturb UGVs more than currently regulated mobile devices.

Even with the estimation of 25% deployment to any and every car and the assumption of very big parking lots there is no significant amount of UWB communication added to the already allowed generic UWB devices.

The Category A systems have less than one tenth of the activity time currently allowed for generic UWB devices. And therefore don’t create a risk for the UGV systems.

The Category B systems have less than two times the activity time currently allowed for generic UWB devices. Taking into account, that those systems are meant to be optional equipment in the car and will have a market penetration of less than 10% of the previously mentioned 25% keyless access systems, this also does not pose a risk for the UGV systems.

Even more, the UWB communication from key to car will only take place in presence of the right key beside the car, so only if the generic UWB device is allowed to communicate anyway at the given position.

FIXED SATELLITE SERVICE

4.4.9 UWB Vehicular access system usage scenarios

A density of 33000 cars / km^2 is assumed as worst case. It is assumed that there is one UWB communication in 30 minutes for a single UWB device Category A and one UWB communication in 60 minutes for a single UWB device Category B.

4.4.10 Technical characteristics of vehicular access UWB devices

Technical characteristics of the UWB vehicular access system devices are given in ETSI TR 103 416 [1] and shown in section 3.

4.4.11 Assumptions on FSS for interference analysis

The typical characteristics of C band receive earth stations considered in the interference assessment are summarised in Table 25. It is recognised that in ECC Report 170 the system noise temperatures for 4.5 m, 3 m and 1.8 m antenna diameter earth station systems can be different from the values assumed in this Report.

Table 23: FSS Earth Station Characteristics in C band

Antenna Diameter (m)	System Noise Temp(°K)	Antenna Rx Gain (dBi)	G/T (dB/K)	Radiation Pattern
9	71	49.2	30.7	RR Appendix-7(WRC-07)
6	71	45.5	27.0	RR Appendix-7(WRC-07)
4.5	150	43.0	21.2	RR Appendix-7(WRC-07)
3	150	39.5	17.7	RR Appendix-7(WRC-07)
1.8	150	35.1	13.3	RR Appendix-8(WRC-07)
1.2	120	31.5	10.7	RR Appendix-8 (WRC-07)

The same parameters may also be applicable to receiving earth stations in the 6 – 8.5 GHz band; in particular to the sub-bands 6 700 – 7 025 MHz and 7 250 – 7 750 MHz. Hence, the interference studies are carried out using the same parameters in both the low and high band. The mean frequency for the considered bands will be used and is listed in Table 24.

A variety of antenna heights is also considered. Again, those are listed in Table 24.

Table 24: FSS Frequency and Antenna Height

Antenna Diameter (m)	Low band frequency (MHz)	High band frequency (MHz)	Antenna Height
9	3600	7575	12
6	3600	7575	3
4.5	3600	7575	3
3	3600	7575	10
1.8	3600	7575	10
1.2	3925	7575	10

Finally, an insertion loss between antenna and receiver input of 2 dB will be assumed, as well as a shallow log normal fading loss of 2.2 dB.

Note that the log-normal fading of 2.2 dB may not be applicable to the shortest separation distances in this table. However, it is assumed that the regulations will be based on the longer separation distances where log-normal fading clearly applies

The antenna radiation pattern used in the simulation presented in this section is the pattern from RR Appendix **7** and **8 (WRC-07).** The pattern of Appendix **7** is depicted below:

$$G(\varphi) = \begin{cases} G_{amax} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda} \varphi \right)^2 & \text{for } 0 < \varphi < \varphi_m \\ G_1 & \text{for } \varphi_m \le \varphi < \varphi_r \\ 29 - 25 \log \varphi & \text{for } \varphi_r \le \varphi < 36° \\ -10 & \text{for } 36° \le \varphi \le 180° \end{cases} \quad (97)$$

$$G_1 = \begin{cases} -1 + 15 \log (D/\lambda) & \text{dBi} \quad \text{for } D/\lambda \ge 100 \\ -21 + 25 \log (D/\lambda) & \text{dBi} \quad \text{for } 35 \le D/\lambda < 100 \end{cases}$$

$$\varphi_m = \frac{20\,\lambda}{D} \sqrt{G_{amax} - G_1} \quad \text{degrees}$$

$$\varphi_r = \begin{cases} 15.85 \, (D/\lambda)^{-0.6} & \text{degrees} \quad \text{for } D/\lambda \ge 100 \\ 100 \, (\lambda/D) & \text{degrees} \quad \text{for } 35 \le D/\lambda < 100 \end{cases}$$

where:

- G_{amax}: main beam axis antenna gain (dBi);
- D: antenna diameter (m);
- λ: wavelength (m);
- G_1: gain of the first side lobe (dBi).

The pattern from RR Appendix 8 (WRC-07) is the following:

$$G(\varphi) = \begin{cases} G_{amax} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda} \varphi \right)^2 & \text{for } 0 < \varphi < \varphi_m \\ G_1 & \text{for } \varphi_m \le \varphi < \varphi_r \\ 29 - 25 \log \varphi & \text{for } \varphi_r \le \varphi < 36° \\ -10 & \text{for } 36° \le \varphi \le 180° \end{cases}$$

$$G_1 = \begin{cases} -1 + 15 \log (D/\lambda) & \text{dBi} \quad \text{for } D/\lambda \ge 100 \\ -21 + 25 \log (D/\lambda) & \text{dBi} \quad \text{for } 35 \le D/\lambda < 100 \end{cases}$$

$$\varphi_m = \frac{20\,\lambda}{D} \sqrt{G_{amax} - G_1} \quad \text{degrees}$$

$$\varphi_r = \begin{cases} 15.85 \, (D/\lambda)^{-0.6} & \text{degrees} \quad \text{for } D/\lambda \ge 100 \\ 100 \, (\lambda/D) & \text{degrees} \quad \text{for } 35 \le D/\lambda < 100 \end{cases}$$

As an example, the antenna patterns for the 1.8 (RR Appendix 8) and 3 metre (RR Appendix 7) antenna dishes are compared in Figure 61.

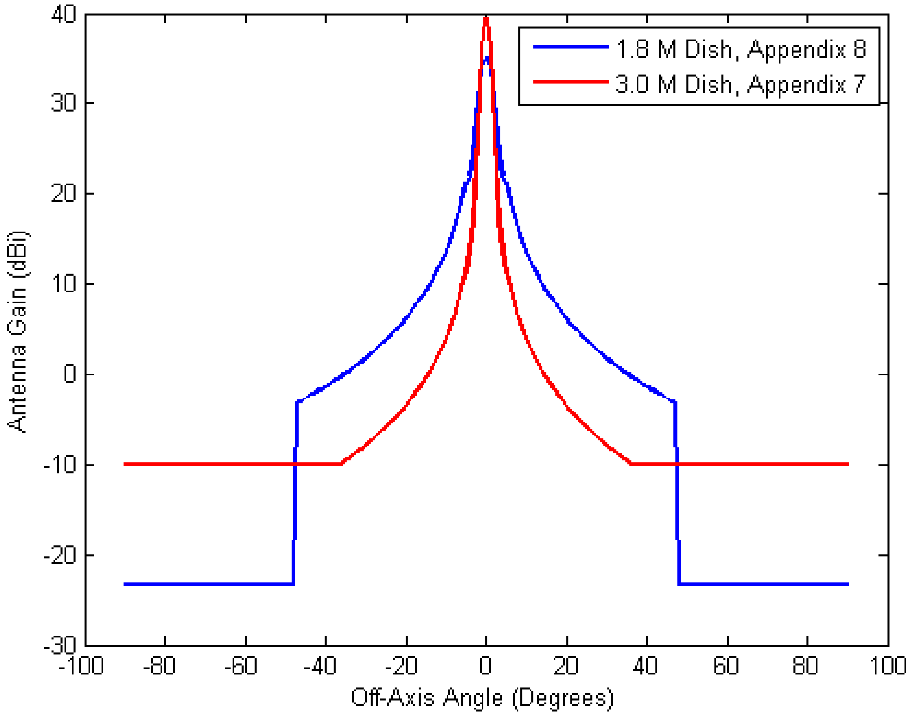

Figure 61: Comparison of FSS antenna patterns

4.4.11.1 Interference Criteria

The interference criteria based on ITU-R Recommendations SF.1006 [24], F.1094 [25] and S.1432 [26] are given in Table 25 for both long-term and short-term interference criteria.

Table 25: Interference Criteria for FSS Earth Stations in the C band levels based on Recommendation ITU-R SF.1006 [24]

Parameter	Values						Units
Antenna size	9	6	4.5	3	1.8	1.2	meters
System temperature	71	71	150	150	150	120	K
ref BW	1000	1000	1000	1000	1000	1000	kHz
p1 (long term)	20	20	20	20	20	20	%
p2 (short term)	0.005	0.005	0.005	0.005	0.005	0.005	%
n2 (no of entries)	3	3	3	3	3	3	
J (ITU-RF.1094/S.1432)	-20	-20	-20	-20	-20	-20	dB
W	0	0	0	0	0	0	dB
Ms	2	2	2	2	2	2	dB

Parameter	Values						Units
NL	1	1	1	1	1	1	dB
Pr(p1) - long term	-140.09	-140.09	-136.84	-136.84	-136.84	-137.81	dBm
Pr(p2) - short term	-121.42	-121.42	-118.17	-118.17	-118.17	-119.14	dBm
p2/n2 - percentage time (short term)	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	%
I/N long term	-20	-20	-20	-20	-20	-20	dB
I/N short term	-1.33	-1.33	-1.33	-1.33	-1.33	-1.33	dB

ITU-R SF.1006 indicates that the level of permissible interference power at the input of the receiver of a terrestrial or an earth station may, in the most general form, be expressed as the unwanted radio-frequency power P_r from any one of n sources of interference, in a reference bandwidth B, to be exceeded for not more than specified percentages of the time, pi. Two such percentages of time are defined; one is p1, chosen to reflect normal (near median) conditions for which interference contributions from all interference sources may be assumed to occur simultaneously and to add on a power basis. The other percentage of time p2 is chosen to reflect significantly enhanced (small percentages of the time) interference conditions, for which interference contributions from all interfering sources may be assumed to occur non-simultaneously and to add on a percentage-of-the-time basis.

4.4.12 Single interferer

4.4.12.1 Introduction

The interference studies for FSS in ECC Report 170 are attached in Annex 4 of that Report. For the purpose of these studies, they have been modified to reflect a maximum PKES transmitter height of 1.5 metres and where appropriate modified to reflect the antenna heights listed in Table 26. Both Category A (activity factor < 0.00035%) and Category B (activity factor < 0.005%) are only short-term interferers as far as FSS is concerned.

4.4.12.2 Methodology

The methodology of Annex 4 in ECC Report 170 is followed.

The propagation model according to Recommendation ITU-R P.452-16 [27] is usually applied in sharing studies. However, as shown in ANNEX 3: of this Report, the mentioned propagation model does not differ from the free space propagation model for the considered scenarios and parameters. Therefore, the free space propagation model is applied for the single entry scenarios

The separation distance is calculated by comparing the FSS protection criterion, Pr(p) from Table 25, against the interference level at the victim receiver for the assumed distance. This calculation is repeated iteratively until the difference equals zero.

For a given distance d between Tx and Rx antenna, the free space path loss L is calculated according to Annex II in RR Appendix-8 (WRC-07):

$$L\,[db] = 20(\log f[MHz] + \log d[km]) + 32.45$$

The free space path loss is combined with the log normal fading loss (2.2 dB) and insertion loss (2 dB).

For every distance, the incident angle at the victim receiver is calculated and used in combination with the antenna radiation patterns of Table 23 to calculate the applicable antenna gain.

The interference level at the victim receiver is then the e.i.r.p. of -41.3 dBm/MHz, plus the antenna gain, minus the free space loss, normal fading and insertion loss.

4.4.12.3 Results

The attached excel file provides the details behind the calculations of the separation distances, in meters.

SE24 WI58 -
ECCRep170_PKESver

The resulting required separation distances, in metres, are copied in Table 26 (for the lower band) and Table 27 (for the upper band) below:

Table 26: Required separation distance (m), single interferer, lower band

PKES Installation - Low Band						
Ant size	Elevation angle in degrees					
	5	10	15	20	25	30
9 m	8	8	8	8	8	8
6 m	135	55	32	22	16	13
4.5 m	85	34	20	13	10	9
3 m	3	3	3	3	3	3
1.8 m	185	66	34	19	17	17
1.2 m	270	102	57	36	25	22

Table 27: Required separation distance (m), single interferer, upper band

PKES Installation - High Band						
Ant size	Elevation angle in degrees					
	5	10	15	20	25	30
9 m	0	0	0	0	0	0
6 m	52	20	11	7	6	6
4.5 m	28	10	5	4	4	4
3 m	0	0	0	0	0	0
1.8 m	3	3	3	3	3	3
1.2 m	66	9	9	9	9	9

Note that the log-normal fading of 2.2 dB may not be applicable to the shortest separation distances in these tables. However, it is assumed that the regulations will be based on the longer separation distances where log-normal fading clearly applies.

4.4.12.4 Discussion

In the high band (7250-7750 MHz), required separation distances for single device interference are in the range 0-66 m. The worst cases where the maximum required separation distances are 52 and 66 metres occurs for elevation angle of 5 degrees. These separation distances are need for fulfil the short term FSS protection criterion (-121.42 -118.17 dBm/MHz for 0.005% time).

In the low bands (3.4-4.2 GHz and 4.5-4.8 GHz), the required separation distances for single device interference tend to be higher, especially for low elevation angles and lower FSS receiver heights. While in half the cases it is below 20 metres, the worst cases require separation distances from 102 to 270 metres.

Therefore, although the required separation distances may look long, when the whole system is considered rather than just the car units, the proposed system leads to less interference to FSS.

4.4.13 Aggregate interference

4.4.13.1 Introduction

Aggregate interference is calculated similar to calculations for the mobile service in section 4.3.

The main modification is that the satellite dish is located 10 metres to the side of the parking lot, while the IMT antenna is assumed to be located in the middle.

4.4.13.2 Methodology

The methodology for this section provides probabilistic results of the aggregated interference level at the victim receiver antenna terminals.

The propagation model according to Recommendation ITU-R P.452-16 is usually applied in sharing studies. However, as shown in ANNEX 3: of this Report, the mentioned propagation model does not differ from the free space propagation model for the considered scenarios and parameters. Therefore, the free space propagation model is applied for the aggregate interference scenarios.

The satellite station is assumed to be located 10 metres from a square parking lot. The cars with UWB transmitters are randomly and uniformly distributed throughout the parking area. All UWB devices transmit with the same e.i.r.p. of -41.3 dBm/MHz.

The cumulative interference power is calculated by simulation. The simulation runs different 20000 events, where each event calculates the interference level at the victim receiver antenna terminals taking into account the transmission probability of each UWB device, the receiver antenna pattern and the appropriate path loss. The transmission probability is calculated by the ratio of the cumulative T_{on} - time over the activity period. After a number of simulation events corresponding to 5 days' worth of operations, a cumulative distribution function is formed based on the calculated interference level results. This function is used to evaluate the probability of interference level, which exceeds a given value.

$$p_{UWB\_C_k} = p_{UWB\_eirp} + 10\log\left(\sum_{i=1}^{z_k} 10^{\frac{(A_{path}(m_{k,i}) + G_A(\varphi(m_{k,i}),\theta(m_{k,i})) - 60))}{10}}\right)$$

where:

- p_{UWB_C}: Cumulated power density at victim receiver [dBm/Hz] for a single simulation event;
- $p_{UWB\_e.i.r.p.}$: Transmit power density of a UWB device [dBm/MHz];
- $m_{k,i}$: device location number which chosen out of all possible device location numbers for the kth simulation event;
- A_{path}: Path attenuation [dB] for a given device location;
- S_{loss}: Screening loss [dB] for a given device location;

- G_A: antenna gain [dBi] considered for a given device location;
- Θ: Elevation angle;
- φ: Azimuth angle;
- n: total number of UWB devices;
- z_k: number of simultaneously radiating UWB devices, Z ~ P(λ) for k^{th} simulation event;
- λ: Mean value of Poisson distribution → $\lambda = T_{on}$ – time / activity period * n.

A maximum number of 10000 vehicles on a large parking lot is considered. With an assumed market penetration of 25%, there are 4000 cars equipped with UWB vehicular access systems considered for the studies.

Free space propagation conditions are assumed. For radio signal path obstructed by car bodies, an additional attenuation is taken into account, according to the model proposed in ANNEX 2:. This model considers three different classes of path loss. A first class considers losses due to obstruction just by neighbouring car bodies, while the second class considers obstruction due to neighbouring as well as own car body. The third class considers obstruction due to neighbouring cars from the wing mirror position. The simulation assumes a quarter of the devices are located on the wing mirror, while the rest are evenly distributed between the other two classes.

The power at the victim receiver is compared to the target I/N listed in Table 25.

4.4.13.3 Results short-term interference

The assumptions on the FSS and PKES systems are listed above. For the short-term interference results, the target I/N is -1.3 dB which can be exceeded only 0.005% of the time (see Table 25). The figures below indicated the percentage of time that the I/N criterion is met. The limit is indicated by a dashed red line.

