Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

THE PROTECTION REQUIREMENTS OF RADIOCOMMUNICATIONS SYSTEMS BELOW 10.6 GHz FROM GENERIC UWB APPLICATIONS

Helsinki, February 2005

EXECUTIVE SUMMARY

This ECC Report considers the protection requirements of radiocommunications services below 10.6 GHz from Generic Ultra Wide Band (UWB) Applications. The study is based mostly on theoretical analysis. The conclusions are based on currently available data on UWB technical characteristics and propagation models, bearing in mind that no specific mitigation techniques for UWB applications were taken into account as they were still under development at the time of writing this report. It should be noted that not all frequency bands which are allocated to the radiocommunications services considered in this report were investigated.

The summary of the results of the compatibility studies are given in section 7. The required maximum generic UWB PSD values to protect the existing radiocommunications services are demonstrated to be more stringent than the values given in the FCC mask.

To reach a sufficient protection from UWB systems, especially for pulsed UWB applications, it is necessary to set an average power limit and a peak power limit (alternatively to setting a peak limit, it is possible to limit the Pulse Repetition Frequency (PRF) to a certain minimum value).

The limits in summary table are valid for the assumption of Additive White Gaussian Noise (AWGN)-like interference effects, which is achievable with the following conditions:

- Scenarios with a sufficient number of interferer (>100);
- Pulse-based UWB emissions with a PRF-range of $PRF > VictimBandwidth$, and
- MB-OFDM (without Frequency Hopping).

The results show that:

- The majority of the considered radiocommunications services require up to 20-30 dB more stringent Generic UWB PSD limits than defined in the FCC masks, indoor as well as outdoor. Only a few EESS applications are sufficiently protected by FCC mask, whereas some RAS bands require 50-80 dB more stringent limits;
- The consolidated limits shown in Fig. 15 indicate that the allowed Generic UWB PSD limit increases with the frequency. The difference between PSD limit at 10 GHz and that at 200 MHz is about 20 dB;
- If the victim radiocommunications service is operated in an outdoor environment only, as is the case for e.g. FS, FSS, RAS, EESS etc, then the increase of noise due to the aggregate UWB interference determines the generic UWB PSD limit. In addition, if the victim radiocommunications service is (also) operated in the indoor environment, e.g. DVB-T, IMT-2000, RLAN, etc, then the closest UWB interferer becomes the determining interference factor due to small spatial separation (small path loss).

It can also be observed that for radiocommunications services using narrow band receivers with higher sensitivity more protection is required.

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1 INTRODUCTION

This ECC Report describes the general technical basis of the CEPT work on UWB. It describes the methodology and calculation results for compatibility studies between generic UWB applications operating in bands below 10.6 GHz and existing radiocommunications services. Actual UWB product parameters have not been considered in this report as these were only being developed at the time of writing this report. There are potential mass deployment scenarios for different types of UWB applications for different environments, which may be relevant depending on a category of victim receiver that is considered. The analysis in this report reflects “worst-case scenario” approach.

The primary outcome of this ECC Report consists of the generic limits for UWB applications in terms of maximum UWB power density, required for the protection of radiocommunications services.

As an important requirement, the key assumptions behind the generic limits will appear clearly in the conclusions, in particular UWB densities and activity factors when aggregate interference analysis was more relevant, or minimum protection distance requirement for single interferer analysis.

Further detailed analysis may be required to consider operational, economical, and technical requirements of specific UWB applications including the results of the measurement campaigns.

Further studies would be also required in order to address issues related to possible introduction of UWB systems above 10.6 GHz.

A preliminary measurement campaign, with the aim of carrying out the single/aggregated UWB interference measurements, has been carried out in certain victim radio services bands. Due to the very premature status of those practical studies at the time of writing this report, corresponding section 6.4 and Annex 16 should be considered as informative only.

2 ULTRA-WIDEBAND APPLICATIONS

In this report, UWB devices are understood as any device transmitting electromagnetic waves, which occupies a relative bandwidth of 20% or more of the centre frequency or an absolute bandwidth of 500 MHz or more.

Dependent on the application, UWB systems would generally have relatively small average power associated with a possible high peak-to-average ratio, therefore both peak and average power should be considered. UWB radiocommunication systems as well as radar applications may be categorised by the following applications, among possible others that are envisaged to be operated in the future:

- Medical applications;
- Consumer communications applications;
- Automotive applications[1];
- Consumer and industrial construction applications;
- Ground penetrating radar (GPR) systems;
- Industrial liquid level gauges;
- Data communications systems;
- Wireless high-speed networking.

Some of these applications, e.g. automotive applications and some communication devices may be operated in large quantities, especially in densely populated regions and are likely to create “hot-spot”-type aggregate interference sources.

The above listed types of UWB applications may be considered to belong to two main basic types of UWB systems considered by the industry below 10.6 GHz. Type 1 of UWB systems, which icludes a variety of very different applications, might be tenatively subdivided further, according to their different usage pattern (e.g. for outdoor/indoor/hot-spot deployment, different device density and utilisation rate), hence its potential impact on aggregation of interference seen by a victim receiver:

Type 1. UWB Communications and measurement systems including:

- Consumer and business data communication applications, for example:
    - ➢ Home entertainment and networking (indoor, high density, in average low utilisation);
    - ➢ Cellular phones’ multimedia interfaces (outdoor and indoor, high density, medium utilisation);
    - ➢ Wireless Personal Area Networks (WPAN) (indoor, hot-spot, low-to-medium utilisation);
    - ➢ Wireless Local Area Networks (e.g. similar to RLAN with enhanced capacity, indoor, hot-spot, high utilisation);

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[1] Automotive UWB applications in higher frequency bands are considered in ECC Report 23 “Compatibility of 24 GHz Automotive Radars with FS, EESS, Radio Astronomy”

- Combined data communication and measurement systems, e.g. measurement and location recording devices (outdoor and indoor, low density, low utilisation).

Type 2. UWB Imaging systems (indoor and outdoor, low density, low-to-high utilisation, possible safety applications), including:

- Ground Penetrating Radars (GPRs);
- In-wall imaging;
- Through-wall imaging;
- Medical imaging;
- Surveillance devices;
- Industrial liquid level gauges.

Type 3. Automotive radars (considered in other ECC Reports)

Considering proportions of UWB Types 1 and 2 in a total number of forecasted UWB units, based on information provided by UWB industry, 98% of deployed devices should be covered by type 1. Furthermore, 88% of all units would be type 1 for indoor use exclusively and only 10% for outdoor applications, see Fig. 1.

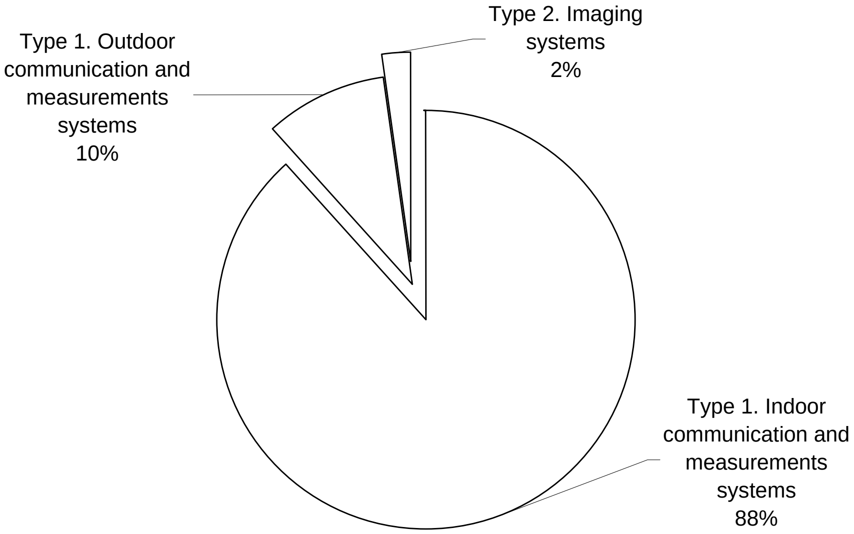


Figure 1: UWB unit types in percentage of total market volume

Notes:

- Type 3 UWB devices are not covered in this report.
- The recent claims by some cellular communication industries of their plans to integrate UWB data interface into mobile terminals might change the aforementioned proportion of type 1 devices between indoor and outdoor applications.

2.1 UWB operating frequency bands

Operating frequency bands of the UWB devices should be finally derived by CEPT, however UWB industry (driven by initial FCC regulations) is looking for intended emissions in frequency bands 0-960 MHz (for most of Type 2 systems), 3.1-10.6 GHz (for most of Type 1 systems) and above 20 GHz (for UWB automotive radars applications).

2.2 Geographic positioning and distribution of UWB devices

Geographic distribution of UWB emissions in a given territory would vary according to the specific type of UWB application concerned and will depend on market penetration. Three macro-subdivision scenarios have been identified for this study.

2.2.1 Random distribution

In this category, UWB systems used for consumer applications indoor (e.g. home entertainment and networking), and outdoor (e.g. cellular phones' data interface) were considered randomly scattered (i.e. without possible detailed prediction) on the territory or within buildings in urban areas.

This distribution scenario was used where the evaluation of co-existence was made as a probabilistic function of the density/km^2.

2.2.2 Deployment hot-spots

Hot-spot deployment scenarios have been used to model situations where:

1) UWB devices are deployed in large quantities in a limited and well defined area;
2) Victim receiver is a "fixed" (or similar) application positioned nearby the UWB "hot-spot".

Regarding the aggregate peak power, assumption was made that all UWB defices affecting a victim receiver are transmitting time-independently in bursts and no one is dominant, them the peak aggregation of N samples within a specified time window may still be considered a random phenomenon, thus following a power aggregation law ($10*\log N$).

One identified UWB applications example in this category are high speed data communication devices for LAN in commercial/industrial indoor applications. In densely populated sub-urban areas, the highest buildings are typically owned by large companies for their headquarters; these companies could select to implement UWB high-speed communication networks among large number of employees as cheaper alternative to wired LAN. In addition, according to modern architecture trends, such buildings often have glass walls and large open-space work places that would give small indoor-to-outdoor attenuation, therefore these buildings would potentially generate high aggregate interference to radiocommunications services operating nearby (e.g. to Fixed Wireless Access (FWA) or GSM/UMTS systems, whose base stations are likely to be located on the roof of such building).

2.2.3 Minimum UWB device separation distance from a potential victim receiver

Besides the aggregate interference from UWB devices in a significant area around the potential victim receiver, many applications (mainly, but not limited to: mobile terminals, computers' peripherals and Earth Stations) may be affected by interference from closely located single UWB device (e.g. device placed on the same desk or office or even within the same computer).

In these cases the study would consider the "minimum separation distance" of an UWB device versus its e.i.r.p. density.

3 TECHNICAL CHARACTERISTICS OF UWB SYSTEMS

The first UWB modulation schemes to be developed were based on the emission of short impulses, derived from radar technology. When the impulses are very short, they have a widely spread spectral characteristics determined by the shape of the pulses, with superimposed spectral lines for the pulse repetition frequency.

UWB systems suitable for short range communications are still in an early phase of market and technology development, but the industry is focusing on modulation schemes that reduce or eliminate spectral lines, e.g. by using very high Pulse Repetition Frequencies (PRF), dithering of the PRF, use of bipolar pulses (DS-UWB), or with non-impulse modulation (OFDM). The objective of these efforts is to achieve that the spectral characteristics of UWB devices are perceived by the receivers of victim radiocommunications services as very similar to bursts of AWGN. By defining average Power Spectral Density (PSD), Peak-PSD and associated measurement procedures it will be possible to ensure that the assumption of AWGN is applicable for all the potential victim service receivers that are currently deployed in the spectral range under consideration for "generic mass deployed UWB".

Further detailed analysis may be required to consider the technical characteristic of actual UWB devices, this would be included in a separate report.

4 POTENTIAL VICTIM RADIOCOMMUNICATIONS SERVICES AND SYSTEMS

4.1 Radiocommunications services and systems considered in this report

Several radiocommunications services and systems were selected to be considered in this study as given below:

1. Fixed Service (FS);
2. Mobile Satellite Service (MSS);
3. Earth Exploration Satellite Service (EESS);
4. Radio Astronomy Service (RAS);
5. Digital video broadcasting: DVB–T;
6. Digital audio broadcasting: T–DAB;
7. Bluetooth PAN;
8. Radio LAN;
9. Public Land Mobile Service (MS): IMT-2000;
10. Radio Navigation Satellite Service (RNSS);
11. Fixed Satellite Service (FSS);
12. Amateur/Amateur Satellite Services (Amateur) ;
13. Maritime mobile service (Maritime), including Global Maritime Distress & Safety Systems (GMDSS);
14. Aeronautical Mobile Service and radio determination service (Aeronautical, AMS, ARNS);
15. Meteorological Radars.

4.2 Possible impact of UWB systems on radiocommunications services

Depending on the UWB application and its typical deployment, different existing or planned radiocommunications services may be affected, depending on their technical characteristics and operational conditions.

The key issue in all considerations with respect to the co-existence between UWB communications devices and existing and planned radiocommunications services is the fact that UWB communications devices are mainly expected to be operated on a license exempt basis. Thus no control over deployment in terms of siting and density of devices is possible.

In the assessment of interference from UWB devices into existing or planned radiocommunications services, different interference scenarios may be distinguished:

- Receivers operating with high gain antennas, where interference may appear over long distances along the boresight of the antenna (e. g. FS Point-to-Point (PP) and FWA terminals, FSS Earth Stations, RAS stations, ARNS, etc);
- Receiver operating with sectorial or omni-directional antennas located well above the local clutter (e.g. MS base stations, FS FWA central stations, etc.);
- User premises' equipment operated in close vicinity to UWB devices (Mobile terminals, Radio and TV broadcasting, etc.);
- Receivers exposed to interference from extensive areas (e. g. GSO and NGSO Space station receivers).

It is vital for all existing and planned radiocommunications services that the impact of emissions from UWB devices on the victim receiver be maintained at a level, which does not jeopardise at all the operation of the concerned services. Since the interference from UWB devices may appear as an increase of the background noise, the tolerable interference levels for the several radiocommunications services needed to be defined very carefully. Depending on its dimension, an increase of background noise at the receiver always leads to a decrease of quality of service to a certain degree, in terms of:

- loss of capacity,
- loss of coverage,
- loss of link availability.

Any significant impact by UWB devices on the existing operating conditions of all other radiocommunications services is totally unacceptable and must be avoided to the greatest extent possible.

4.3 Disturbance effects of UWB

Interference generally not only results from an increasing noise energy, but also from changes of the statistical properties of the interference signal inside the victim receiver.

Theoretical studies of UWB devices, based on pulse position modulation and on multi-band OFDM modulation, were performed to examine these effects and the results can be summarised as follows:

- AWGN-interference assumption is valid for the following cases (for continuous transmission for pulse-based and MB-OFDM without FH):

- A sufficient number of non-synchronised UWB interferers disturbs one victim (e.g. for a satellite-scenario). This is independent of the type of UWB device;
- For pulse-based UWB devices with PRF dithering:
  - for victims employing single carrier QAM without spreading and channel coding, when the ratio of the victim receiver bandwidth *Bv* and the PRF of interfering UWB devices is lower than 1 (*Bv/PRF*<1, corresponding to *PRF>Bv*);
  - for OFDM- or CDMA-victims, UWB devices will still appear as AWGN if the PRF is reduced by a factor *k*: *PRF>Bv/k*, for OFDM- victims *k* corresponds to the number of sub-carriers and for CDMA *k* corresponds to the spreading factor;
- MB-OFDM UWB without FH.