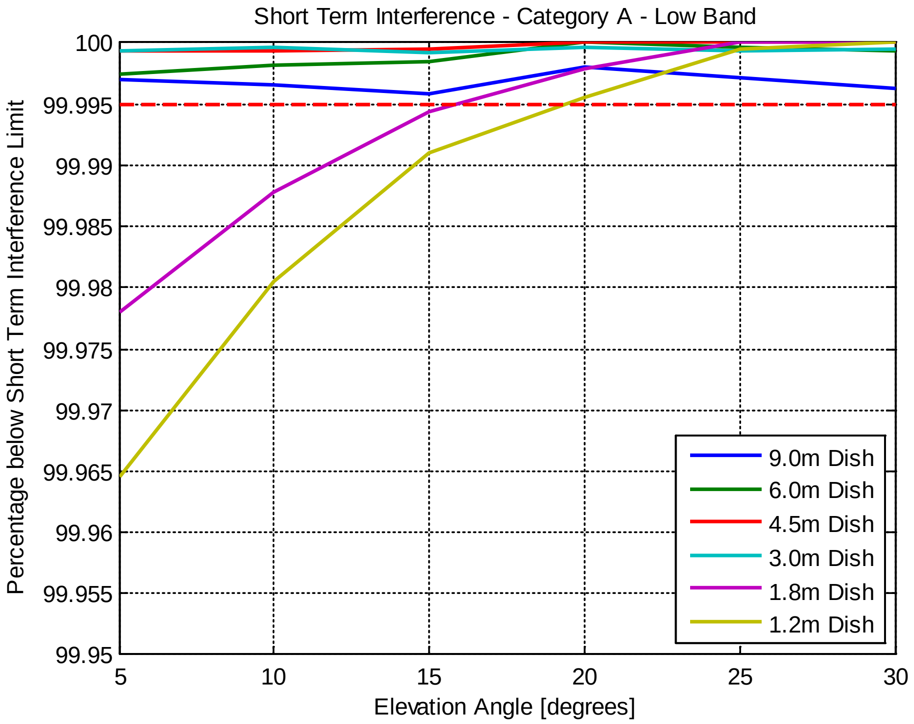

Figure 62: Short-term aggregate interference from Category A devices in the low band

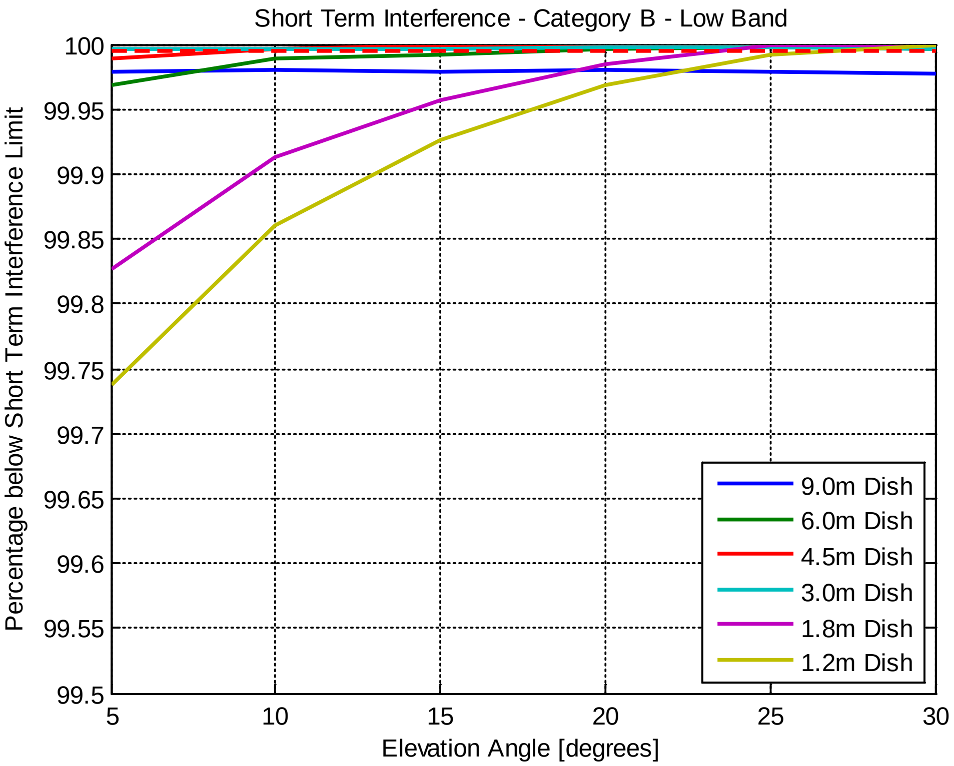

Figure 63: Short-term aggregate interference from Category B devices in the low band

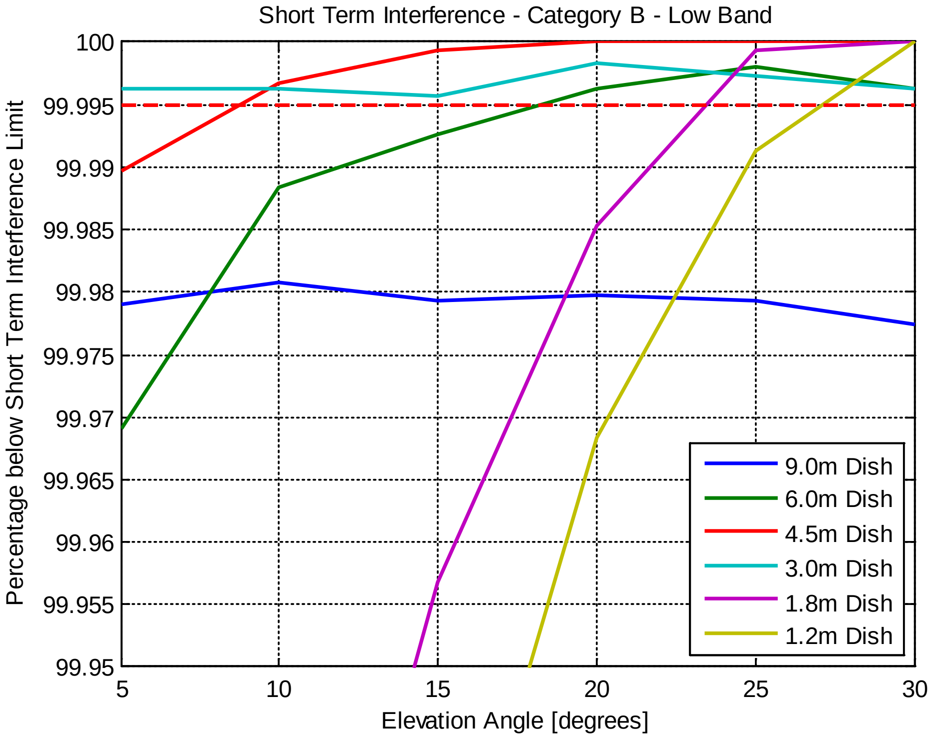

Figure 64: Short-term aggregate interference from Category B devices in the low band (zoom)

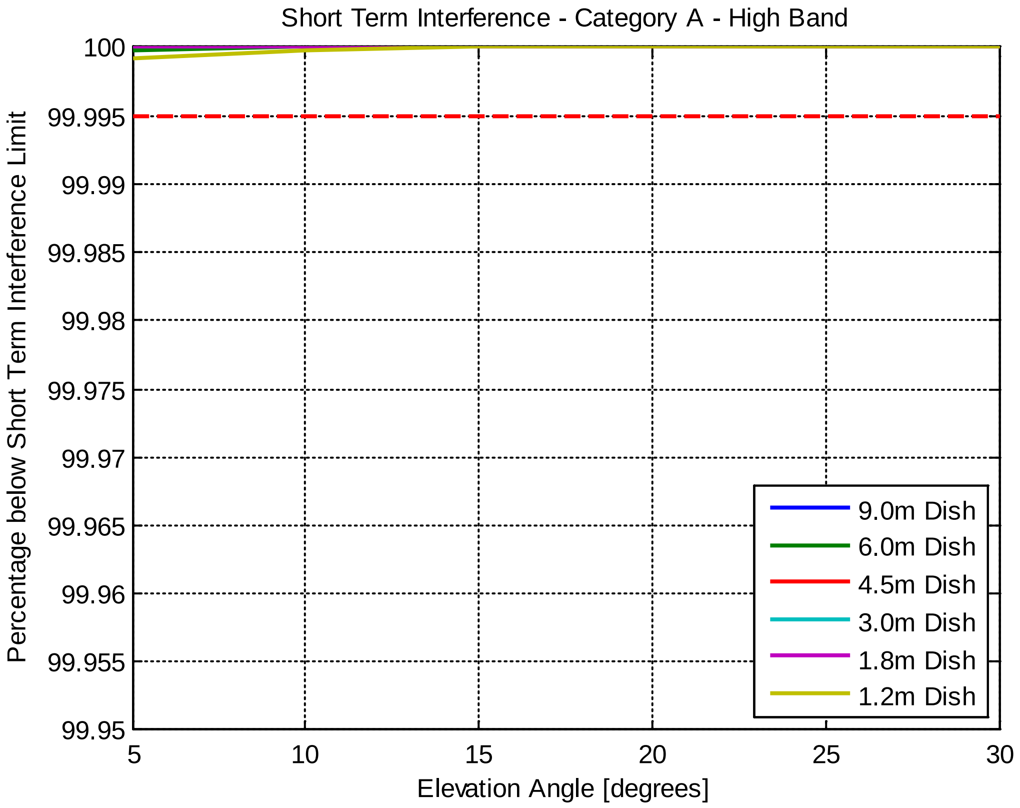

Figure 65: Short-term aggregate interference from Category A devices in the high band

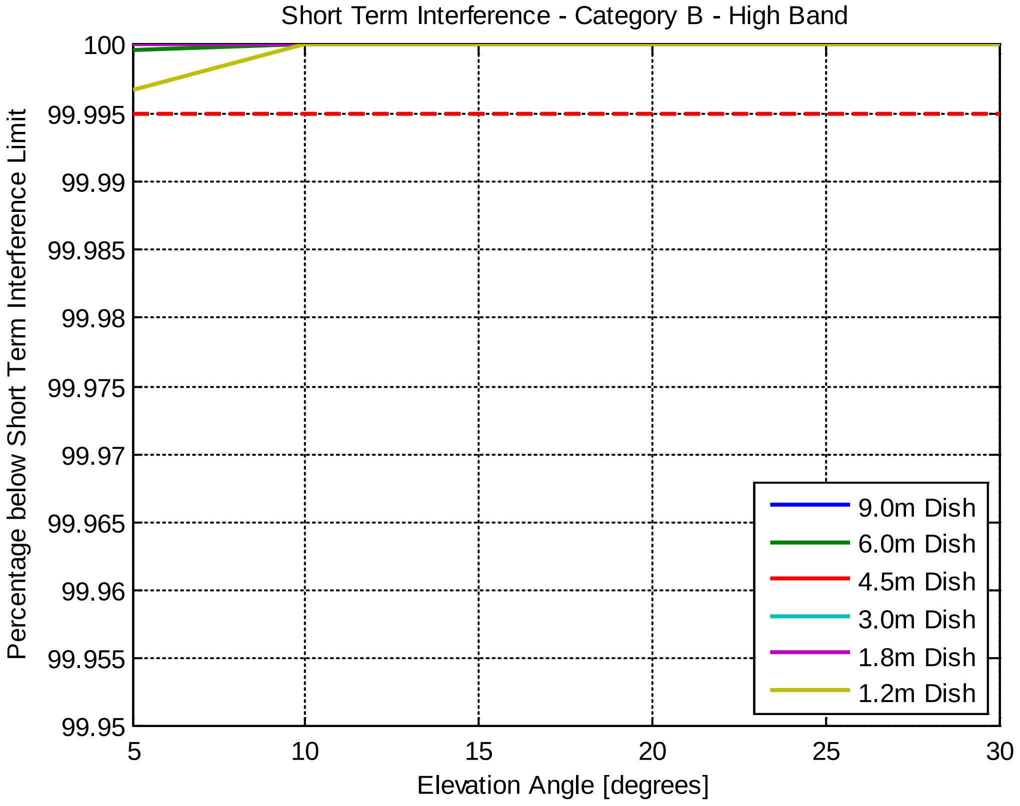

Figure 66: Short-term aggregate interference from Category B devices in the high band

4.4.13.4 Results long-term interference

The assumptions on the FSS and PKES systems are listed above. For the long-term interference results, the target I/N is -20 dB which can be exceeded 20% of the time (see Table 25). The figures below indicated the percentage of time that the I/N criterion is met. The limit corresponds to an 80% level in the figures. Since this is outside the scale of the figures, the limit is not shown on the figures.