Note: the studies did not cover the OFDM UWB with FH.

- The AWGN-interference assumption leads to an underestimation of disturbances from pulse-based UWB for the following cases:
  - *Bv/PRF≥1* (i.e. *PRF≤Bv*): a correction is necessary e.g. Band Width Correction Factor (BWCF) described in chapter 6.3.3;
  - *Bv/PRF<1* without dithering: the victim sees white noise (AWGN-assumption is valid) or a continuous wave interferer. This CW-case can produce very strong disturbances dependent on the ratio *Bv/PRF* and the type of victim. In this case the disturbance effect in the victim receiver is independent of the receiver bandwidth (e.g. a victim with 1 kHz bandwidth will receive the same disturbance like a receiver with 1 MHz bandwidth). Therefore, to take into account this effect, the studies should always be carried out with the bandwidth of the victim receiver.

The consideration of such special disturbance effects of UWB signals, which can reach to an underestimation of disturbance effects when using the AWGN assumption, was necessary in this report. Generally there are two different possibilities to realise this:

- Conduct measurements to check the validity of the AWGN protection criteria (*C/I* or *I/N*) for every victim against UWB systems.
- Consider all three UWB disturbance cases in each study: AWGN-like (no correction), CW-like and pulse-like (correction by BWCF described in chapter 6.3.3).

Most of the studies in this report are based on the assumption of AWGN-like UWB interference (e.g. for EESS, RAS, and IMT-2000 victims), in some studies measurements were performed to establish special protection criteria (separation distances) for UWB interferer (e.g. for FS, RLAN, and DVB-T victims), other studies have used the corrections by BWCFs as set by NTIA (e.g. for MSS, and FSS victims).

Validity of the compatibility studies, which were based on AWGN-assumptions without corrections and not on measurements, is limited to the following cases:

- Scenarios with a sufficient number of interferer (in the order of 100 or more),
- Pulse-based UWB transmissions with a PRF-range of *PRF>(Bv/k)* (*k*= Spreading Factor for CDMA-victims and k=number of sub-carriers for OFDM-victims, *k*=1 for QAM-victims; to avoid continuous wave interferences for victims with a bandwidth lower then 1 MHz it is necessary to do the calculations with the victim bandwidth), and
- MB-OFDM (measurement of average power without Frequency Hopping).

4.4 Generic power spectral density (r.m.s.) limits for a single UWB interferer

New UWB applications will lead to usage scenarios where UWB devices may operate close to victim receivers of existing radiocommunications services. As an example, UWB devices and victim receivers may be used in the same room.

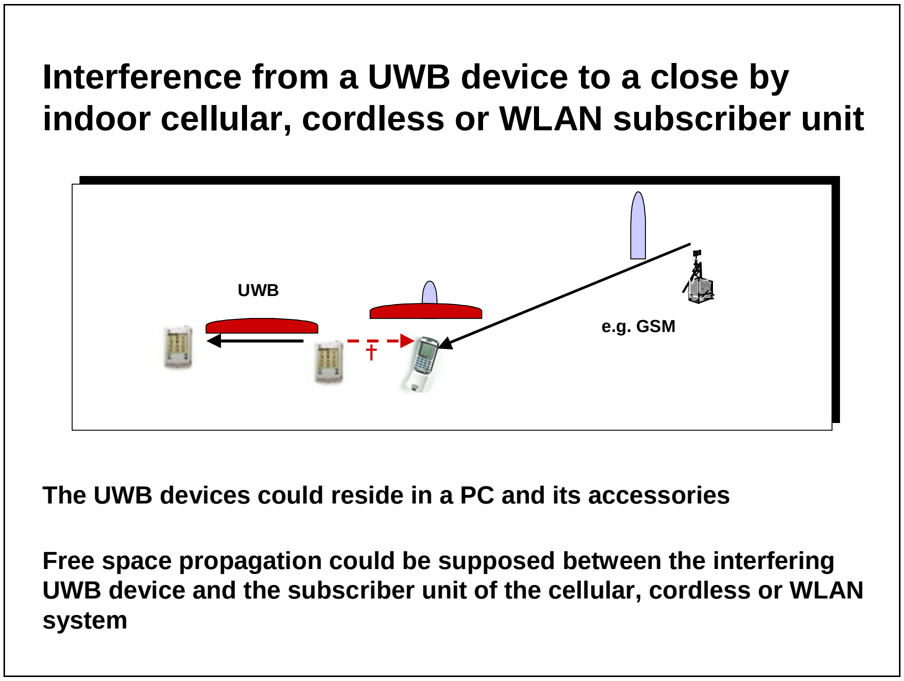
Therefore very small separation distances should be considered between UWB transmitters and victim receivers of other services. Separation distances of *r*=20 cm and 1 m are considered in the first example of this section.

A second example is when UWB device operates close to the building where there is a fixed installation of radiocommunications station that might operate with high gain antennas (e.g. MS base station or FS terminal receiver).

4.4.1 Case of victim receiver close to UWB emission

At short distances (up to 5 m), the Line-of-Sight (LoS) conditions and free space propagation path loss will be experienced. In the first scenario considered here, both the interfering UWB transmitters and the victim receiver operate indoors.

In this case, the number of UWB transmitters that couple to victim receiver with the assumption of free space path loss is considered to be small, since this assumption would be limited to UWB transmitters being in the same room as the victim receiver. In such a scenario, one can assume that the strongest UWB interferer at the distance of 20 cm (or 1m) to the victim receiver will dominate over all other UWB interferers (see Fig. 2). Therefore, this case does not consider the aggregate interference from multiple UWB transmitters. The UWB devices could reside in a PC and its accessories, and the victims could be indoor subscriber units belonging to a cellular, cordless or WLAN system.



Interference from a UWB device to a close by indoor cellular, cordless or WLAN subscriber unit

The UWB devices could reside in a PC and its accessories

Free space propagation could be supposed between the interfering UWB device and the subscriber unit of the cellular, cordless or WLAN system

Figure 2: Example of a single UWB device interfering with an indoor wireless subscriber unit

The link degradation caused to the existing systems (within their allocated bands) by such a nearby new UWB transmitter has to be small. UWB interference will add to the receiver noise floor $N_{receiver}$, which has impact on the link budget and on the capacity of the existing system. The link budget degrades by a factor that is equal to the interference ratio with and without UWB interference I_{UWB}:

$$\frac{I_{UWB} + N_{receiver}}{N_{receiver}} = \frac{I_{UWB}}{N_{receiver}} + 1$$

This interference ratio is called UWB noise rise, whereas the term $I_{UWB}/N_{receiver}$ is called UWB I/N ratio. Both are independent of the considered bandwidth. Therefore, I_{UWB} and $N_{receiver}$ may be specified with respect to any arbitrary bandwidth. Here a generic reference bandwidth of 1 MHz was chosen.

Fig. 3 depicts the relation between the UWB noise rise and I_{UWB}/N ratio, both measured in dB.