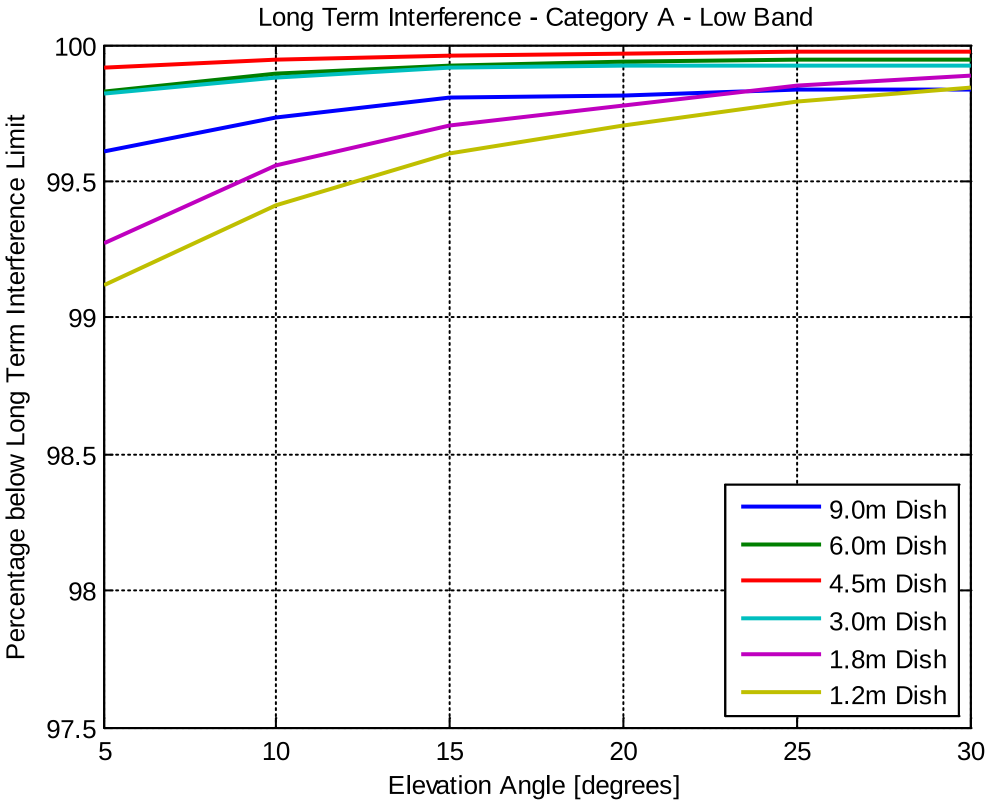

Figure 67: Long-term aggregate interference from Category A devices, low band

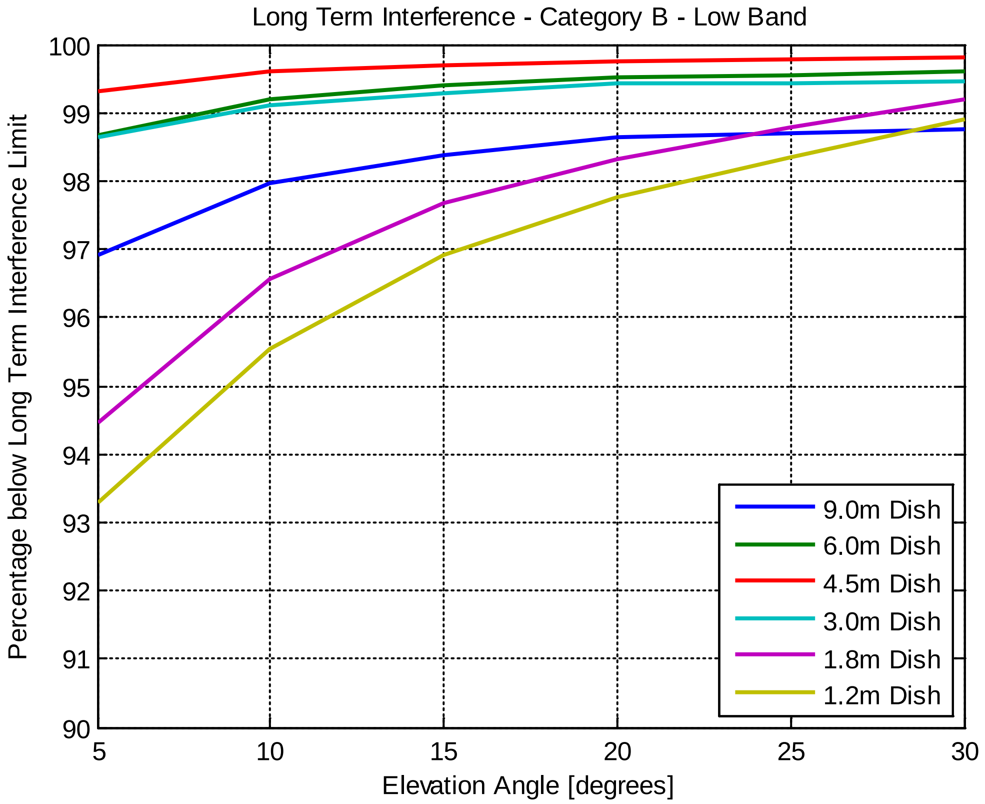

Figure 68: Long-term aggregate interference from Category B devices, low band

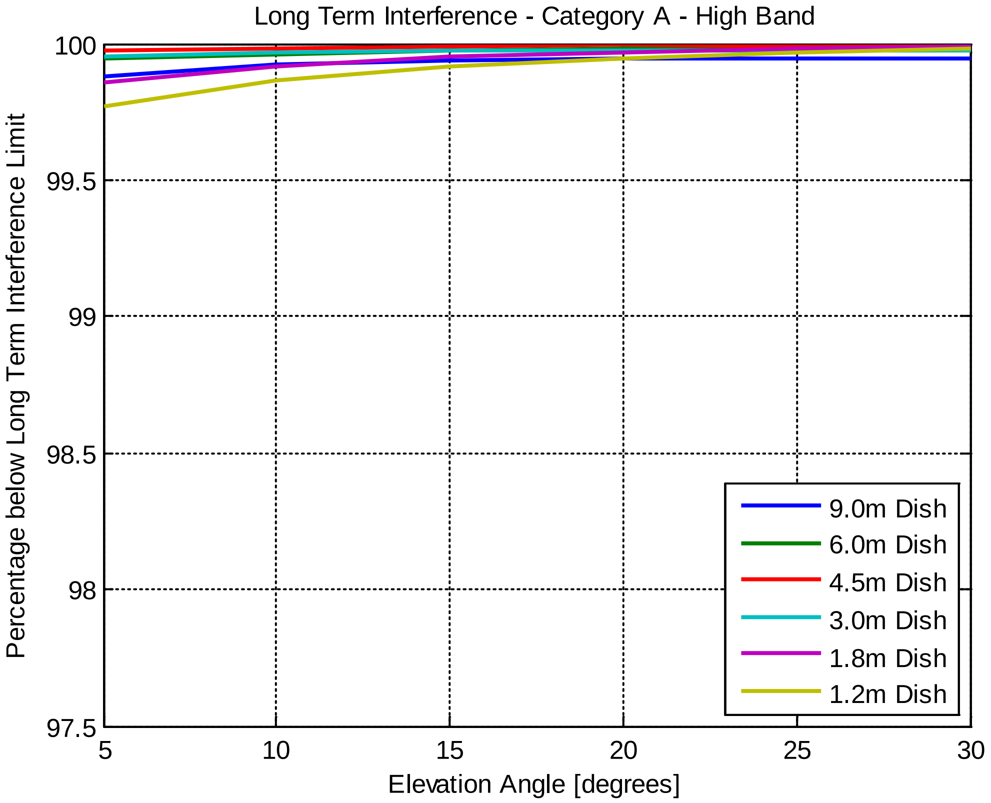

Figure 69: Long-term aggregate interference from Category A devices, high band

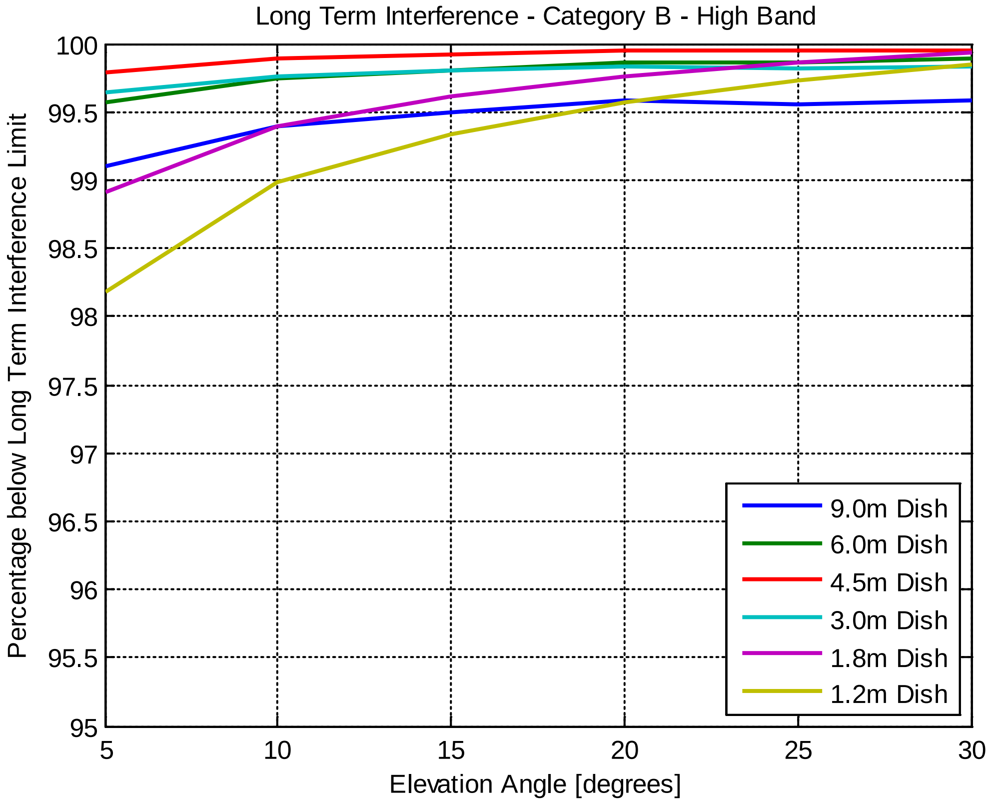

Figure 70: Long-term aggregate interference from Category B devices, high band

4.4.13.5 Discussion

The long-term interference criterion is easily met by both Category A and B systems in both the low and high bands.

In the upper band, both Category A and B systems meet the short-term interference requirements. In the lower band, Category A devices exceed the permitted level for more than the permitted time only for the smaller 1.2 and 1.8 metre dishes at elevation angles up to 15-20 degrees. Category B devices operating in the lower band would mostly fail the short-term interference criteria.

Given that the corresponding key fob operating under the existing generic regulations can already transmit at -41.3 dBm/MHz, the overall interference to FSS systems would still be reduced when the proposed PKES system is allowed. The higher transmit power from the car units will improve the link budget, resulting in less transmissions compared to devices operating under the current vehicular UWB regulation.

4.4.14 Conclusions for FSS

Previous interference studies between UWB and FSS (ECC Report 64 [5] and ECC Report 170 [7]) have shown that the main scenario of interference is in the space to earth direction (in the 3-4 GHz range), and that the risk of interference to the FSS space station in the earth to space direction is therefore assumed to be negligible. Therefore, studies here focused on the space to earth links.

By making the necessary modifications to the assumptions used in ECC Report 170, single and aggregate interference from PKES to FSS has been evaluated. In all cases, the lower antenna height and lower activity factor of UWB make the results considerably better than in ECC Report 170.

In the upper band (7250-7750 MHz), required separation distances for single device interference are in the range of 0-66 m. The worst case where the maximum required separation distances are 52 and 66 metres occurs for elevation angles of 5 degrees only. These separation distances are need for fulfil the short term FSS protection criterion (-121.42-118.17 dBm/MHz for 0.005% time). Long-term single and aggregate interference criteria for FSS are met as activity factors for Category A and Category B UWB are significantly less than required 20% of time according to the simulations carried out.

In the low bands (3.4-4.2 GHz and 4.5-4.8 GHz), the required separation distances for single device interference tend to be higher, especially for low elevation angles and lower FSS receiver heights. While in half of the cases it is below 20 metres, the worst cases require separation distances from 102 to 270 metres. The long-term aggregate interference requirements are met similarly as for the high band case. In the considered scenario of a parking lot with 10000 cars for Category A UWB devices the short term FSS protection criterion is not met for FSS earth stations with 1.2 and 1.8 m antennas and elevation angles up to 15-20 degrees, and for Category B UWB devices the short term FSS protection criterion is not met for FSS earth stations with 1.2, 1.8, 6, 9 m antennas and elevation angles up to 25 and more degrees.

However it should be noted, that the considered keyless entry system consists of a key fob, which is regulated as a generic UWB device with a maximum eirp of -41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal Ton time. Therefore any interference analysis result of single entry scenario is independent of the application of the exterior limit..

Also taking into account that studies conducted here very much considered worst-case scenarios, it can be concluded that in the most cases the proposed PKES system does not cause harmful interference.

4.5 RADIO ASTRONOMY IN THE BAND 6.55 TO 6.6752 GHZ

4.5.1 Use of the band by RAS and Regulatory Status

Presently, the methanol (CH3OH) line (6.65 – 6.675.2 GHz) is covered in Footnotes **5.149** and **5.458A** of the Radio Regulations. According to footnote **5.149** of the Radio Regulations, administrations are urged to take all practicable steps to protect the RAS from harmful interference in the band 6650.0-6675.2 MHz.

4.5.2 Parameters used in the study

The parameters for the UWB devices used in this study are shown in section 3 of this Report.

The parameters for the radio astronomy station are defined in Recommendation ITU-R RA.769-2 [28] and are shown in Table 28 below.

Table 28: Radio astronomy station parameters

System Parameter	Macro Suburban Value/Description	Remarks
Integration Time	2000 s	
Side lobe gain G	0 dBi	According ITU-R RA.769-2, only side lobe receptions need to be considered
Threshold interference level: Spectral pfd SH_RA	-228 dBW/m^2/Hz	For spectroscopic observations: interpolated from ITU-R Rec. RA.769-2 table 2 column 9
Antenna height	10 m	Not specified in any Recommendation

For single entry scenario as well as for aggregated interference scenarios, the propagation model according to Recommendation ITU-R 452-16, including TX clutter loss for rural area (high crop fields, park land, sparse trees, orchard, and sparse houses), is applied.

4.5.3 Interference scenarios and methodologies

4.5.3.1 Emitted Spectral Power Flux Density

The emitted spectral power flux density of a single UWB device, in the unit (dBW/m^2/Hz), is calculated assuming isotropic radiation as shown below:

$$S_{H\_UWB} = P_{UWB} - 30 - 60 + 10\log(\frac{4\pi v_0{}^2}{c^2})$$

where:

- S_{H_UWB}: emitted spectral power flux density (dBW/m^2/Hz) of a UWB transmitter;
- P_{UWB}: Transmit power density of a UWB device (dBm/MHz e.i.r.p.);
- V_0: frequency (Hz) (The same symbol v0 is used here as in Rec. ITU-R RA.769-2);
- c: speed of light (m/s).

4.5.3.2 Single entry scenario

Using a deterministic approach, the minimum separation distance between mobile station and an UWB device is evaluated. The minimum required coupling loss is evaluated according the following formula:

$$A_{Min} = S_{H\_UWB} - S_{H\_RA} + 10\log\left(\frac{T_{on}}{T_{\text{int}egral}}\right)$$

where:

- A_{Min}: Minimum coupling loss (dB);
- S_{H_UWB} :emitted spectral power flux density (dBW/m^2/Hz) of a UWB transmitter;
- S_{H_RA}: allowed spectral power flux density threshold (dBW/m^2/Hz) of a RA receiver;
- T_{on} : Total on-time of a single UWB transmitter;
- $T_{integral}$: Integration time of the Radio Astronomy detector (s).

The reduction of the minimum required coupling loss by short impulsive interference considers the influence of the integration time to the detectable power level change of a RA detector as defined in Recommendation ITU-R RA.769-2. The same method is also applied in ITU-R Report RS.2308 in chapter 3.3.1 [29].

The propagation model according to ITU-R P.452-16 correspond to the free space propagation model in line-of-sight conditions plus consideration of clutter loss. In case of rural area (high crop fields, park land, sparse trees, orchard, sparse houses) the clutter loss to be considered is $A_{Clutter}$ = 16 dB.

The minimum separation distance for free space attenuation considering clutter loss is calculated as shown below:

$$d_{Min} = 10^{\frac{A_{Min} - A_{Clutter} - 32.4 - 20\log(f)}{20}}$$

where:

- d_{Min}: Minimum separation distance (km);
- A_{Min}: Minimum coupling loss (dB);
- $A_{Clutter}$: Clutter Loss for rural area;
- f: frequency (MHz)].

4.5.3.3 Multiple interferers

It seems to be very unlikely that a radio astronomy station is in the proximity of a large parking lot. However, at any place nearby a big parking lot, a high level of man-made noise have to be expected and is therefore not suited for radio astronomy operations.

A more realistic scenario would be a parking lot of 100 cars with 25 % of the cars being equipped with UWB devices radiating twice an hour a number of interfering signals, which are integrated in the radio astronomy receiver: With an integration time of 2000 s, the energy of 28 UWB impulses is accumulated in the receiver integrator on average. To consider the worst case scenario, it is assumed that all the 25 cars with integrated UWB devices on board have line-of-sight propagation conditions. So as in the case of the single entry scenario, the propagation model according ITU-R P.452-16 is applied for the interference calculation. This assumption implies that all parked cars are stringed in a line of a length of 25 * 6m = 150 m as shown in Figure 71.

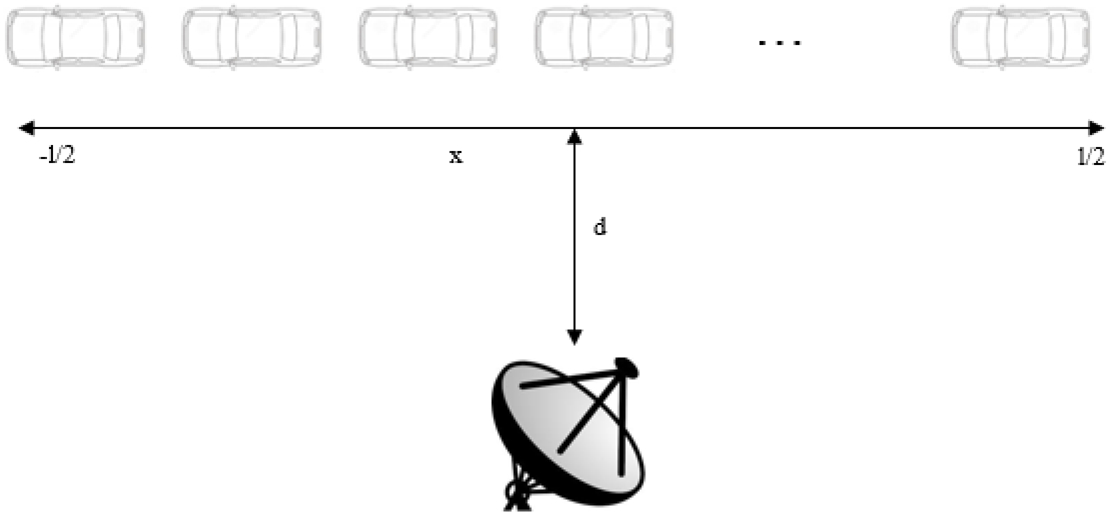

Figure 71: Scenario for aggregated interference

Based on the fact, that the propagation loss according Recommendation ITU-R P.452-16 [27] for short distances is equal the free-space-loss and additional clutter loss, the average propagation loss is calculated based on the free space propagation model (according Recommendation ITU-R P.525-3 [30]) as follows:

$$A_{Free\_space} = -20\log\left(\frac{\lambda}{4\pi d}\right)$$

$$A_{PATH\_AV} = -10\log\left(\frac{1}{l}\frac{\lambda}{4\pi}\int_{-l/2}^{l/2}\left(\frac{1}{\sqrt{d^2+x^2}}\right)^2 dx\right) + A_{Clutter}$$

The minimum required attenuation is calculated is calculated as follows:

$$A_{Min} = S_{H\_UWB}\cdot N - S_{H\_RA} + 10\log\left(\frac{T_{on}}{T_{\text{int}\,egral}}\right)$$

where:

- A_{Min}: Minimum coupling loss (dB];
- S_{H_UWB}: emitted spectral power flux density (dBW/m^2/Hz] of a UWB transmitter;
- S_{H_RA}: allowed spectral power flux density threshold (dBW/m^2/Hz] of a RA receiver;
- T_{on}: Total on-time of a single UWB transmitter;
- $T_{integral}$: Integration time of the Radio astronomy detector (s];
- N: Number of transmitted UWB pulses.

The minimum separation distance is evaluated graphically by identifying the intersection of the path attenuation curve APATH_AV with the A_{Min} attenuation value.

4.5.4 Results

4.5.4.1 Single entry scenario

$$S_{H\_UWB} = P_{UWB} - 30 - 60 + 10\log\left(\frac{4\pi v_0^{\ 2}}{c^{\ 2}}\right)$$

= -93.27 dBW/m^2/Hz

where:

- P_{UWB} = -41.3 dBm/MHz;
- V_0 = 6663 MHz;
- C = 3E8 m/s.

$$A_{Min} = S_{H\_UWB} - S_{H\_RA} + 10\log\left(\frac{T_{on}}{T_{\text{int}\,egral}}\right)$$

= 88.73 dB (Category A), 100.4 dB (Category B)

where:

- S_{H_RA} = -228 dBW/m^2/Hz;
- S_{H_UWB} = -93.27 dBW/m^2/Hz;
- T_{on} = 50 ms (Category A devices), 750 ms (Category B devices);
- $T_{integral}$ = 2000 s.

The minimum required separation distance between a single vehicular UWB device and a Radio Astronomy station is 15.6 m for Category A UWB devices and 59.74 m for Category B UWB devices when a clutter loss of 16 dB is considered. This separation distances are surprisingly short due to the very weak interference energy of a single UWB transmission radiated by a single UWB device and the 16 dB clutter loss. At those very short distances, the clutter loss of 16 dB, as defined in Recommendation ITU-R P.452-16 is not applicable because the nominal distance for the considered clutter category is 100 m. The calculated minimum separation distances for clutter loss of 0 dB or 16 dB are shown in Table 29.

Table 29: Minimum separation distances for single entry scenarios

Device category	Clutter loss	Minimum separation distance (m)
A	0	98.30
A	16	15.60
B	0	376.8
B	16	59.74

Because of the above conclusion regarding nominal distance, the clutter loss is assumed in this case to be 0 dB. Accordingly the minimum separation distance is 98.3 m for Category A devices. For Category B devices the nominal clutter distance as defined in Recommendation ITU-R P.452-16 is longer than the separation distance, when considering 16 dB clutter loss. Hence 16 dB clutter loss is not applicable in this case as well. Accordingly a minimum separation distance of 376.8 m is required for Category B devices.

4.5.4.2 Multiple interferers

$$A_{Min} = S_{H\_UWB} \cdot N - S_{H\_RA} + 10\log\left(\frac{T_{on}}{T_{\mathrm{int}\,egral}}\right)$$ = 103.2 dB (Category A), 114.7 dB (Category B)

where:

- S_{H_RA} = -228 dBW/m^2/Hz;
- S_{H_UWB} = -93.27 dBW/m^2/Hz;
- T_{on} = 50 ms (Category A devices), 750 ms (Category B devices);
- $T_{integral}$ = 2000 s;
- N = 28

Figure 72: Separation distance as a function of the attenuation

Table 30: Minimum separation distance for aggregated interferences

Device category	Clutter loss	Minimum separation distance (m)
A	0	602.1
B	0	1985

4.5.5 Conclusions for the RAS

For single entry interference scenarios, the minimum required separation distance between considered Category A UWB devices or Category B UWB devices and the radio astronomy station is 98.3 m or 376.8 m respectively to protect the radio astronomy service from harmful interference.

For aggregated interference, the minimum separation distances are 602.1 m and 1985 m. The calculated separation distances are applicable to public parking places, where all day long UWB devices are active. For other parking places, e.g. parking places for factory workers where only during lunch time the assumed scenarios apply, such that the calculated interference exists only for a single 2000 s integration period of the radio astronomy receiver. During morning and evening, the interference is at least 3 dB lower than during lunch time, because only a single activation per car occurs instead of two. However, the required limit according recommendation ITU-R RA.1513 of 2% data loss – which represents a single interfered 2000 s - measurement interval in a single day – would in the example of factory workers parking not be exceeded, even when the separation distance would be shorter that the calculated figures.

5 CONCLUSION

The Current regulation for UWB devices which are installed in road and rail vehicles with Low Duty Cycle (LDC) mitigation technique limit their e.i.r.p. emission to -53.3 dBm/MHz, based on the application of the exterior limit as defined in 2014/702/EU [4] (Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC). The limit for the power spectral density for Generic UWB applications applying LDC mitigation technique is defined at -41.3 dBm/MHz for indoor as well as for outdoor applications. The corresponding study results are shown in ECC Report 64 [5].

Study results presented in this Report evaluate whether compatibility with incumbent system could be achieved, when UWB devices are operating as car keyless entry systems without the application of the exterior limit, but instead operating like generic LDC UWB devices with an e.i.r.p. of -41.3 dBm and applying the new trigger-before-talk mitigation technique. The new trigger-before-talk mitigation technique results in a very low activity and correspondingly reduced probability of interference aggregation. Two different Ultra Wide Band device categories are studied in this Report: Category A for proximity verification and Category B for proximity monitoring purposes. Both category types work by using different activity factors.

Therefore, results of sharing studies related to aggregate interference or on probability of interference are particularly interesting. For single entry scenarios, the interference behaviour of the considered trigger-before-talk UWB system is the same as that one for generic LDC UWB devices[2]. The intention of the "exterior limit" introduction was to limit interference probability of moving objects which are transmitting periodically UWB signal with a given duty cycle.

A big parking lot with a capacity of 10000 cars was identified as a worst-case scenario for aggregated interference studies. In order to create a realistic propagation model for the particular case of UWB devices radiating from vehicles placed in big parking lots, the results obtained from detailed radio wave propagation measurements have been used as a base for all aggregated interference compatibility studies. Therefore any interference analysis result of single entry scenario is independent of the application of the exterior limit.

However, it should be noted, that the considered keyless entry system consists of a key fob, which is regulated as a generic UWB device with a maximum e.i.r.p. of - 41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal T_{on} time.

Single entry and aggregated interference are considered in the compatibility studies of the following incumbent systems:

Mobile Service

Protection of 5G, considering protection criterion I/N = -20 dB, was assessed.

Mobile station as well as base station receivers are studied as victim systems. As a worst case scenario, this study considers a big parking lot placed around a victim mobile station.

Because the separation distance between the mobile station and the UWB devices on vehicles is longer than the separation distance between the mobile station and the key fob, the impact of the vehicular UWB devices on the interference is for that scenario comparatively negligible.

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[2] Regulated in 2007/131/EC, Generic UWB devices which are not used at a fixed outdoor location or connected to a fixed outdoor antenna, installed in flying models, aircraft and other aviation as regulated in 2007/131/EC.

For 5G AAS victim receiver, interference caused by category A UWB devices never exceeds the protection criterion I/N = -20 dB with a probability of more than 2% of time in aggregated scenario. The probability of exceedance caused by UWB category B devices may be up to 22% of time in aggregate scenarios.

Unmanned Aircraft Systems (UAS)

UAS are operating under Mobile allocation in the band 4.4-4.99 GHz.

As their operating parameters have not changed since the studies made in ECC Report 170 [7] separation distances have been updated to protect UAS from LTA. Furthermore, due to the low possibility of simultaneous transmission, the aggregated effect is considered limited. The current regulatory limits of Table 3 in ECC Report 170 for the frequency band 4400-4800 MHz can be considered relevant to protect UAS in 4.4-4.8 GHz.

Unmanned Ground Vehicles (UGVs)

The interference potential of the vehicular access system in the case of Unmanned Ground Vehicles (UGV) is re-evaluated using the activity scenarios related to vehicular access systems. Since the usage of the vehicular access systems is only possible with parked cars, the worst case scenarios given in ECC Report 170 have been adapted and calculations have been re-assessed.

The studies conclude that even with the estimation of 25% for the market penetration factor and the assumption of very big parking lots, the probability of interference is negligible compared with generic UWB devices studied in ECC Report 170.

Fixed Service (FS)

The most critical interference scenario is the one involving the Category B devices operating in the lower UWB band. Simulations show that even if a sufficient level of protection can be reached for victim FS receivers operating in this band as defined by the long-term and the short-term criterion, there is a probability that interference slightly exceeds the protection criteria for a reduced range of power spectral density (PSD) limited to the case of very low antenna gains (i.e. much lower that the range defined by Recommendation ITU-R F.758-6 [8], Table 6).

For all other simulated cases, UWB devices operating in the keyless scenario with trigger-before-talk mitigation but without exterior limit fulfil the protection criterion with enough margins.

It is considered a worst-case scenario, i.e., lower antenna gains and maximum density of interfering devices within a parking lot area that has been positioned at a distance from the FS antenna corresponding to the worst case (i.e. for most of the case including FS antenna main beam and sidelobes). No minimal separation distance except the one provided by the antenna height has been used. Generally, the upper UWB band is much less affecting FS receivers owing to the intrinsically higher losses that occur due to the propagation mechanism (geometric attenuation from the free space propagation assumption). Furthermore, the fact that the same propagation model as the one developed for the low UWB band has also been used for the higher band provides an additional confidence margin on the simulations performed in the 6-8.5 GHz, where no significant impact has been noticed on the incumbent Fixed Service.

Fixed Satellite Service (FSS)

Previous interference studies between UWB and FSS (ECC Reports 64 and 170) have shown that the main scenario of interference is in the space to earth direction (in the 3-4 GHz range), and that the risk of interference to the FSS space station in the earth to space direction is therefore assumed to be negligible. Therefore, studies here focused only on the space to earth links (i.e. interference caused to the earth stations).

By making the necessary modifications to the assumptions used in ECC Report 170, single and aggregate interference from car keyless entry systems to FSS earth stations have been evaluated. In all cases, the lower antenna height and lower activity factor of UWB make the results considerably better than in ECC Report 170.

In the upper band (7250-7750 MHz), required separation distances for the single entry scenario are low. The worst case occurs for low elevation angles (5 degrees) where the maximum required separation distance 52 and 66 metres. Both short- and long-term aggregate interference criteria are respected especially regarding the maximum activity factor of 0.005% for UWB category B devices.

In the lower bands (3.4-4.2 GHz and 4.5-4.8 GHz), the required separation distances for the single entry scenario tend to be higher, especially for low elevation angles and lower FSS receiver heights. While in many cases it remains below 20 metres, the worst cases require a separation distances from 102 to 270 metres. Once again, the long-term aggregate interference requirements are met similarly as for the high band case. In the considered scenario of a parking lot with 10000 cars, Category A devices fail to meet the short-term interference criteria for the smaller dishes (1.2 and 1.8 m) and elevation angles up to 15-20 degrees. Category B devices fail to meet the short-term interference criteria in most cases.

However it should be noted, that the considered keyless entry system consists of a key fob, which is regulated as a generic UWB device with a maximum eirp of - 41.3 dBm/MHz and a device integrated in a car which is regulated as a vehicular device. Both devices of the system radiate RF signals with equal T_{on} time. Therefore any interference analysis result of single entry scenario is independent of the application of the exterior limit.

Also taking into account that studies conducted here very much considered worst-case scenarios, it can be concluded that in the most cases the proposed PKES system does not cause harmful interference.

Radio altimeter

Due to the lack of an approved value for minimum aircraft height above ground to be considered for the compatibility studies, two scenarios A and B representing different aircraft height levels are taken into account. Scenario A assumes a minimum aircraft height of 50 m and scenario B assumes a minimum aircraft height of 153 m according to ECC Report 272 [9].

At a minimum aircraft height level of 50 m, assumed by scenario A, the protection level for radio altimeter is exceeded, while at aircraft height level of 153 m assumed by scenario B the protection level is not exceeded.

Based on the results of scenario A, and noting the information from ICAO stipulating a minimum separation distance to vehicles in the order of 5 meters for protection of both fixed-wing and rotary-wing aircraft, it can be concluded that in the frequency band 4.2-4.4 GHz the exterior limit has to be applied to satisfy the protection criterion I/N = -6 dB. It should be further noted that the report does not consider the situation when the radio altimeter receives higher power which may be the case for low flight altitudes.

In the case of Wireless Avionics Intra-Communication (WAIC), separation distances of less than 10 m are calculated and therefore present a low risk of interference in a single entry scenario.

Radio astronomy

The application of the big parking lot scenario to the radio astronomy study is not appropriate because at any place nearby a big parking lot, a high level of man-made noise has to be expected and is therefore not suited for radio astronomy operations. Instead a scenario is considered with a parking lot of 100 cars.

For single entry interference scenarios, the minimum required separation distance between considered Category A UWB devices or Category B UWB devices and the radio astronomy station is 98.3 m or 376.8 m, respectively to protect the radio astronomy service from harmful interference.

For aggregated interference, the minimum separation distances are 602.1 m and 1985 m when assuming a worst case car deployment on the parking and a frequent car usage.

Conclusions on compatibility

In conclusion, the operation of the considered UWB devices in a road vehicle for the application of car keyless entry systems without the application of the exterior limit, but instead operating like a generic LDC UWB devices with an e.i.r.p. of -41.3 dBm/MHz causes no interference or interference with low probability. In general, the aggregated interference levels from UWB devices operating with trigger-before-talk mitigation technique are lower than those from UWB devices operating with LDC mitigation technique. With respect to single entry scenarios, the same separation distance has to be considered as for generic UWB devices operating with LDC mitigation technique. Radio astronomy services can be protected by respecting a reasonable separation distance. Therefore compatibility with the incumbent services in the bands 3.8 - 4.2 6-8.5 GHz can be achieved when trigger-before-talk mitigation is used.

In the band 3.4 - 3.8 GHz, it can be considered that the percentage of time exceeding I/N =--20 dB towards 5G is 2% for category A and 22% for category B devices. Reduction of category B activity factor could cause significant improvement of the interference situation.

In the band 4.2-4.4 GHz, it can be stated that the exterior limit has still to be applied. In the band 4.4-4.8 GHz, it can be stated that the exterior limit has still to be applied.

ANNEX 1: MONTE CARLO SIMULATION LIMITATIONS FOR QUASI SIMULTANEOUS UWB SIGNAL EMISSIONS

A1.1 INTRODUCTION

In this Report two transmission durations are considered. Category A devices have a T_{on} time of 50 ms, while Category B devices have a T_{on} time of 750 ms. It appears that reporting interference results for different T_{on} times may have given the impression that the interference evaluation is somehow only applicable to a discrete time base. This Annex aims at showing that this is not the case.

The methodology for aggregated interference studies applied in this Report is based on the approach used in the SEAMCAT simulation tool.

A1.2 CHANCES OF INTERFERENCE AT ANY GIVEN TIME

To calculate the chances of interference at a certain time, it is important to realise that the interfering transmitter must have started transmitting between the considered time instance and a period of up to T_{on} before that.

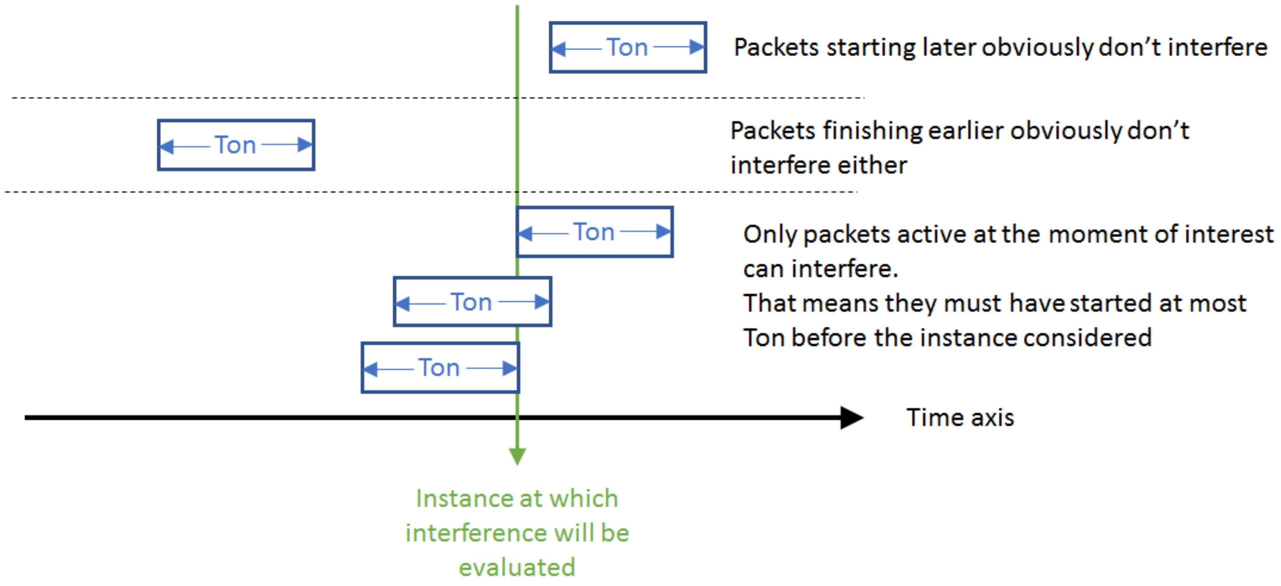

Figure 73: Chances of interference considering packets of T_{on} duration

A1.3 NUMBER OF INTERFERERS AT ANY GIVEN TIME

The section above shows that to interfere at a certain time, the interfering transmitter has to have started transmitting in an interval between the considered time instance and up to T_{on} before it.

For aggregate interference scenarios, it is also important to know how many interferers are active at the considered time instance.

If the individual interfering transmitters operate independently but with a constant average activity factor, the Poisson distribution gives the probability of a certain number of transmitters starting within a given interval.

A1.4 TIME AXIS ASSUMPTIONS

Note that in the analysis above, there are no restrictions on the time axis.

A1.5 CONCLUSION:

There are no restrictions on the time axis of the interference analysis. The use of T_{on} reflects the logical fact that to interfere at a certain time, the transmission must have started in an interval of length T_{on} before that time.

ANNEX 2: PROPAGATION MODEL TO BE USED FOR AGGREGATED INTERFERENCE SCENARIOS ON LARGE PARKING LOTS

A2.1 PROPAGATION MODEL FOR THE FREQUENCY RANGE 3.4 – 4.8 GHZ

A2.2 INTRODUCTION

The propagation conditions of UWB radio waves on a big car parking are influenced by different phenomena: free space propagation, propagation by diffraction and propagation trough car body windows. Because of the different car shapes (for cars which are parked side by side) and used materials for the car body construction (including car windows), no general valid model can be defined which adequately defines a typical situation to be used for an empirical simulation of UWB radio wave attenuation due to a car body (which obstructs the radio wave propagation path or acts as reflector). Furthermore the geometrical situation for radio wave propagation path on a car parking is different for every individual parking place. This makes the development of a standard propagation model even more difficult.

As an alternative, an empiric simulation model based on field measurements is used for this study.

A2.3 MEASUREMENTS

Measurements were done by using a test transmitter placed at 6 different transmitting positions on selected cars of a big parking lot. The placements of the transmitter are described below and shown in Figure 74.

- VA: in the front bumper at the most distant position from the victim receiver;
- VI: in the front bumper at the position closest to the victim receiver;
- HA: in the back bumper at the most distant position from the victim receiver;
- HI: in the back bumper at the position closest to the victim receiver;
- MA: in the side mirror at the most distant position from the victim receiver;
- MI: in the side mirror at the position closest to the victim receiver.

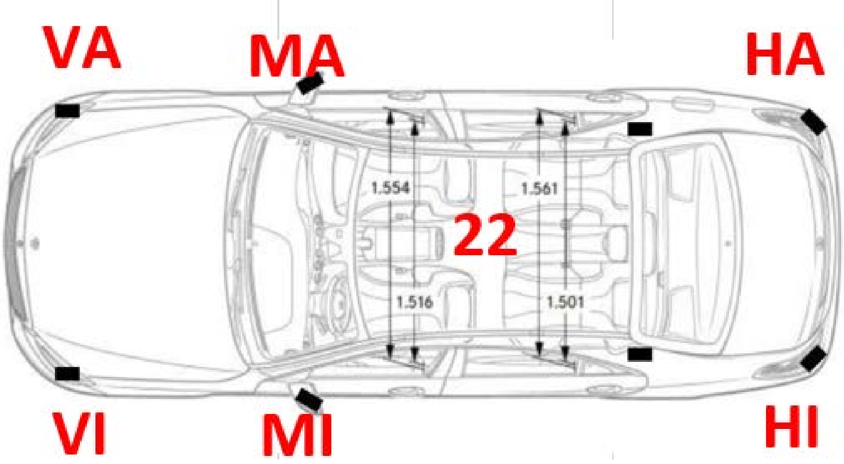

Figure 74: Sensor placements on the car body

The height of the test transmitter for positions VI, VA, HI, HA is 0.4 m above ground, for the positions MI and MA at the height of the side mirrors. This is done for a selection of different cars on a big parking lot. Only a vertical polarised transmitting antenna was used. The transmitting antenna has a half wave length dipole radiation characteristic.