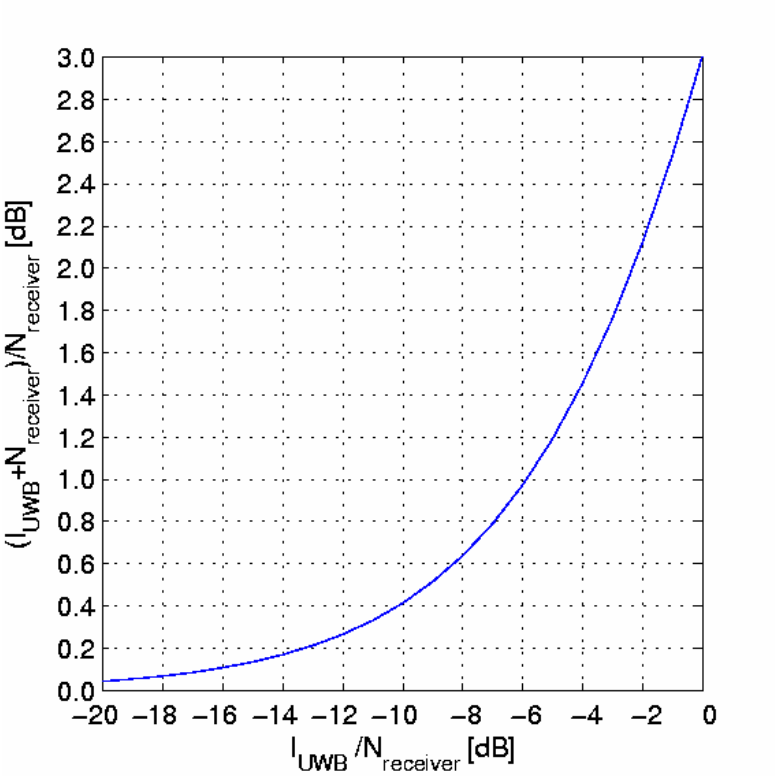


Figure 3: UWB noise rise versus $I_{UWB}/N_{receiver}$ ratio

Fig. 3 illustrates the following:

- If $I_{UWB} << N_{receiver}$, there will be no impact on the victim (e.g. cellular) system;
- $I_{UWB} \geq N_{receiver}$, there will be severe impact on the victim (e.g. cellular) system link budget.

For example:

- $I_{UWB} = N_{receiver}$ will give 3 dB link budget degradation and
- $I_{UWB} = (N_{receiver}$ -6 dB) will give 1 dB link budget degradation.

Potential interference that could cause 1-3 dB link budget degradation in some cases are regarded as harmful, since this could imply loss of coverage within large parts of a cell. A potential link budget degradation of 1 dB might be acceptable if it affects only a very small fraction of the victim receivers. The larger the fraction of victim receivers that experience a certain link budget degradation, the smaller should be this degradation.

Therefore, the calculations performed here for 1 dB and 3 dB degradation are only examples. The actual protection requirements are defined in the system-specific annexes.

The case of 3 dB degradation is considered to be particular because the equality of UWB interference and receiver noise allows translating the results easily to smaller degradations, using figure 3.

The receiver noise $N_{receiver}$ in dBm/MHz is the sum of the thermal noise $N_{thermal}$ and the noise factor F.

Thermal noise level: $N_{thermal}$ = -114 [dBm/MHz]

Receiver noise level [dBm/MHz]: $N_{receiver}$ = -114 + Receiver Noise Factor

The calculations were made for a technology independent generic portable victim device, where the radiocommunications receiver has a noise factor of 9 dB as a typical value. For very low cost receivers, the noise factor may be a few dB higher. For more expensive receivers, e.g. base stations of radiocommunications networks, the receiver noise factor is smaller, typically 5dB. Thus:

$N_{receiver}$ for base stations:	Typically -109 [dBm/MHz]
$N_{receiver}$ for portable terminals:	Typically -105 [dBm/MHz]

From this receiver noise and the tolerated UWB I/N ratio, the tolerable interference I_{UWB} at the victim receiver can be calculated. The tolerable power spectral density (PSD) P_{UWB} at the UWB transmitter at a distance r to the victim receiver can then be calculated from I_{UWB} assuming free space propagation path loss L:

- $P_{UWB} = N_{thermal} + F + (I_{UWB}/N) - L$ [all in dB];
- L[dB]=$20\cdot\log_{10}(\lambda/4\pi) - 20\cdot\log_{10}(r$[m]).

4.4.2 Case of fixed victim receiver with high antenna gain placed near the location of UWB emission

In this case the same considerations as described in § 4.4.1 apply, but they should be extended to consider the additional propagation losses (e.g. indoor-to-outdoor) and the antenna gain and directivity of the victim receiver.

5 VICTIM RECEIVER CHARACTERISTICS

For each of the selected victim applications referenced in chapter 4.1, the following receiver characteristics might be necessary for the co-existence studies and are provided in relevant Annexes 1-15:

- Receiver Sensivity;
- Co-Chanel Rejection;
- Victim receiver bandwidth;
- Acceptable interference criteria (e.g. *I/N* or *C/I*);
- Receiver Antenna characteristics.

The following receiver charactecrics were considered not relevant in this study:

- Spurious Response Rejection;
- Inter Modulation Response Rejection;
- Blocking and Desensitization.

It was considered that the co-channel interference will be predominant for this study.

5.1 Receiver modelling

5.1.1 Receiver susceptibility

Receivers are designed to respond to certain types of electromagnetic signals within a predetermined frequency band. However, receivers also respond to undesired signals having various modulation and frequency characteristics. For the purpose of this report, potentially interfering signals were considered to be co-channel interference from UWB signals emitted within the victim receiver's pass-band. For specific (sensitive) systems, it might be then necessary to consider the spurious response rejection, the receiver front-end desensitisation and the receiver intermodulation at a later stage.

In general two kinds of receivers might be envisaged from the point of view of their susceptibility to interference:

- receivers for communications systems, where real-time data are transmitted:
  - In this case the reduction of receiver's useable signal level range by the increase of noise power due to UWB (r.m.s.) emissions will impair potential victim systems' performance (e.g. the covered cell area of GSM/UMTS or FWA base stations) particularly in adverse propagation periods. In addition, the possible very high peak factor of UWB devices might instantaneosly exceed the acceptable interference level causing e.g. high-error-rate bursts. The latter effect could manifest in victim receivers having wide bandwidth;
- receivers for other purposes, where, in most cases, real-time signals are received from either naturally occurring phenomena or from man-made or man-induced processes:
  - in this case the reduction of receiver's useable signal level range by the increase of noise power due to UWB (r.m.s.) emissions will impair potential victim system's performance (e.g. sensitivity of RAS radio telescope) particularly in adverse propagation periods. In addition the possible very high peak factor of UWB devices might instantaneously exceed the acceptable interference level causing e.g. false artefacts in the collected datasets which are difficult toidentify and remove.

5.1.2 Antennas

Since a large variety of radiocommunications services need to be considered with both omni-directional and highly directive antennas, appropriate antenna models need to be applied. In order to avoid interference through the main beam of receiving antennas as well as through the side lobes, the peak envelope models need to be applied. Several ITU-R Recommendations and ETSI ENs provide typical antenna pattern for different radiocommunications services over a wide range of frequency bands, e.g.:

- FS P-P applications: ITU-R Rec. F.699, Note 1;
- FSS: ITU-R Rec. F.465;
- FWA: ITU-R Rec. F.1336 and EN 302 085.

Note 1: the pattern was accepted from ITU-R F.699. It has been noted that side-lobe radiation pattern given in ITU-R Recommendation F.1245 might have been formally more appropriate in some cases; however, it was shown that the aggregation result is dominated by the main lobe contribution, which is exactly the same in both Recs. F.699 and F.1245. Therefore, the final evaluation has been carried out using an originally proposed ITU-R Rec. F.699.

Horizontal as well as vertical components of the antenna pattern need to be taken into consideration in the case of directive antennas. In the case of short distances between interfering transmitter and victim receiver, the near-/far-field considerations may be necessary as well.

5.1.3 Receiver characteristics

The detailed receiver characteristics for the potential victim services or systems considered in this report are described in Annexes 1-15.

5.2 Sharing criteria and interference objectives

For all victim services and systems considered in this report, depending on their network structure and operational requirements, different sharing criteria apply that in turn leads to specific interference objectives.
In some cases these may be found in a relevant ITU-R recommendation, in other cases they had to be derived in these studies and reported here.
The detailed sharing criteria and interference objectives for the considered victim services or systems are also described in Annexes 1-15.

6 INTERFERENCE SCENARIOS FOR CO-EXISTENCE STUDIES

Depending on the deployment pattern of both potential victim system and UWB applications, different scenarios might be needed to describe the worst-case interference.
The general assumptions for the co-existence studies are defined in section 6.3.2 and detailed interference scenarios are also described in Annexes 1-15 for each service or system considered.

6.1 Propagation prediction methods for UWB co-existence studies

6.1.1 Background

The characterization of UWB signal propagation channels is fundamental for the determination of received UWB signals, in order to be able to define the UWB system link budget and coverage distances that might be necessary to appropriately perform the co-existence studies. Thus, one of the key issues in any interference assessment is the determination of propagation loss between an interfering transmitter and its intended (own) receiver, as well as to the victim receiver.
In the context of UWB systems, one has to take into account the large bandwidth of the signal. Indeed, narrowband studies and measurements may not adequately reflect the special bandwidth-dependent effects associated with propagation of UWB signals. Specifically, as the bandwidth of the channel probing signal increases, a composite narrow bandwidth propagation channel may be transformed into distinguishable large bandwidth propagation channels with distinct propagation delays. This corresponds to characterizing the channel transfer function over a broader frequency range.
The goal of selecting appropriate UWB propagation channel models is to capture both the path loss and multipath characteristics of typical environments where UWB devices are expected to operate. The existence of multipath propagation with different time delays and amplitudes gives rise to complex spatial and time varying transmission channels that place limitation on the performance of wireless systems. Nevertheless, the very fine time resolution of UWB signals allows resolving multipath components down to differential delays on the order of tenths of a nanosecond when using an appropriate UWB receiver, thus significantly reducing or eliminating fading effects in relatively dense multipath environment.
Measurements have demonstrated the robustness of UWB signal transmissions in multipath environments with received signal varying by less than 5 dB when received by a UWB receiver compared to narrow band systems, where received signal can vary in excess of 20-30 dB. In fact, radio signal energy, be it a time-harmonic waveform or a sequence of short impulse wavelets, propagates by simple spherical wave expansion (“free space propagation”) yielding the familiar square law, i.e. $\gamma=2$ propagation index. For analyses involving terrestrial or in-door path loss, calculation of the energy can be additionally shed or time-dispersed into multipath, which would impose a further attenuation phenomenon which then can raise the propagation index to approximately $\gamma=3$ or greater.
A UWB impulse receiver is capable of resolving short-wavelet signals differently than a narrow band receiver; the UWB receiver can more readily recover the time-dispersed energy using either rake gain or sampling techniques. It

can be shown[2] that a theoretically ideal rake gain can recover multipath energy and apparently reduce the effective propagation index to approach the free space value. Narrow band victim receivers can not do this either when receiving interfering UWB impulses or when receiving their useful narrow band signals. Consequently the compatibility scenarios involving narrow band victim receivers should be governed by narrow band propagation phenomena, even for UWB interfering signals, and the relevant propagation index is approximately γ=3 or greater in multipath.

Therefore, the receiver bandwidth is a part of the complete propagation modelling for UWB signals. The effect can manifest itself as a difference in the apparent propagation exponent. Thus, appropriate propagation exponents consistent with the path between a UWB transmitter and a narrowband receiver should be used in compatibility studies.

6.1.2 Radio Channel Modeling

A radiocommunications channel is a complex mathematical attempt to describe the propagation phenomena trough air and physical obstacles, including people. The model described by the term “radio-mobile channel” has to physically represent the sum of all the effects of loss and distortion that signals suffer during their propagation from a transmitter to a receiver. In the case of studies of UWB co-existence with other services, this study was interested in knowing how the UWB signals will propagate through air and how this might affect the link budget of other systems. The main effects that a radio wave encounters during its propagation can be divided in:

- **long-term (median) path loss** characteristics: describe the mean signal strength as a function of the distance at a given frequency. The loss is gradual with received power decreasing almost as an exponential decay in logarithmic scale;
- **medium-term (shadowing, slow fading)** characteristics: show the time- and place-varying factors, such as shadowing from buildings or similar big obstacles and is represented as a random fluctuation with a log-normal distribution, with a standard deviation dependent on propagation conditions;
- **short-term (multi-path, fast fading)** characteristics: describe the sudden variations of the received signal strength due to multi-path propagation phenomena and reflections coming from particularly moving objects.

In real life conditions these three effects will apply cumulatively and are not easily discernible in normal conditions.

A classical way to represent the propagation phenomena independently from the transmitter and receiver characteristics is to give an appropriate definition of the channel impulse response *h(t)* between a source signal *x(t)* and a received signal *y(t).* The channel is represented by multiple paths having real positive gain $\{E_i\}$ and propagation delays $\{\tau_i\}$ where *i* is the path index. The channel impulse response is given by:

$$h(t)=\sum_{i=1}^{N}E_i(t)\cdot\delta(t-\tau_i(t))$$

where $\delta(\cdot)$ is the Dirac delta function.

The channel impulse response is therefore described as the sum of *N* scattered $E_i(t)$ signals arriving at the receiver with different time delay (with *N* typically considered between 6 and 20). Each scatter will be in itself the summation of numerous partial waves. Thus, each single scattered E_i is the result of the sum of N_{waves} (theoretically infinite, but in typical simulation models limited to 100) each characterized by amplitude a_i, phase φ_i, angle of incidence α_i (relative to the movement vector of the user):

$$E_{iFF}(t)=\sum_{k=0}^{Nwaves}a_{ik}(t)\cdot e^{j(\varphi_{ik}+\frac{2\cdot\pi}{\lambda}\cdot v\cdot t\cdot\cos\alpha_{ik})}$$

The summation of these N_{waves} partial waves is at each instant a good representation of the short term characteristics. But added on top of these fast fading effects, one should also consider the long and medium term variation in the signal strength at a given distance, represented by the attenuation At_i (including path loss and shadowing) of each single scatter:

$$E_i(t)=At_i(t)\cdot E_{iFF}(t)$$

The simple analysis often used in coexistence studies limit the propagation characteristics to the long-term average (path loss) of the signal loss at given distances. In mathematical terms, the mean received power, around which there will still be shadowing and multipath, will vary with distance with an exponential law. The total loss *PL(d)* at a distance *d* is generally given by:

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[2] K. Siwiak, “UWB Propagation Phenomena” (Online): http://grouper.ieee.org/groups/802/15/pub/2002/Jul02/02301r3P802-15_SG3a-UWB-Propagation-Phenomena.ppt

$$PL(d) = PL_o + 10n\log_{10}(\frac{d}{d_0})$$

where PL_0, the intercept point, is the path loss at distance d_0 and defined similarly to free space propagation:

$$PL_0 = 20\log\left(\frac{4\pi f_c d_0}{c}\right) \text{ and } f_c = \sqrt{f_{\min} f_{\max}} .$$

where f_c is the geometric centre frequency of UWB waveform with f_{min} and f_{max} being the (-10) dB edges of the waveform spectrum. The parameter n is the important path loss exponent.

6.1.3 Propagation models for assessing compatibility of UWB devices with conventional (relatively narrow band) receivers

The particular propagation model used for each system-specific study in this report is quoted in the summary tables in chapter 7.

The co-existence and compatibility scenarios involving UWB signals is invariably one where the potential 'victims' are narrow band receivers. In that case, theconsidered physics of the propagation path are the same as if involving only narrow band signals, as already mentioned in section 6.1.1.

Multiple reflections and diffractions in the propagation environment result in a channel impulse response (CIR) comprising many signal echoes that are closely spaced. These closely spaced paths are the same for impulses as they are for narrow band signals since they depend only on the physical geometry of the environment. The paths can only be resolved by a UWB receiver. A narrow band receiver inevitably 'rings' for a period commensurate with the reciprocal of its bandwidth for each received impulse in CIR. That ringing time (microseconds for sub-MHz bandwidths) stretches nanosecond UWB pulses so that the closely spaced multipath echoes of pulses constructively and destructively combine in the narrow band receiver just like narrow band signals combine. This fact matters greatly in the consideration of how a 'victim' receiver is impacted by a UWB signal as the victim receiver:

measures only the UWB energy in its narrow bandwidth, and stretches impulses to a time length commensurate with the reciprocal of its bandwidth.