A2.4 EVALUATION OF THE RESULTS

Based on the measured field strength, the relative path loss is calculated. The path loss is assumed to be characterised by two effects: free space propagation loss and an additional loss due to car screening attenuation.

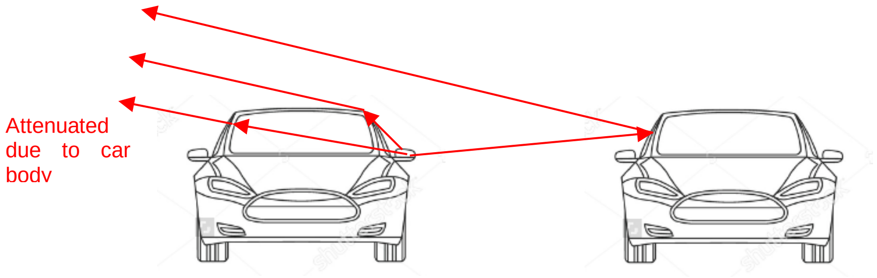

Figure 75: Considered UWB signal propagation phenomena

The car screening attenuation considers the three different propagation phenomena: diffraction loss, reflection loss and attenuation of wave propagation trough car body and car body windows as detailed in Figure 75.

A2.5 CLASSIFICATION OF THE RESULTS AND STATISTICAL TESTS

Statistical analysis (Spearman’s Rank Correlation) of the measured data of car bumper placed transmitters shows that the correlation of the data to any monotonous function is $\rho=-0.633$ with 100% significance (considering 32 out of 64 samples) in the best case.

From radio engineering point of view, there are two classes of test transmitter positions:

- Class QLOS representing data from measurements where the test transmitter position is on the same side of the car as the receiving antenna (not necessarily line of sight for all cases);
- Class QNLOS representing data from measurements where the test transmitter position is on the opposite side of the car seen from the receiving antenna (not necessarily non line of sight for all cases).

Measurement data of the QNLOS class have an improved rank correlation of -0.761 with 100% significance, but the QNLOS correlation has a rank correlation of just -0.394 and 97% significance. However, there is some benefit on statistical significance when discriminating between the two classes QLOS and QNLOS.

A2.6 ATTENUATION MODEL

A simple approach to create an attenuation model can be done by regression on a power function as shown in Figure 76 to Figure 78. This models are valid for victim antenna height h_{RX} = 6 m. For other victim antenna heights h_{RX}, the same models can be applied when the distance parameter is transformed according to the following formula:

$$distance(h_{Rx}) = \frac{\mathrm{distance\ [m]}}{h_{Rx}\ \mathrm{[m]}} 6$$

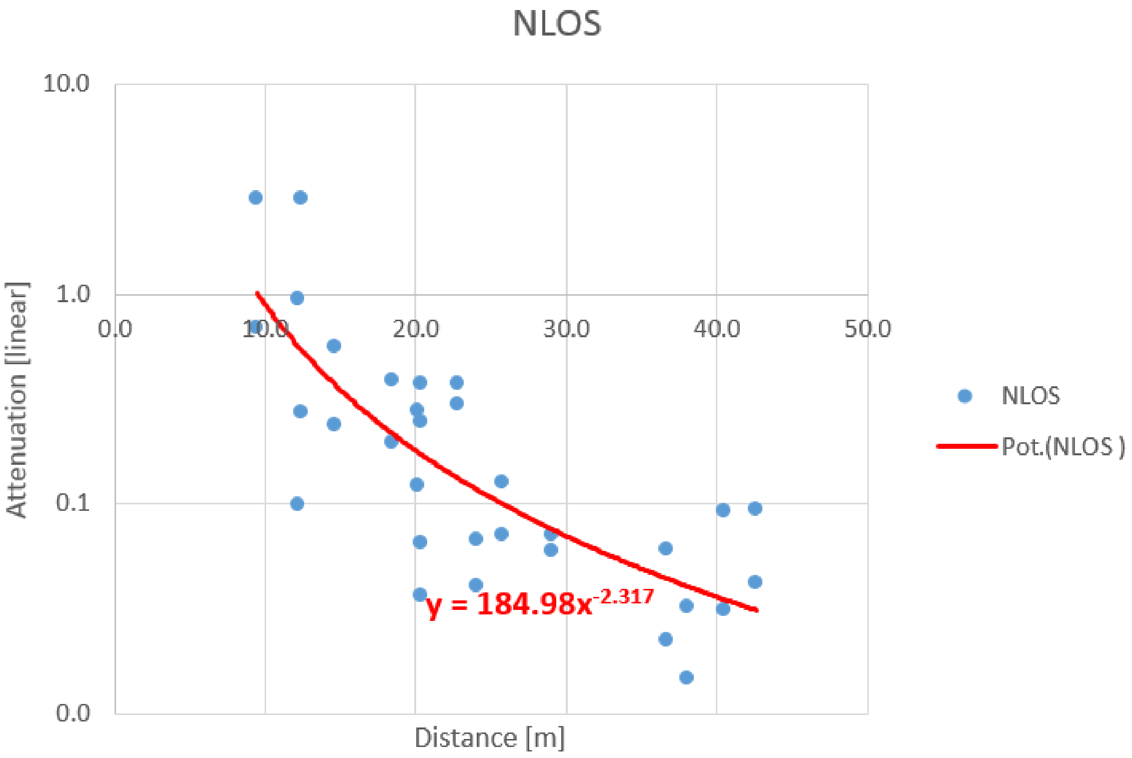

Figure 76: Regression function on NLOS class samples from car bumper measurements

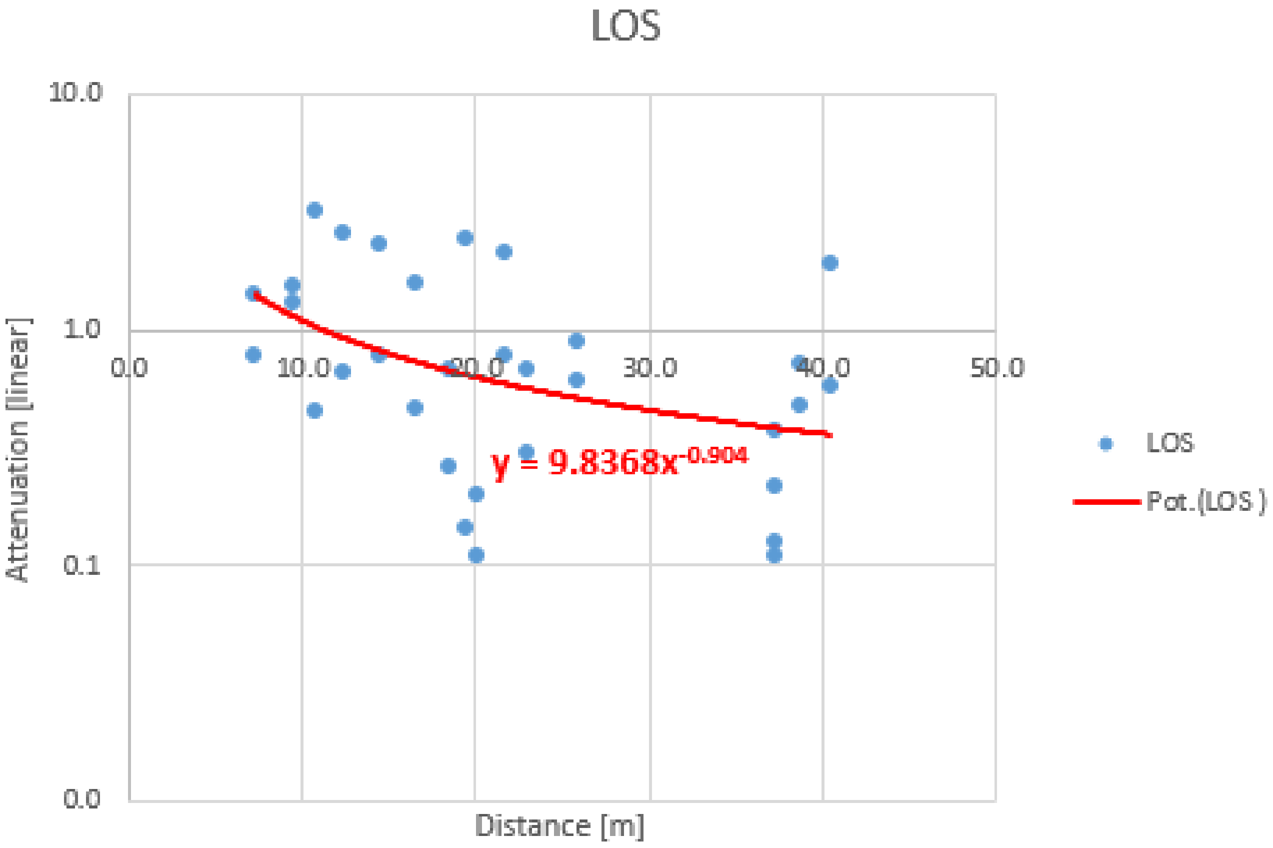

Figure 77: Regression function on LOS class samples from car bumper measurements

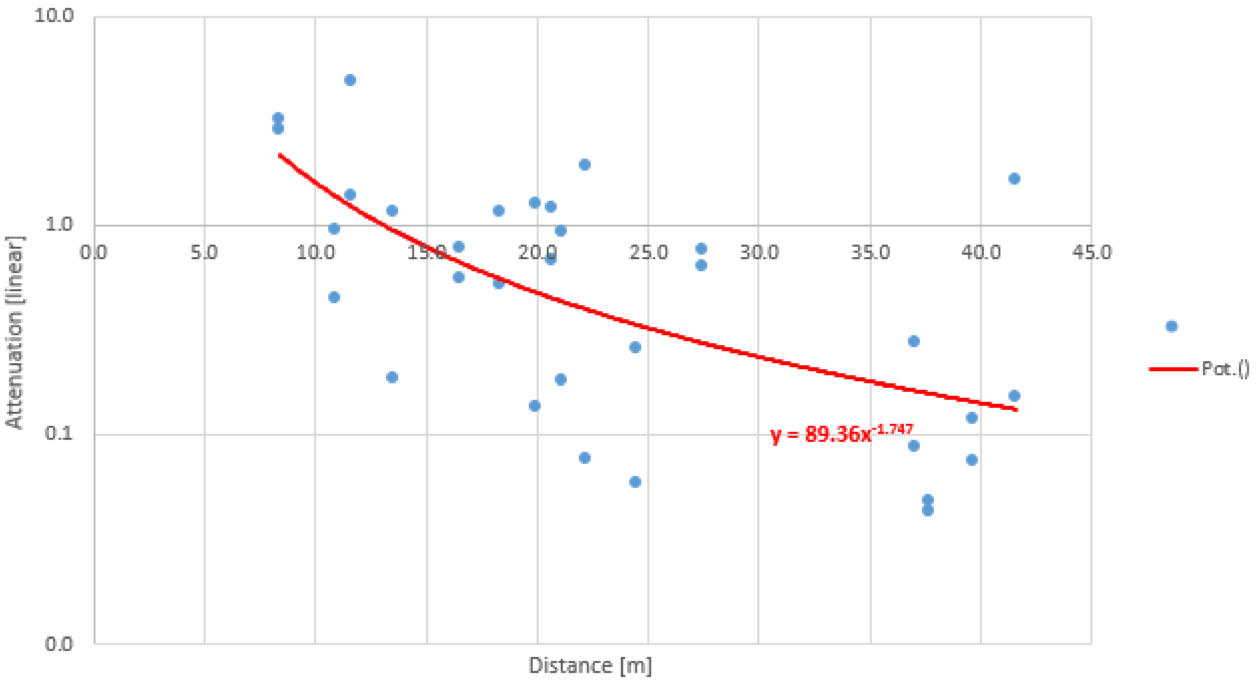

Figure 78: Regression function on samples from side mirror measurements

The selection of the regression functions is done based on the assumption that the additional attenuation increases monotonously with distance but not with a linear characteristic. Therefore a polynomial approach is not appropriate. Rather a power function or exponential function should be envisaged. The depicted power functions showed the best fit. As example of how the fit was tested, the residual for power and exponential function are shown in Figure 79 and Figure 80.

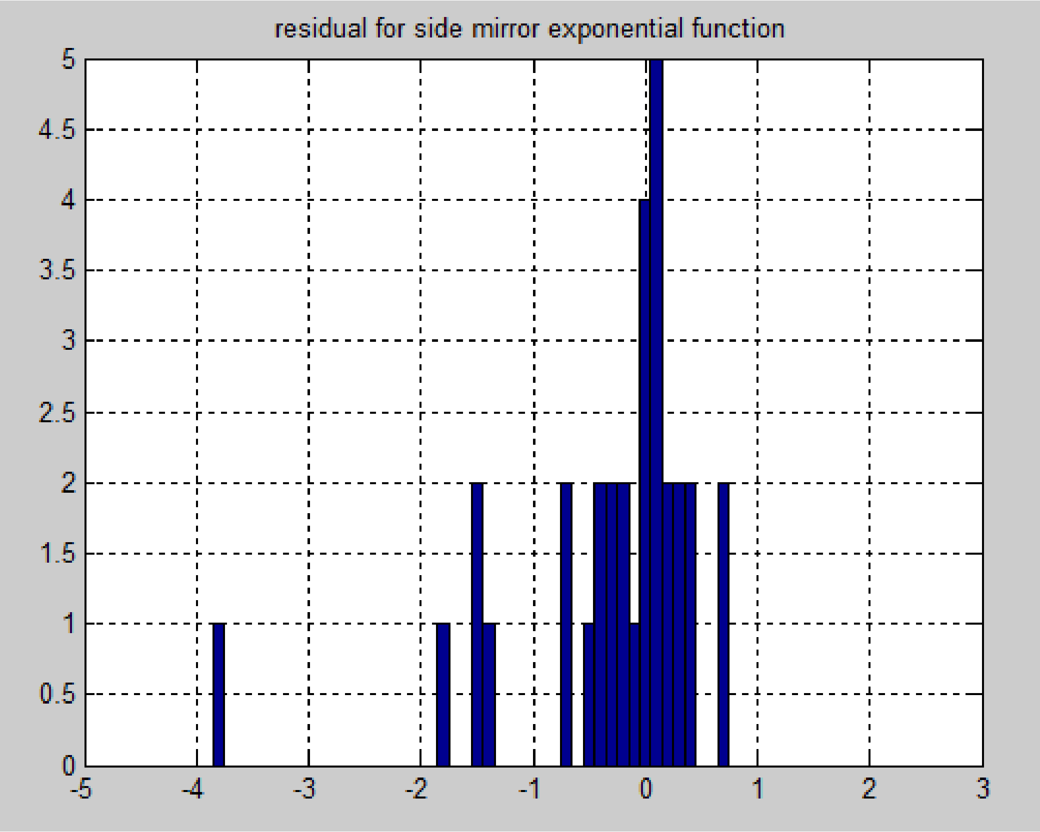

Figure 79: Residual for exponential function

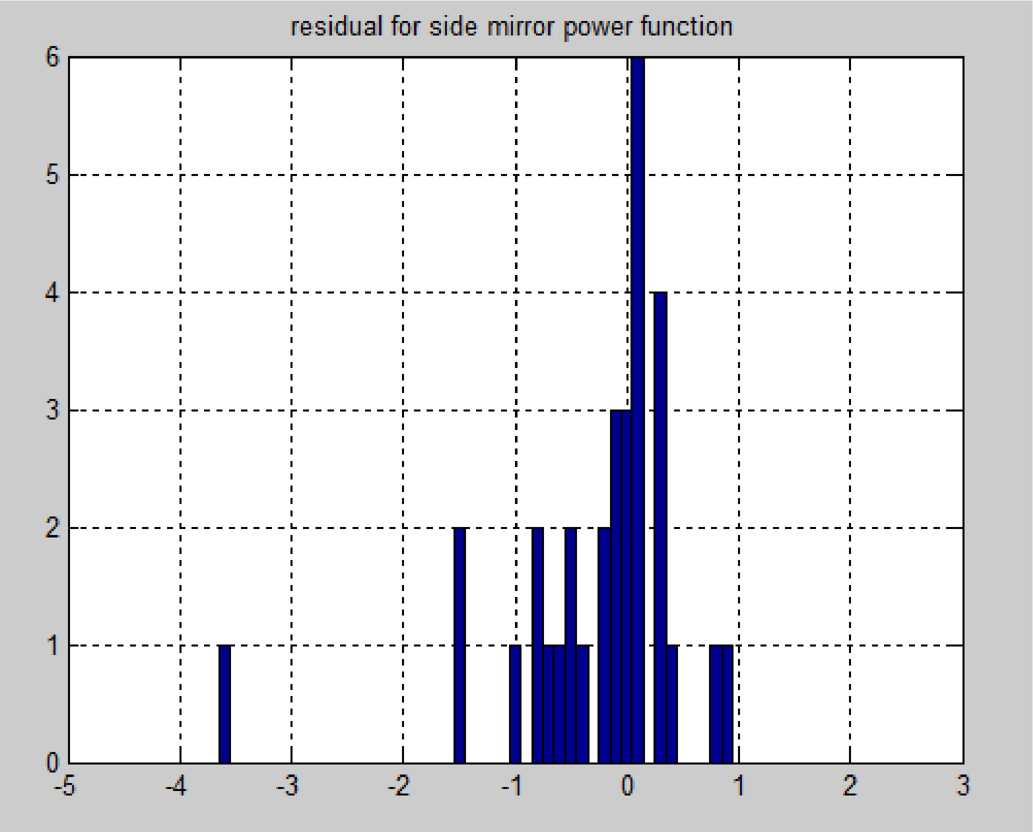

Figure 80: Residual for power function

A2.7 DETAILS ON THE MEASURMENT CAMPAIGN

The test transmitter is placed at the mentioned 6 different transmitting positions on the car body. The height of the test transmitter for positions VI, VA, HI, HA is 0.4 m above ground, for the positions MI and MA at the height of the side mirrors. This is done for a selection of different cars on a big parking lot. Only vertical polarised transmitting antenna was used. The transmitting antenna has a half wave length dipole radiation characteristics. There were many different types of cars from different brands parked on the parking lot. Different cars at different places on a big parking lot are selected to be used for the measurements. A selection of cars for the parking 1, 2 and 3 of the parking lot is shown in detail in Figure 81.

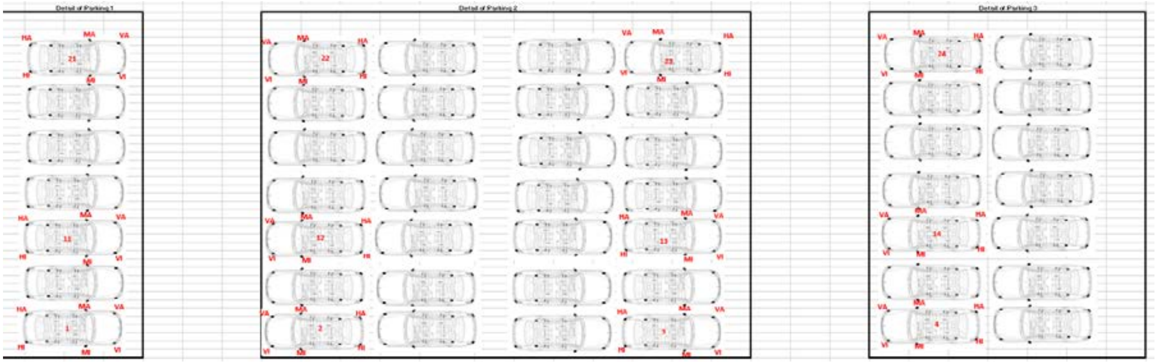

Figure 81: Detail of parking no. 1, 2 and 3 of the parking lot

An overview of all selected cars of the parking lot with indication of the distance is shown in Figure 82. The yellow marked places represent the sampled cars. The red marked place represents the receiving antenna.

Figure 82: Overview of the parking lot

For each transmitting position (VI, VA, HI, HA, MI, MA) and each selected car the field strength was measured. At that receiving antenna the orientation (azimuth and elevation) was varied to find the maximum receiving level. The receiving antenna height is constant 6 m. The polarization of the receiving antenna is vertical. Each measurement result is labelled with the car sample number of the relative test transmitter position (e.g. HI32 → test transmitter position HI, car sample 32). Figure 83 shows the receiving antenna and a detail of the car parking.

Figure 83: Receiving Antenna

A2.8 EVALUATION OF THE RESULTS

Based on the measured field strength, the relative path loss is calculated. The path loss is assumed to be characterised by two effects: free space propagation loss and an additional loss due to car screening attenuation. The car screening attenuation considers different propagation phenomena like diffraction loss, multipath propagation and attenuation of wave propagation trough car body windows. While the free space path loss can easily be calculated based on known geometrical condition, the additional loss needs to be evaluated. For this elaboration, antenna gains of transmitter and receiver need to be known. As earlier mentioned, the direction of the receiving antenna is tuned to that orientation of maximum receiving level. Accordingly, only the maximum gain of the receiving antenna needs to be known. The gain of the transmitting antenna needs to be corrected with respect to the pattern and the elevation angle of the ray representing the radio wave propagation path.

An in situ calibration is conducted to get a reference. For this calibration, two measurements are conducted at two different transmitter–receiver distances: 7 m and 12 m. The receiving antenna height is 6 m, the transmitting antenna height is 1.5 m. A calibration procedure for the e.i.r.p. is applied according to Table 31.

Table 31: Calibration process data

Horizontal Distance RX- TX [m]	Measured Field strength [dBµV/m]	Distance of radio path [m]	TX Dipol gain for given elevation of radio path	Free space loss [dB]	received power (TX pattern corrected) [dBm]	Measured e.i.r.p.= received power + free space loss [dBm]
7.00	89.54	9.22	-1.20	63.95	-56.95	7.00
12.00	87.75	13.42	-0.48	67.21	-59.45	7.76

The “received power (TX pattern corrected)” refers to the aperture of 0.12 λ2 at a frequency of 4.1 GHz. The value of the theoretical e.i.r.p. of the transmitter is 6.5 dBm. For the following evaluation of the additional loss for all measurement results, all values are referenced to an e.i.r.p. of 7 dBm.

The evaluation of the additional loss is based on the following formula:

$$propagation\ loss\ [dB] = 10\log\left(\frac{0.12\lambda^2 E^2}{377}\right) + 30 - G_{TX} - 7dBm$$

$$additional\ \ loss\ [dB] = FreeSpace\ Loss[dB] + propagation\ loss$$

As an example the evaluation of the data of the car sample number 1 is shown in Table 32.

Table 32: Evaluation of the additional loss

Place / Position	Measured field strength [dBµV/m]	Distance of radio path [m]	TX Dipol gain for given elevation of radio path	Free space loss [dB]	Received power (TX pattern corrected) [dBm]	Propagation loss [dB]	Additional loss [dB]
HA1	77.37	18.50	-0.20	70.00	-70.11	-77.12	-7.12
HI1	80.34	18.50	-0.20	70.00	-67.14	-74.15	-4.15
MA1	84.39	16.45	-0.29	68.98	-63.01	-70.01	-1.03
MI1	82.86	16.45	-0.29	68.98	-64.54	-71.54	-2.56
VA1	85.32	14.40	-0.40	67.82	-61.96	-68.97	-1.14
VI1	90.04	14.40	-0.40	67.82	-57.24	-64.25	3.58

A2.9 CLASSIFICATION OF THE RESULTS AND STATISTICAL TESTS

Statistical analysis (Spearman’s Rank Correlation) of the measured data of car bumper place transmitters shows that the correlation of the data to any monotonous function is ρ=-0.633 with 100% significance (considering 32 out of 64 samples) in the best case. From radio engineering point of view, there are two classes of test transmitter positions:

- Class LOS representing data form measurements where the test transmitter position is on the same side of the car as the receiving antenna is (not necessarily line of sight for all cases);
- Class NLOS representing data form measurements where the test transmitter position is on the opposite side of the car seen from the receiving antenna is (not necessarily non line of sight for all cases).

Measurement data of NLOS class have an improved rank correlation of -0.761 with 100% significance, but the NLOS correlation have a rank correlation of just -0.394 and 97% significance.

From a statistical point of view, there is little benefit to distinguish the data in two classes (see Table 33 and Table 34):

Table 33: Measurement data of class LOS and NLOS samples of car bumper measurements

NLOS			LOS		
	Distance [m]	Attenuation [linear]		Distance [m]	Attenuation [linear]
HA1	18.5	0.19	HI1	18.5	0.38
HA11	20.2	0.12	HI11	20.2	0.27
HA21	25.8	0.07	HI21	25.8	0.13
HA31	40.5	0.03	HI31	40.5	0.09
VA2	9.5	0.69	VI2	9.5	2.85
VA12	12.4	0.27	VI12	12.4	2.84
VA22	20.4	0.06	VI22	20.4	0.38
VA32	36.7	0.06	VI32	36.7	0.02
VA3	12.3	0.10	VI3	12.3	0.94
VA13	14.6	0.23	VI13	14.6	0.56
VA23	20.4	0.04	VI23	20.4	0.24
VA33	38.0	0.01	VI33	38.0	0.03
HA4	22.8	0.37	HI4	22.8	0.30
HA14	24.1	0.07	HI14	24.1	0.04
HA24	29.0	0.06	HI24	29.0	0.07
HA34	42.6	0.04	HI34	42.6	0.09
HI1	18.5	0.38	VI1	14.4	2.28
HI11	20.2	0.27	VI11	16.5	1.59
HI21	25.8	0.13	VI21	23.1	0.68
HI31	40.5	0.09	VI31	38.8	0.72
VI2	9.5	2.85	HI2	7.3	0.77
VI12	12.4	2.84	HI12	10.8	3.22
VI22	20.4	0.38	HI22	19.4	2.41
VI32	36.7	0.02	HI32	37.2	0.37
VI3	12.3	0.94	HI3	9.5	1.53
VI13	14.6	0.56	HI13	12.4	2.59
VI23	20.4	0.24	HI23	21.8	2.13
VI33	38.0	0.03	HI33	37.2	0.22
HI4	22.8	0.30	VI4	18.5	0.26
HI14	24.1	0.04	VI14	20.2	0.11

NLOS			LOS		
HI24	29.0	0.07	VI24	25.8	0.61
HI34	42.6	0.09	VI34	40.5	1.90
Spearman's Rank Correlation	ρ =	-0.761	Spearman's Rank Correlation	ρ =	-0.641
	Student’s ltl =	6.429		Student’s ltl =	4.570
	Stat. Sign. =	100.0%		Stat. Sign. =	100.0%

Table 34: Values of arbitrarily selected data of car bumper measurements

Arbitrarily selected data			Arbitrarily selected data		
	Distance [m]	Attenuation [linear]		Distance [m]	Attenuation [linear]
HA1	18.5	0.19	HA21	25.8	0.07
VA32	36.7	0.06	VA12	12.4	0.27
VA3	12.3	0.10	VA33	38.0	0.01
HA34	42.6	0.04	HA24	29.0	0.06
VI2	9.5	2.85	HI1	18.5	0.38
VI32	36.7	0.02	VI12	12.4	2.84
HI4	22.8	0.30	VI3	12.3	0.94
HI34	42.6	0.09	HI24	29.0	0.07
VI31	38.8	0.72	VI21	23.1	0.68
HI32	37.2	0.37	HI12	10.8	3.22
HI3	9.5	1.53	HI33	37.2	0.22
VI34	40.5	1.90	VI24	25.8	0.61
HA2	7.3	1.40	VA1	14.4	0.77
HA32	37.2	0.13	HA12	10.8	0.45
VA4	18.5	0.67	HA3	9.5	4.47
VA34	40.5	0.58	VA24	25.8	0.90
HA31	40.5	0.03	HA11	20.2	0.12
VA2	9.5	0.69	VA22	20.4	0.06
VA13	14.6	0.23	VA23	20.4	0.04
HA4	22.8	0.37	HA14	24.1	0.07

Arbitrarily selected data			Arbitrarily selected data		
HI21	25.8	0.13	HI11	20.2	0.27
HI31	40.5	0.09	VI22	20.4	0.38
VI13	14.6	0.56	VI23	20.4	0.24
HI14	24.1	0.04	VI33	38.0	0.03
VI11	16.5	1.59	VI1	14.4	2.28
HI2	7.3	0.77	HI22	19.4	2.41
HI13	12.4	2.59	HI23	21.8	2.13
VI4	18.5	0.26	VI14	20.2	0.11
VA21	23.1	0.30	VA11	16.5	0.46
VA31	38.8	0.48	HA22	19.4	0.15
HA13	12.4	0.67	HA23	21.8	0.78
VA14	20.2	0.20	HA33	37.2	0.11
Spearman's Rank Correlation	ρ =	-0.525	Spearman's Rank Correlation	ρ =	-0.633
	Student’s ltl =	3.381		Student’s ltl =	4.480
	Stat. Sign. =	99.8%		Stat. Sign. =	100.0%

For side mirror UWB transmitter positions, the following measurement data are obtained. To differ into two classes, as it is done for the results of bumper position measurements, is useless, because of very poor statistical significance for the NLOS class results.

Measurement data from side mirror UWB transmitter positions are shown in Table 35.

Table 35: Measurement data of side mirror measurements

	Distance [m]	Attenuation [linear]
1 MA	16.5	0.79
11 MA	18.3	0.53
21 MA	24.4	0.06
31 MA	39.6	0.12
4 MA	20.7	1.22
14 MA	22.1	0.08
24 MA	27.4	0.77
34 MA	41.5	0.15
1 MI	16.5	0.55

	Distance [m]	Attenuation [linear]
11 MI	18.3	1.16
21 MI	24.4	0.26
31 MI	39.6	0.08
4 MI	20.7	0.69
14 MI	22.1	1.93
24 MI	27.4	0.63
34 MI	41.5	1.66
2 MI	8.4	2.87
12 MI	11.6	4.84
22 MI	19.9	1.28
32 MI	37.0	0.28
3 MI	10.9	0.45
13 MI	13.5	1.17
23 MI	21.1	0.93
33 MI	37.6	0.05
2 MA	8.4	3.20
12 MA	11.6	1.38
22 MA	19.9	0.14
32 MA	37.0	0.09
3 MA	10.9	0.96
13 MA	13.5	0.19
23 MA	21.1	0.18
33 MA	37.6	0.04
Spearman's Rank Correlation	ρ =	-0.577
	ltl =	3.870
	Stat. Sign. =	99.9%

A2.10 APPLICATION OF THE MODEL FOR THE FREQUENCY BAND 6000 – 8500 MHZ

Due to lack of measurement data, an approximated model has to be found for the frequency range 6000 – 8500 MHz, which represents a worst case situation (minimum attenuation).

A simple approach is to use the same model for both frequency ranges, 3 400-4800 MHz and 6 000-8 500 MHz, based on the assumption that the losses are either the same for both frequency ranges or increase at higher frequencies.

In the following the validity of this assumption is verified. For this purpose the three radio wave propagation effects “diffraction loss”, “reflection loss” and “attenuation of waves propagating trough car body a car windows” are separately verified for their frequency dependence.

A2.11 DIFFRACTION LOSS

The method of diffraction loss calculation according the Recommendation ITU-R P.526-13 [31] is applied to the scenario shown in Figure 84.

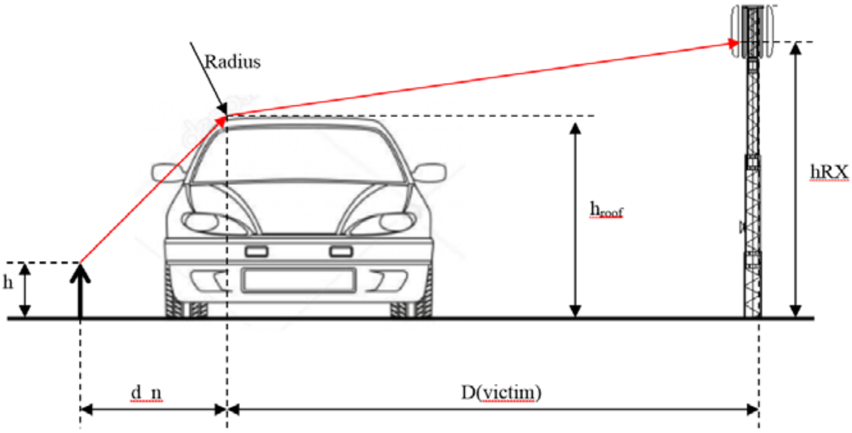

Figure 84: Model / set – up for diffraction loss calculation

The following parameters are used for the calculation:

- h = 0.4 m, 1 m
- d_n = 1m, 3m
- Radius = 0.1m
- D(victim) = 10m .. 100m
- h_{roof} = 1.5 m
- h_{RX} = 10 m
- f = 4.1 GHz, 6.7 GHz

In Figure 85, the results of the calculated diffraction losses are shown graphically. When analysing the data in detail, it turns out that the diffraction loss at a frequency of 6.7 GHz is significantly higher than at a frequency of 4.1 GHz for all considered situations, except in case of d_n = 4 m, h = 1 m and in a range 70 m - 74 m, where the loss is lower by less than 2.7 dB. It can be concluded, that the diffraction loss in general increases with the frequency.

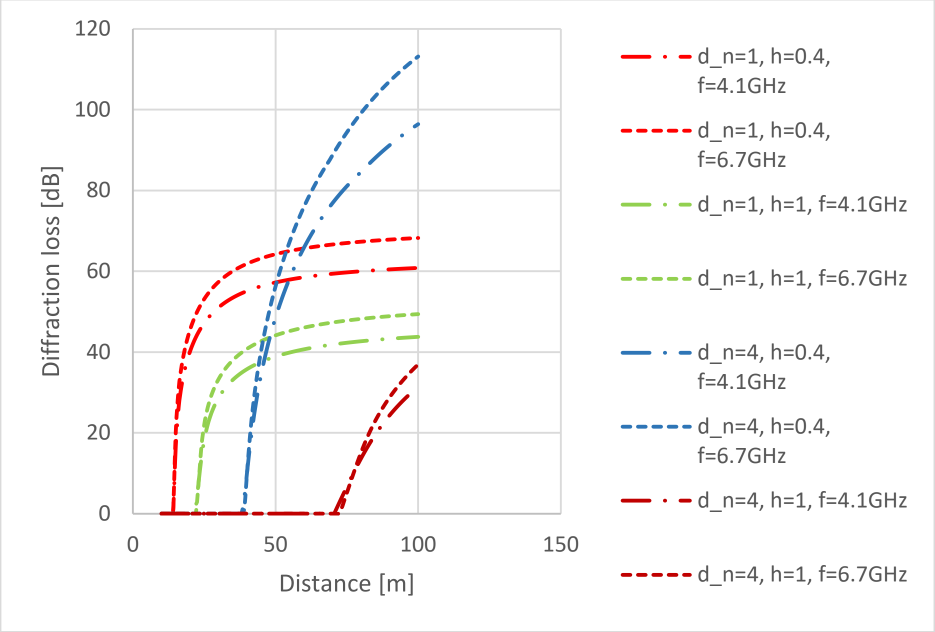

Figure 85: Diffraction loss according ITU-R P.526-13

A2.12 REFLECTION LOSS

Due to lack of measurement results and analytical model for the analysis of the reflection propagation phenomena, propagation data are produced with computer based numerical electromagnetic simulation (MoM technique). The simulations assume a vertical half wave dipole radiating at a frequency of 4.1 GHz and 6.7 GHz nearby a car body. The antenna is placed at a distance of 1 m from the car body at that positions where UWB devices would be installed in the front bumper or side mirror of neighbouring cars. This simulation setup with the coordinate system description is shown in Figure 87. No ground plane is considered in the simulations. The simulation calculates the normalised electric field strength on sphere surrounding the radiating elements as shown in Figure 86. The normalised field strength in the unit Volts is simulated in the far field. To get the effective field strength at any position, the normalised field strength needs to be divided by the distance between the point of the simulated field strength and the dipole antenna. The centre of the sphere is located at the position of the radiating antenna.