Thus, narrow band propagation models traditionally used for narrow band signals are also sufficient for studying UWB compatibility scenarios involving narrow band receivers.

The ITU-R P-Series recommendations cover a broad frequency range, including the considered frequency bands for UWB devices. Therefore it was assumed that for assessing the interference from UWB devices via linear media into conventional, i.e. relatively narrowband receivers the following ITU-R P Recommendations could be used, within their range of applicability:

- Recommendation ITU-R P.525 provides for Free-Space attenuation;
- Recommendation ITU-R P.528 provides propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF, and SHF bands;
- Recommendation ITU-R P.618 provides propagation data and prediction methods for Earth-space links;
- Recommendation ITU-R P.1238 provides propagation information relating to short paths specifically for indoor situations, in the frequency range from about 900 MHz to 100 GHz;
- Recommendation ITU-R P.1411 provides propagation methods for short paths in outdoor situations, in the frequency range from about 300 MHz to 100 GHz. A subsection dealing with characteristics of direction of arrival of signals has been transferred to Recommendation ITU-R P.1407 where additional and more fundamental propagation information is given;
- Recommendation ITU-R P.452 describes the procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above 0.7 GHz;
- Recommendation ITU-R P.1546 provides the method for point-to-area predictions of field strength for terrestrial services in the frequency range 30 MHz to 3 GHz.

It should be pointed out that Recommendation ITU-R P.1546 provides the method for propagation path loss calculations at distances between 1 km and 1000 km. However, the application of this Recommendation has not been extended beyond 3 GHz which may not cover the frequency range intended for UWB emissions. Recommendation ITU-R P.1411 is intended for distances up to 1 km. Furthermore, concerning the applicability of ITU-R P.1411 to the FS-UWB study the following remarks have to be considered:

- The title of P.1411 defines its applicability "…for the planning of short-range outdoor radiocommunications systems and radio local area networks…". This means that this Recommendation is tailored for assessing the planning of similarly deployed systems (i.e. short-range and RLAN) and is not intended to be used to address propagation aspect of interfering path to other services, such as FS;

- ITU-R P.1411 and other similar ITU-R P-Series recommendations offer, in general, few experimental data for having an idea of the physics in models very close to the tested one; the data are valid to represent an *"average worst-case of attenuation"* that is useful to operators for defining the *"average minimum coverage"* for the short-range service to be deployed (i.e. to derive the required number of base stations). But for the inter-service sharing studies one needs an *"average better-case"* of the attenuation in order to define the *"average maximum interference"* expected. Therefore P.1411 could be only applied for adding the (negligible) contribution of signals from those UWB devices that are under Non-LoS (NLoS) conditions.
- ITU-R P.1411 is focused on *"less than 1 km"* propagation effects on similar "short-range" systems deployed in the same area. In UWB-FS study the aggregate interference on a potential FS victim might have a significant increment up to ~ 10 km and in completely different conditions.

6.1.4 Propagation models to assess co-existence of different UWB devices or to determine UWB link budget for general compatibility studies

An important aspect that is relevant for UWB studies, but not currently covered by the listed in §6.1.3 ITU-R P-Series recommendations is consideration of specific propagation models for UWB emissions. Such propagation models are required to assess co-existence between different UWB devices, not addressed for the moment, or for the determination of the UWB link budget necessary in several general compatibility studies.

A theoretical model for UWB signals in multi-path environment initially has a basic $1/d^2$ behaviour of spherical wave expansion, and then a further $1/d^{(\gamma-2)}$ behaviour beyond a breakpoint distance d_t due to shedding of energy to multi-path dispersion, yielding a total behaviour of $1/d^{\gamma}$. The resulting dual slope propagation model[3] is:

$$PL(d) = -10\log\{[c/4\pi d f_m]^2\,[1-\exp(-(d_t/d)^{\gamma-2})]\}$$

where:

f_m - the geometrical mean of the UWB signal frequency;
c - is the velocity of propagation.

Suitable values of index $\gamma>2$ with $d_t= 1$ are discussed below and given in Table 1. The formula, with $d_t=h_1h_2 4\pi f_m/c$ and $\gamma= 4$, is also useful in a two-ray path model between antennas h_1 and h_2 meters above a plane earth, when the shape of the UWB wavelet is not specified[4]. That is, it approaches the free space asymptote before the breakpoint and the 20 $\log(h_1h_2/d^2)$ asymptote beyond the breakpoint. The next Figure 4 demonstrates an example of the dual slope model with f_m=4.7 GHz, and with γ=3 beyond the breakpoint distance of d_t =3 m.

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[3] K. Siwiak, H. L. Bretoni and S. M. Yano, "Relation between multipath and wave propagation attenuation", Electronic Letters, Vol. 39, No 1, Jan. 9, 2003, pp. 142-143

[4] K. Siwiak and D. McKeown, "Ultra-Wideband Radio Technology, UK: Wiley Publications, April 2004

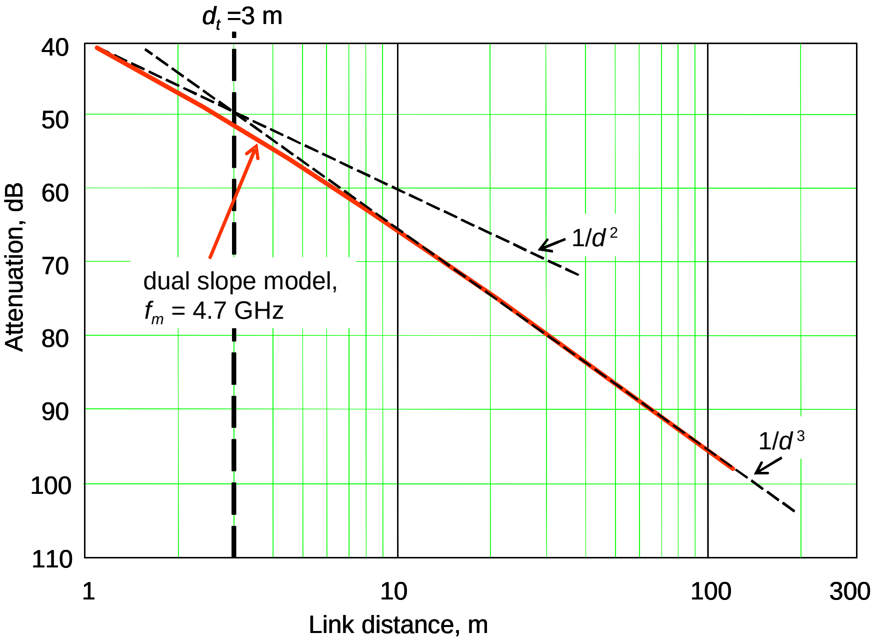

Figure 4: A theoretical UWB propagation model in multi-path environment

If all of the energy in the CIR were to be coherently collected, the resulting effect would be to nearly nullify the additional $1/d$ effect of multi-path. In other words, if a perfect rake receiver could be built, its apparent effect would be to exhibit a gain that would make the propagation path appear similar to a free space path. This is one of the benefits of a UWB system: namely, that multi-path propagation can be resolved by a UWB receiver, and with sufficient effort, an effective rake receiver could be constructed. Measurements have demonstrated the robustness of UWB signal transmissions in multi-path environments with the signal varying by less than a few dB when received by UWB receivers.

Due to the recent developments of UWB systems, many studies in the field of UWB propagation have been done and extensive measurement campaigns between 1 and 10 GHz have been performed, both in the USA and Europe, for different indoor and outdoor environments. Depending on the studies, different situations were considered that could be classified between LoS and NLoS. It should be noted that a LoS path between the transmitter and the receiver seldom exists in indoor environments, because of natural or man-made blocking, and one must rely on the signal arriving via multipath. In this context, different definitions of indoor NLoS have been applied depending on the studies, i.e. NLoS or Soft-NLoS and Hard-NLoS or NLoS^2. In fact, the differentiation is made between NLoS, e.g. standard obstacle (at least one plasterboard) and hard-NLOS, e.g. large number of obstacles or at least one concrete wall. An overview and comparison of these different UWB propagation studies[5] and consideration of the comments given by the authors in the case of certain experiments[6], allow proposing adequate basic UWB transmission loss in the following traditional form:

$$PL(d) = PL_0(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad \text{(dB)}$$

where: $PL_0(d_0)$ is the path loss at the reference distance d_0;

n is the path loss exponent;

X_σ is the lognormal shadow fading, i.e. a zero-mean Gaussian random variable in dB with standard deviation σ.

Path loss is traditionally understood to be frequency dependent. With narrowband systems the change in received power over the signal bandwidth is usually ignored as it has little effect. However, UWB signals can occupy octave or even decade bandwidths so the frequency dependency could have a considerable effect in the case of UWB

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[5] ITU-R Documents 1-8/6-E, 3K/5-E, 3M/4-E, 10 October 2003

[6] CEPT WG SE24, Documents M25_22 and M25_23, 29-31 March 2004

propagation. However, the frequency dependency in UWB propagation arises actually due to antenna impact rather than path loss itself[7]. Therefore, the traditional path loss model typically used in narrowband signals as given in the above equation can be used in modeling the path loss experienced by UWB signals.

It should be pointed out that depending on the studies, two kinds of path loss models have been proposed, i.e. single slope models corresponding to the previous formula and dual slope models also named "breakpoint" models where two equations are given, as shown previously in this section, one for the ranges below- and one for the range above a certain breakpoint distance d_{BP} (d_t). These two kinds of models show a more or less similar dependence on the path loss exponential factor considering the fact that in the breakpoint models the propagation before breakpoint is mostly assimilated to LoS situations and the propagation after breakpoint corresponds generally to NLoS situations or sometimes to Hard-NLoS for large breakpoint distance d_{BP}, e.g. $d_{BP} > 10$ m. Therefore, by differentiating between LoS, NLoS and Hard-NLoS situations, it is possible to compare the different studies and to give a unified formulation of the path loss equation in the form of the above single slope UWB path loss model.

The derived parameters for the UWB path loss equation are given in the table below for the different environments and specific situations. They are based on measurements and are suitable for distances of 15 m or less.

UWB Path Loss Model @ 1 – 10 GHz	$PL(d) = PL_0(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma$			
Environment	**Path Loss Exponent *n***	**Intercept $PL_0(d_0)$ [dB]**	**Ref. dist d_0 (d_t) [m]**	**Shadowing σ[dB]**
Indoor Residential				
LOS	~1.7	$20\log(4\pi f d_0/c)$	1	1.5
NLOS	3.5 – 5	$20\log(4\pi f d_0/c)$	1	2.7 – 4
Hard-NLOS	≥ 7	$20\log(4\pi f d_0/c)$	1	4
Indoor Office/Laboratory				
LOS	~1.5	$20\log(4\pi f d_0/c)$	1	0.3 – 4
NLOS	2.5 – 4	$20\log(4\pi f d_0/c)$	1	1.2 – 4
Hard-NLOS	4 – 7.5	$20\log(4\pi f d_0/c)$	1	≥ 4
Outdoor				
LOS	~2	$20\log(4\pi f d_0/c)$	1	0.5 – 1
NLOS	3 - 4	$20\log(4\pi f d_0/c)$	1	< 3

Table 1: General proposal for the propagation path loss modelling parameters for UWB-to-UWB cases

It should be noted that the UWB technology and measurement techniques used in the different studies are in some extent different from one experiment to another, thus leading to a certain variability of the results. In particular, different receiver structures lead to different values of path loss exponent *n* and standard deviation σ.

Nevertheless, the good agreement of the different studies concerning the path loss exponent *n* for LoS situations allows an almost precise definition of this important parameter. Furthermore, it is possible to determine the path loss exponent for NLoS situations within a reasonable value range in particular for indoor NLoS cases considering on the one side the high environment dependence of the determining parameters like geometry of the rooms, construction materials, characteristics of the obstacles, etc and on the other side the fact that the definitions of NLoS, Soft- or Hard-NLoS or NLoS^2 are slightly different from one experiment to another.

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[7] ITU-R Document 3K/30-E, 13 November 2003

6.1.5 UWB propagation models for compatibility studies between indoor UWB devices and space services

When the compatibility studies address indoor UWB devices and space services, an additional factor has to be added to the outdoor propagation loss to account for the building attenuation, depending on the frequency range.
An important aspect that is the building attenuation is frequency dependent according to the following Table 2.

Frequency range	Building attenuation in dB for space applications
Below 1 GHz (around 400 MHz)	5
L band (1.2-1.6 GHz	9
S band (2 GHz)	12
C band (5 GHz)	17
Around 10 GHz	17

Table 2: Building attenuations for compatibility analysis between indoor UWB devices and space services

The advantage of having this kind of generic building attenuation given in Table 2 is that it allows to avoid long calculations for each type of building. This additional provisional factor may be used for compatibility analysis with indoor UWB transmitters.
The values of the building attenuation for space applications in Table 2 were taken from various studies and reports from ITU-R and ERC/ECC. These values may also be used when appropriate for assessment of the average building attenuation in compatibility studies between indoor UWB devices and terrestrial victim receivers.

6.2 UWB Spectrum masks

The UWB radiated power densities considered for the interference scenarios in this report were derived from the following spectral masks, described thereafter:

- The -41.3 dBm/MHz flat limit
- "FCC mask" (indoor & outdoor)
- "Slope mask" (indoor & outdoor)

6.2.1 The -41.3 dBm/MHz flat limit

This limit corresponds to the average EIRP spectral density which is equivalent to the average field strength specified in Part 15 of the FCC's Rules for devices operating above 1 GHz (a field strength of 500 µV/m at a 3 m separation distance measured in a 1 MHz bandwidth). This limit was applied for UWB devices until the FCC released on 14th of February 2003 the new specific UWB mask limits that were approved on 22nd of April 2002 (see § 6.2.2).

6.2.2 FCC UWB emission limits

Different spectral masks depending on the type of application characterise the new UWB emission limits released by the FCC; these are the spectral masks for: Wall imaging & medical imaging systems, for Thru-wall imaging & surveillance systems and, finally, for communications and measurement systems (indoor and outdoor).
Although the interference potential from UWB imaging and surveillance systems are not to be underestimated, the following estimations will consider only the UWB communications and measurement systems since these last systems are expected to follow the strongest deployment and will represent about 98 % of the market. The spectral masks for communications and measurement systems are depicted below in Figures 5 and 6.