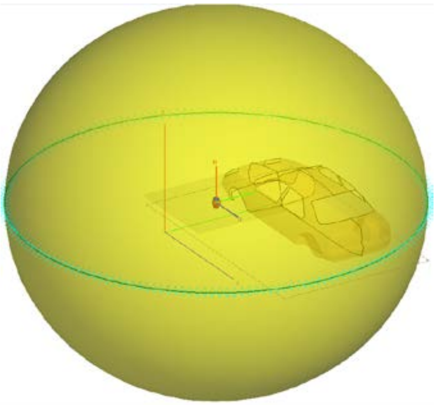

Figure 86: Simulation set up showing the spherical surface for E-field simulation

The field strength is simulated for 360° azimuth angles and for 90°, 75°, 60°, 45°, 30° and 15° elevation angle for both mentioned frequencies. The results are shown in Figure 88 to Figure 93. Due to practical reasons, only the results for the side mirror position of the radiating antenna are shown in this section. The conclusion which can be made on the results of side mirror position simulations and bumper simulations are the same.

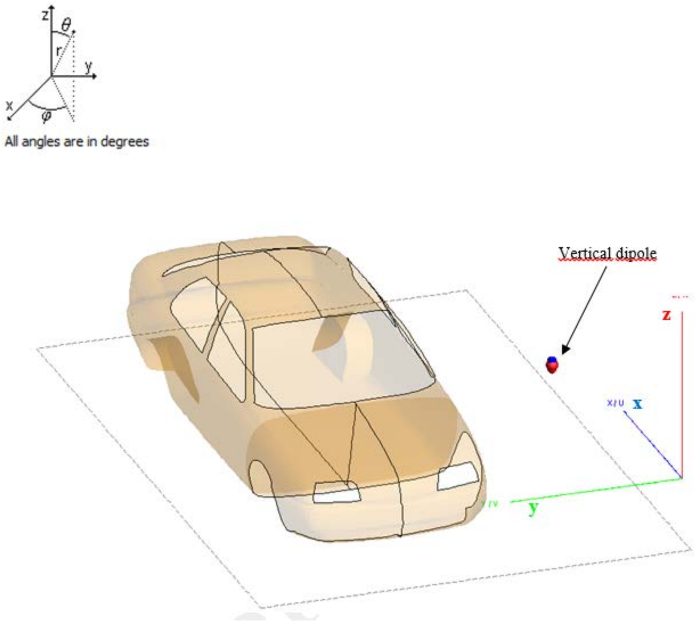

Figure 87: Set up and coordinate system definition for reflection simulation

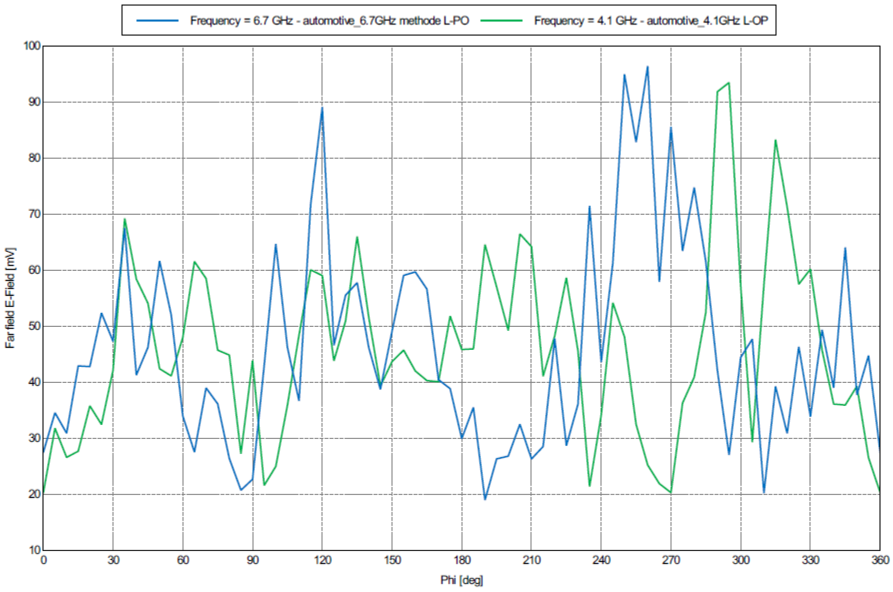

Figure 88: Normalised E-Field at theta = 15°, side mirror position

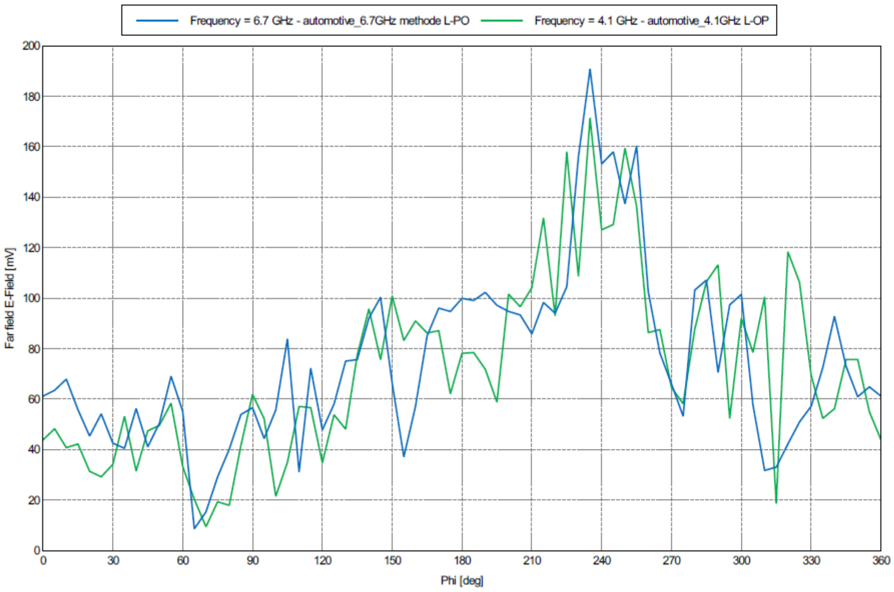

Figure 89: Normalised E-Field at theta = 30°, side mirror position

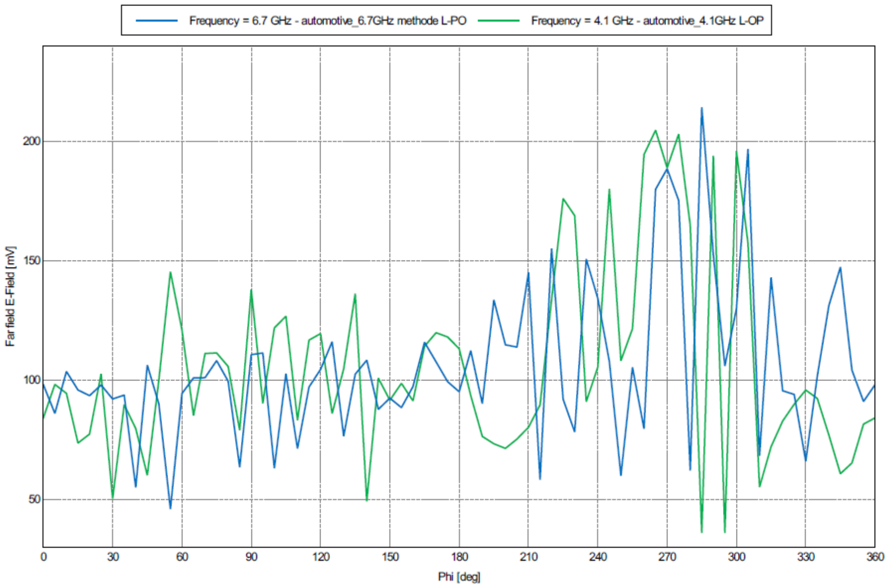

Figure 90: Normalised E-Field at theta = 45°, side mirror position

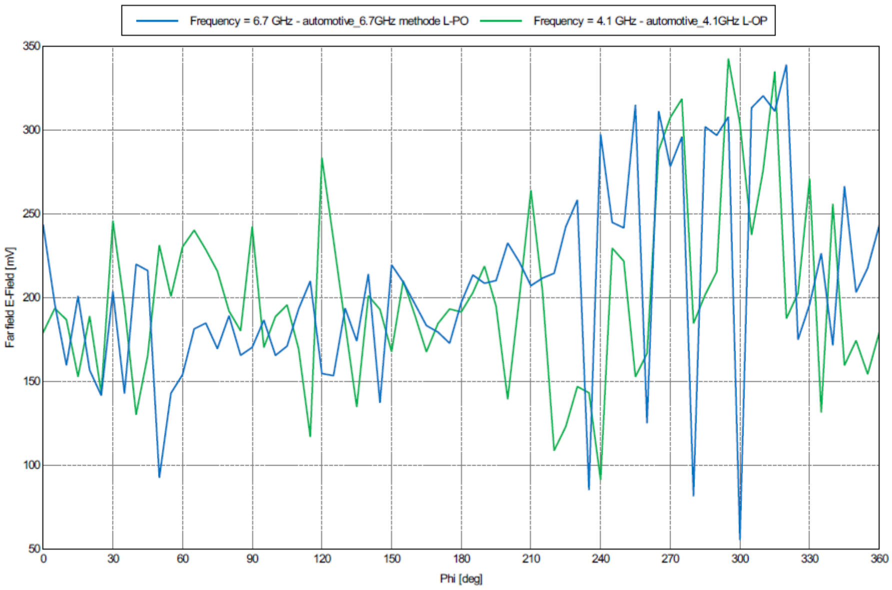

Figure 91: Normalised E-Field at theta = 60°, side mirror position

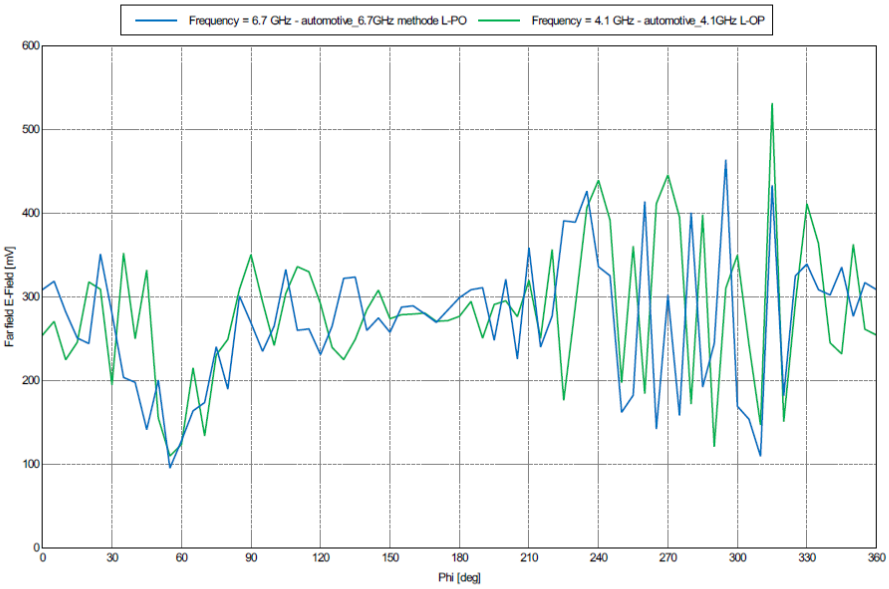

Figure 92: Normalised E-Field at theta = 75°, side mirror position

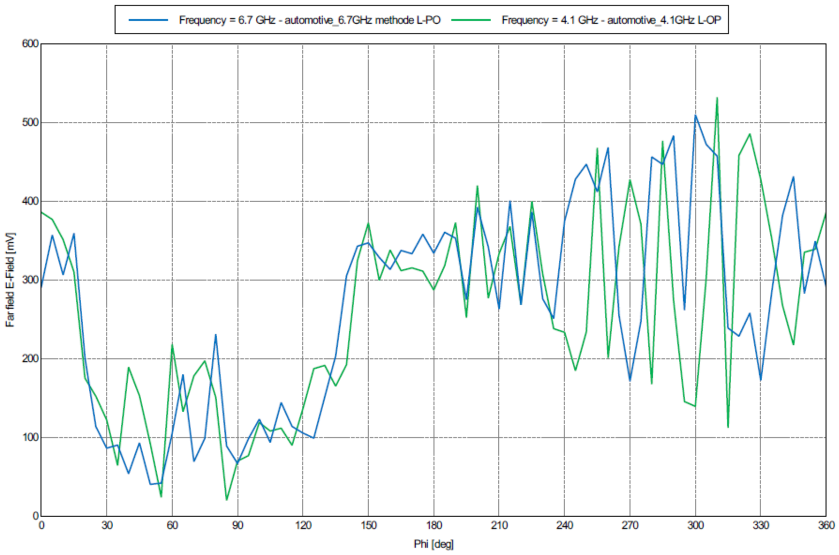

Figure 93: Normalised E-Field at theta = 90°, side mirror position

When analysing the data shown in Figure 88 to Figure 93, it can be concluded that the pattern of the reflected radiated waves changes at higher frequency, but that on average there is no increase in the radiation when the frequency is increased.

A2.13 ATTENUATION OF WAVE PROPAGATION TROUGH CAR BODY AND CAR WINDOWS

Results of car shielding attenuation measurements are presented and shown in Figure 94 to Figure 96, based on material made available in ETSI. In those measurements the total radiated power outside the car is recorded, while a CW signal generator inside cars at various positions and antenna polarizations was emitting CW signals. The measurement covered emissions in the frequency range between 0.85 GHz and 11 GHz. Based on those measurements, the attenuation of the signal was evaluated. For sake of clarity, Figure 94, Figure 95 and Figure 96 are copied here and the presented results show that in general no decrease of the attenuation can be observed when the frequency is increased.

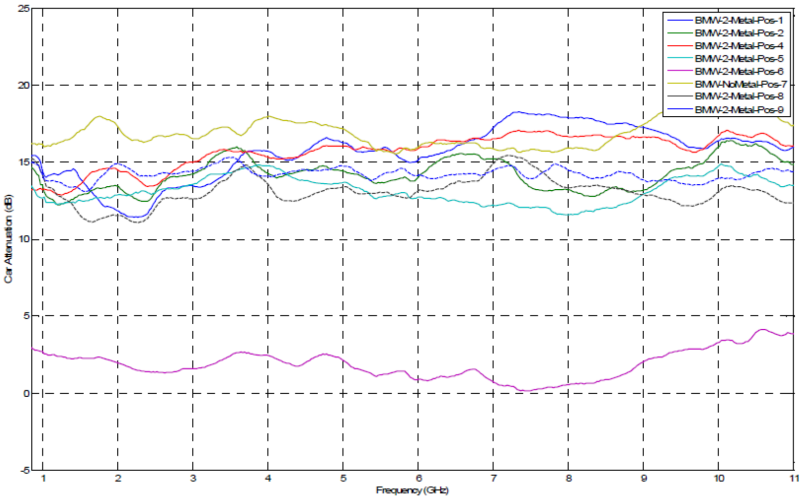

Figure 94: Car attenuation BMW-1 (with metallized front window) according to material discussed in ETSI

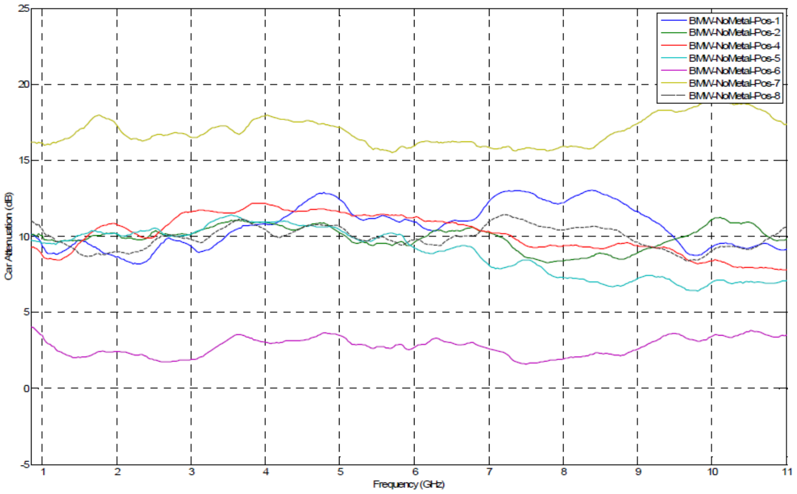

Figure 95: Car attenuation with metallized shielded windows according to material discussed in ETSI

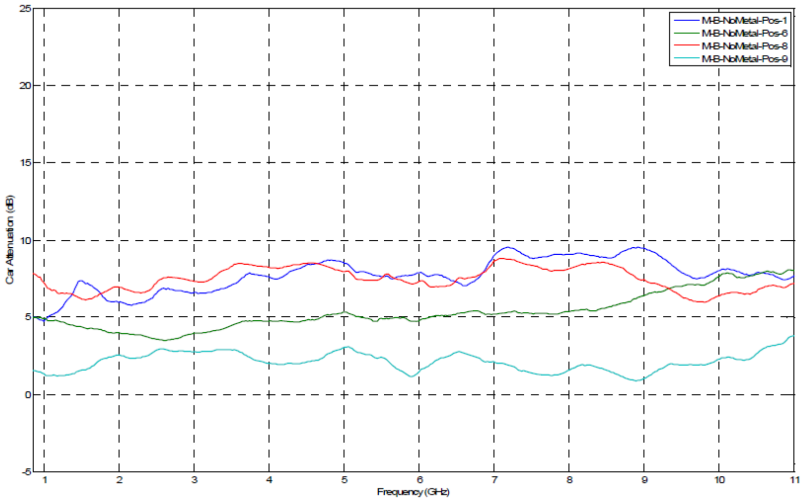

Figure 96: Car attenuation MB without metallized shielded windows to material discussed in ETSI

A2.14 CONCLUSION

The three radio wave propagation effects “diffraction loss”, “reflection loss” and “attenuation of waves propagating trough car body and car windows” are verified for their frequency dependence separately. The mentioned propagation effects do not show a decrease but rather an increase of the attenuation with increasing frequency. Therefore the model proposed for the frequency range 3.4 GHz – 4.8 GHz can be used for the frequency range 6 GHz – 8.5 GHz as a case of worst case interference.

ANNEX 3: ANTENNA PATTERNS AND PATH LOSS FOR DIFFERENT FS ANTENNAS

Patterns and path loss for the different antenna models used in the simulations:

- ITU-R F. 699: model used for point-to-point FS in in single entry scenario (pattern envelope adjusted on peak sidelobes);
- ITU-R F. 1245: model used for point-to-point FS in in aggregated scenario (pattern envelope adjusted on mean sidelobes);
- ITU-R F. 1336: model used for point-to-multipoint for both single entry and aggregated (pattern envelope adjusted on peak sidelobes, parameter k=0).

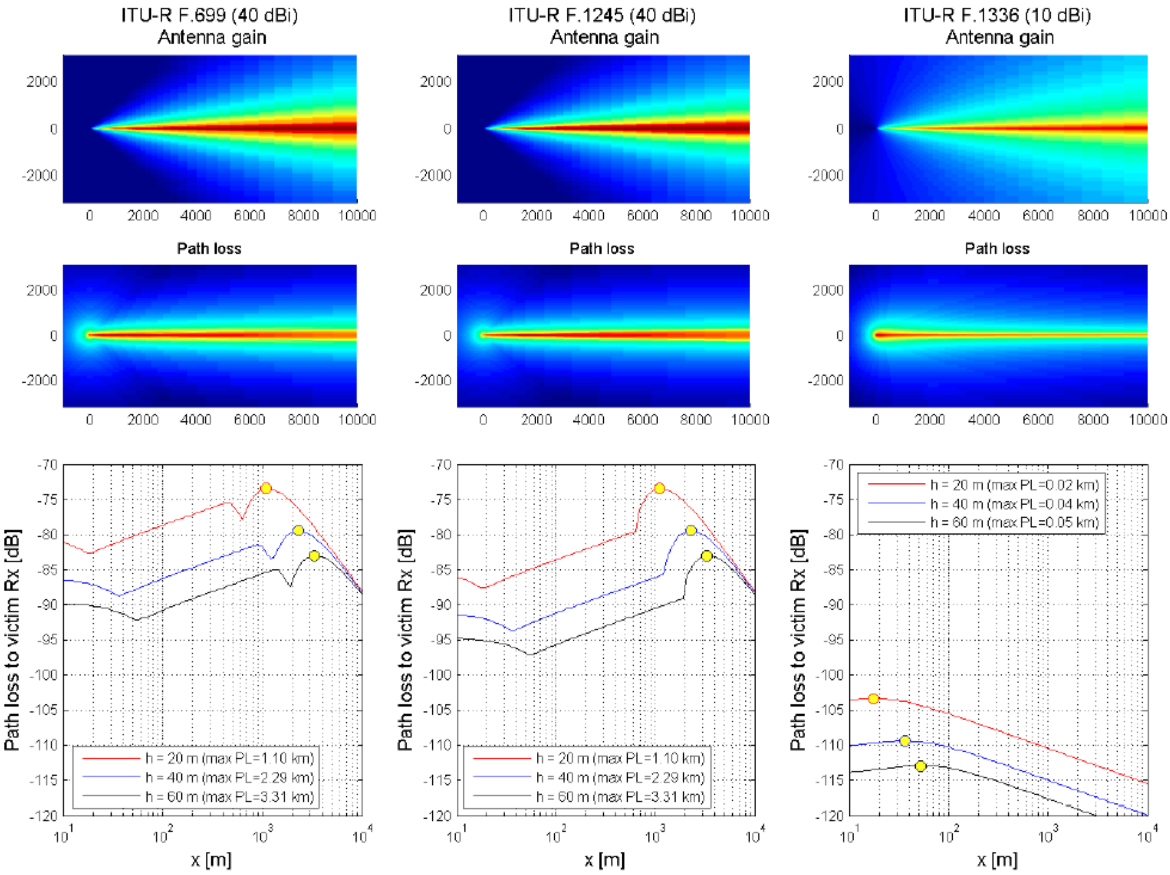

Figure 97: Antenna patterns and path loss for different FS antennas

ANNEX 4: PROPAGATION MODEL FOR FSS STUDIES

The applicability of the free space propagation model is proven by assessment with the propagation model ITU-R P.452-16 for the considered scenarios as shown in the following.

The free space loss model is used for single entry interference scenario.

The application of the ITU-R P.452 propagation model gives higher attenuation than the free space loss only due to the clutter loss. The model ITU-R P.452 does not show any statistical behaviour for the considered scenarios:

The propagation model in Recommendation ITU-R P.452 considers different wave propagation phenomena. A basic distinction is made between clear air prediction (Section 4) and hydrometeor - scatter interference prediction (Section 5). The hydrometeor - scatter prediction is obviously not appropriate for the considered interference scenario. Accordingly, just clear air prediction method applies for the considered studies.

The overall loss prediction for the clear – air propagation model is calculated according to formula 64 in Recommendation ITU-R P.452 where L_{bs} is considering troposcatter effects. Because losses due to troposcatter effects are much higher than propagation loss under LOS conditions, the formula 64 simplifies for the considered scenarios to:

$$L_b = L_{bam} + A_{ht} + A_{hr}$$

Because the considered scenarios are dealing with distances below 300 m, the value of the path angular distance gets small, and consequently the value for the interpolation factor as defined in formula 58 is larger than 0.99. Furthermore, because the loss 0.01 * L_{bda} is much less than L_{minb0p}, the transmission loss L_{bam} as defined in formula 63 simplifies to:

$$L_{bam} = L_{minb0p}$$

The loss L_{minb0p} is calculated according to formula 60 where represents diffraction losses, which does not need to be considered, because of LOS conditions for all considered scenarios. Furthermore, the value of the interpolation factor Fj is not below 0.99 for the considered scenarios. Accordingly, the formula 60 simplifies to:

$$L_{minb0p} = L_{b0p} \qquad for\, p < \beta_0$$

$$L_{minb0p} = L_{b0\beta} \qquad for \quad p \geq \beta_0$$

The losses L_{b0p} and $L_{b0\beta}$ are calculated according to the formulas 11 and 12. Those formulas represent LOS losses, with multipath and focusing effects. Those effects are following statistical effects and are calculated according to formulas 10a and 10b. In those formulas the time percentages p and β0 as well as the distances d_{lt} and d_{lr} are parameters. Because of small values of the distances, the formula 11 and 12 simplifies to:

$$L_{b0p} = L_{b0\beta} = L_{bfsg}$$

The loss L_{bfsg} is calculated according to formula 8.

L_{bfsg} = 92.5 + 20 log f + 20 log d + Ag

Considering all the above mentioned findings, the overall clear – air loss is calculated according to the following formula

L_b = 92.5 + 20 log f + 20 log d + Ag + Aht +Ahr

This formula can be interpreted as free space loss model taking into account clutter loss and attenuation due to atmospheric gases. This interpretation can be verified numerically by means of MATLAB scripts or the EXCEL simulation tool which is published on the ITU-R web site:

The propagation loss based on the two above mentioned models are calculated based on the parameters in Table 36.

Table 36: Parameters used for the model ITU-R P.452

Parameter	values
Path distance [km]	0.05 - 10
Frequency [GHz]	3.8, 6.7
Time percentage	1%, 50%
Polarization	H, V
Tx latitude [deg]	46.9
Tx longitude [deg]	7.5
Tx antenna height [m]	1.5
Tx antenna gain [dB]	0
Rx latitude [deg]	46.9
Rx longitude [deg]	7.501
Rx antenna height [m]	2, 4, 6, 8
Rx antenna gain [dB]	0
DN (N-units/km)	45
No (N-units/km)	325
Pressure (hPa)	1000
Temperature [deg]	20
Tx, Rx clutter [dB]	0
Dct, dcr	500

When analysing the results in Table 37, then it can be concluded that for the considered range of distances both models give very similar results. Statistical effects on the propagation loss occur only at distance ranges beyond those considered in this Report; no significant differences occur below distances of 1 km.

Table 37: Calculated path loss based on ITU-R P.452 propagation model and free space propagation model and evaluation of the difference

f [MHz]	Path distance [km]	TX antenna height [m]	RX Antenna height [m]	Time percentage [%]	Pol. [H/V]	Loss (P.452) [dB]	Free space loss [dB]	Difference [dB]
3800	0.4	1.5	8	50	H	96.14	96.04	0.10
3800	0.2	1.5	8	50	H	90.11	90.02	0.09
3800	0.1	1.5	8	50	H	84.1	84.00	0.10
3800	0.05	1.5	8	50	H	78.1	77.98	0.12
3800	0.4	1.5	8	1	H	96	96.04	-0.04
3800	0.2	1.5	8	1	H	90	90.02	-0.02
3800	0.1	1.5	8	1	H	84.1	84.00	0.10
3800	0.05	1.5	8	1	H	78.1	77.98	0.12
3800	0.4	1.5	8	50	V	96.14	96.04	0.10
3800	0.2	1.5	8	50	V	90.11	90.02	0.09
3800	0.1	1.5	8	50	V	84.1	84.00	0.10
3800	0.05	1.5	8	50	V	78.1	77.98	0.12
3800	0.4	1.5	8	1	V	96	96.04	-0.04
3800	0.2	1.5	8	1	V	90	90.02	-0.02
3800	0.1	1.5	8	1	V	84	84.00	0.00
3800	0.05	1.5	8	1	V	78.1	77.98	0.12
6700	0.4	1.5	8	50	H	101.1	100.96	0.14
6700	0.4	1.5	8	1	H	100.89	100.96	-0.07
6700	0.4	1.5	8	50	V	101.1	100.96	0.14
6700	0.4	1.5	8	50	V	100.89	100.96	-0.07
3800	0.4	1.5	6	1	H	96	96.04	-0.04
3800	0.4	1.5	4	1	H	96	96.04	-0.04
3800	0.4	1.5	2	1	H	96	96.04	-0.04

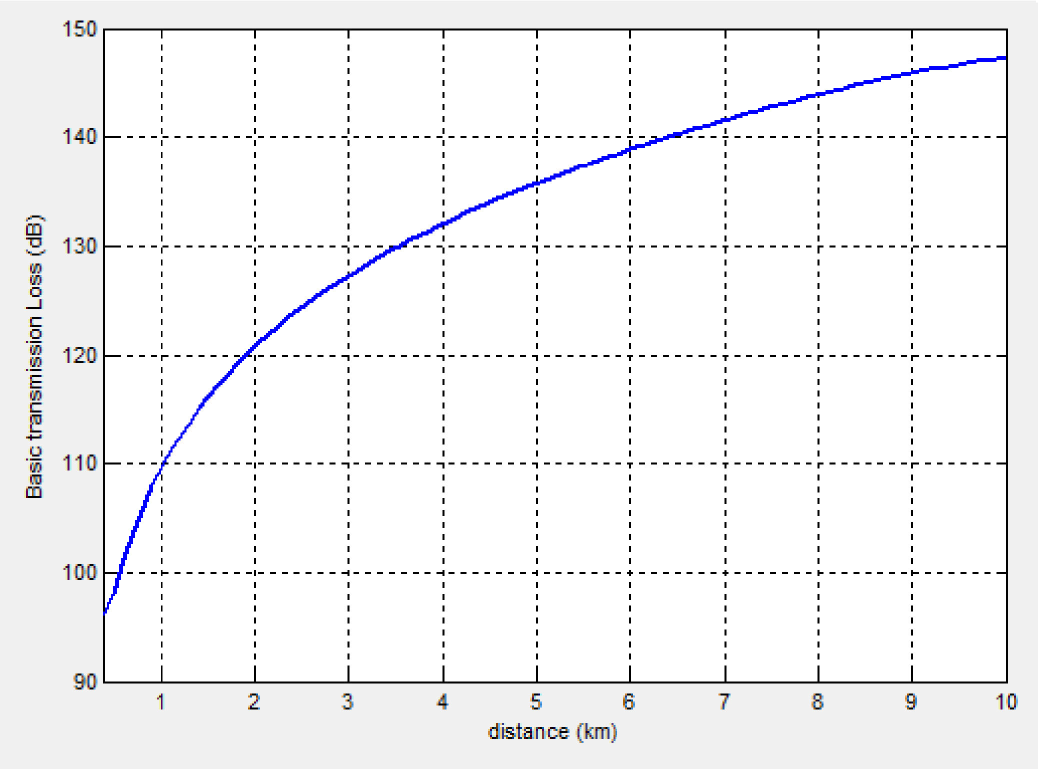

Figure 98: Path loss calculated according to ITU-R P.452 using the following parameters p = 1%, H_tx = 1.5, H_rx = 2, pol = H, f = 3.8 GHz

ANNEX 5: LIST OF REFERENCE

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

[2] ETSI TR 102 495 V1.2.1: "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 applications2

[3] ECC Report 254 "Operational guidelines for spectrum sharing to support the implementation of the current ECC framework in the 3600-3800 MHz range"

[4] 2014/702/EU (Commission Implementing Decision of 7 October 2014 amending Decision 2007/131/EC)

[5] ECC Report 64: "Generic UWB applications below 10.6 GHz"

[6] 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", June 2013

[7] ECC Report 170: "Specific UWB applications in the bands 3.4 - 4.8 GHz and 6 - 8.5 GHz LAES, LT2 and LTA"

[8] Recommendation ITU-R F.758-6: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference"

[9] ECC Report 272: "Earth Stations operating in the frequency bands 4-8 GHz, 12-18 GHz and 18-40 GHz in the vicinity of aircraft"

[10] EN 302 065 V1.2.1: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB) for communications purposes; Harmonised EN covering the essential requirements of article 3.2 of the R&TTE Directive"

[11] ERC Rec 70-03: "Relating to the use of Shot Range Devices (SRD)"

[12] CEPT Report 17: "Identify the conditions relating to the harmonised introduction in the European Union of radio applications based on UWB technology"

[13] Recommendation ITU-R SF.1650-1: "The minimum distance from the baseline beyond which in-motion earth stations located on board vessels would not cause unacceptable interference to the terrestrial service in the bands 5 925-6 425 MHz and 14-14.5 GHz"

[14] Recommendation ITU-R F.2086-0: "Deployment scenarios for point-to-point systems in the fixed service"

[15] Recommendation ITU-R F.699-7: "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz"

[16] Recommendation ITU-R F.1245-2: "Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz"

[17] Recommendation ITU-R F.1336-4: "Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz"

[18] Recommendation ITU-R M.2059: "Protection criteria for telemetry systems in the aeronautical mobile service and mitigation techniques to facilitate sharing with geostationary broadcasting-satellite and mobile-satellite services in the frequency bands 1 452-1 525 MHz and 2 310-2 360 MHz"

[19] Recommendation ITU-R M-2067-0: "Technical characteristics and protection criteria for Wireless Avionics Intra-Communication systems"

[20] Report ITU-R M.2319-0: "Compatibility analysis between wireless avionics intra-communication systems and systems in the existing services in the frequency band 4 200-4 400 MHz"

[21] Recommendation ITU-R M.2085-0: Technical conditions for the use of wireless avionics intra-communication systems operating in the aeronautical mobile (R) service in the frequency band 4 200 - 4 400 MHz

[22] Report ITU-R M.2292-0: "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses"

[23] Recommendation ITU-R P.1411-8: "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz"

[24] Recommendation ITU-R SF.1006-0: "Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service"

[25] Recommendation ITU-R F.1094-2: “Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources”
[26] Recommendation ITU-R S,1432-1: “Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz”
[27] Recommendation ITU-R P.452-16: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”
[28] Recommendation ITU-R RA.769-2: “Protection criteria used for radio astronomical measurements”
[29] Report ITU-R RS.2308: “Radio frequency compatibility of unwanted emissions from 9 GHz EESS synthetic aperture radars (SAR) with the EESS (passive), SRS (passive), SRS and RAS operating in the frequency bands 8 400-8 500 MHz and 10.6-10.7 GHz, respectively”
[30] Recommendation ITU-R P.525-3: “Calculation of free-space attenuation”
[31] Recommendation ITU-R P.526-13: “Propagation by diffraction”
[32] Preliminary draft new Recommendation ITU-R M.[AMS 4.4-5GHz] – “Technical characteristics of, and protection criteria for aeronautical mobile (AMS), except aeronautical mobile telemetry (AMT), systems operating in the frequency band 4 400-4 990 MHz”
[33] Report ITU-R M.2039-3: "Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses"
[34] ECC Report 281: “Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800 MHz band”, July 2018
[35] Recommendation ITU-R M.2085-0
[36] 3GPP TR 37.840, Study of Radio Frequency (RF) and Electromagnetic Compatibility (EMC) requirements for Active Antenna Array System (AAS) base station