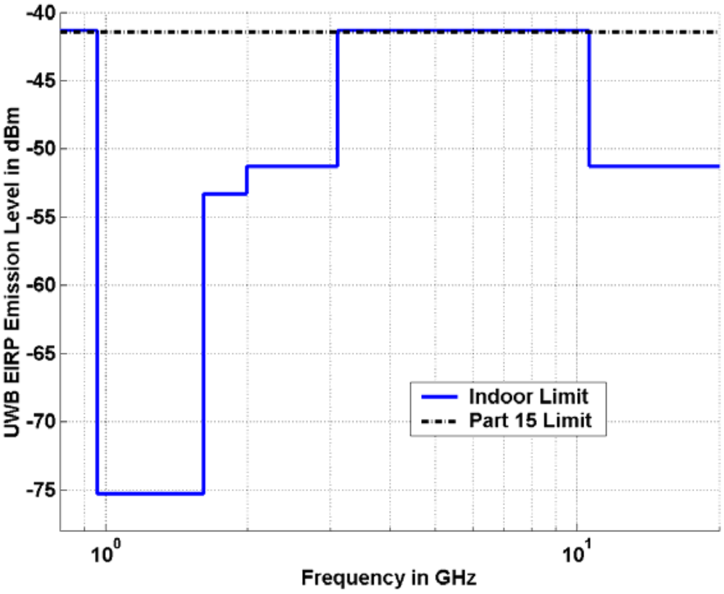


Figure 5: FCC UWB emissions limits measured in 1 MHz for indoor communications and measurement systems (units with centre frequencies greater than 3.1 GHz)

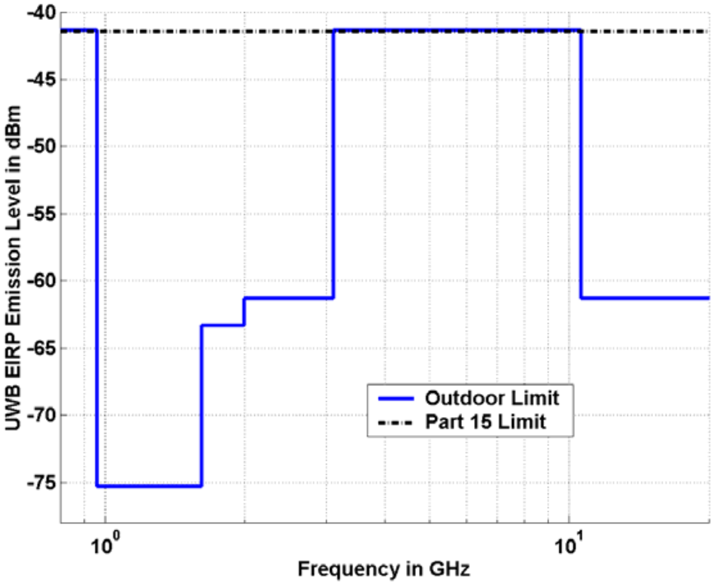


Figure 6: FCC UWB emissions limits measured in 1 MHz for outdoor communications and measurement handheld systems (units with centre frequencies greater than 3.1 GHz)

6.2.3 Slope mask interpolated from FCC mask

FCC issued a staircase spectrum mask limits for UWB radiated power density, as described in previous section. However UWB can not utilize the staircase mask fully and it was therefore proposed to consider also a slope mask in the compatibility studies. The advantage of this mask is:

a slope offers more interference protection to critical sensitive victim services operating below 3.1 GHz and above 10.6 GHz;

a slope itself does not reduce the performance of UWB products.

At low frequencies, an attenuation roll-off for the proposed mask meets FCCs requirement at 3.1 and 1.66 GHz with a radiated power density limits of –51.3 dBm/MHz and –75 dBm/MHz respectively.

At high frequencies the proposed spectrum mask meets FCCs requirement at 10.6 GHz with a radiated power density limit of –51.3 dBm/MHz. The roll-off factor at high frequencies mirrors the low frequency slope.

Two different spectrum masks for radiated power density were proposed for indoor and outdoor use respectively. The mask for outdoor use is 10 dB lower than the indoor mask.

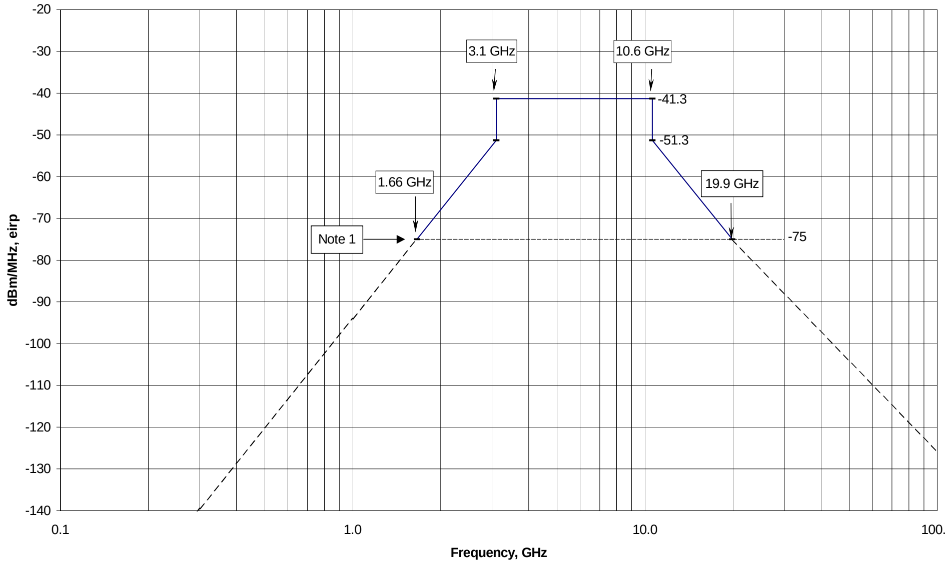
The proposed spectrum masks for indoor and outdoor use are defined in Table 3 below.

UWB type	**Frequency, GHz**		
	f < 3.1 GHz **dBm/MHz**	**3.1 GHz < f < 10.6 GHz** **dBm/MHz**	**f > 10.6 GHz** **dBm/MHz**
Type I (Indoor use)	–51.3 + 87 log (f/3.1)	–41.3 dBm/1 MHz	–51.3 + 87 log (10.6/f)
Type II (Outdoor use)	–61.3 + 87 log (f/3.1)	–41.3 dBm/1 MHz	–61.3 + 87 log (10.6/f)

Table 3: Maximum UWB band-edge mask for average power density

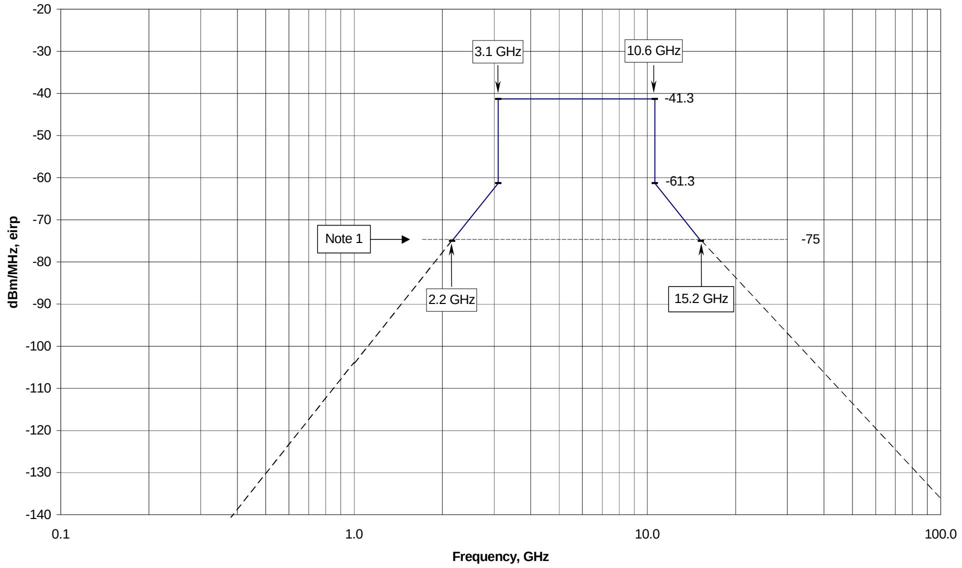
A graphical representation of the indoor and outdoor slope masks is shown in Figure 7 below. These slope masks are in logarithmic scale instead of linear scale.

a)



Note1: Current measurement technology prevents measurements below –75 dBm in a one MHz bandwi

b)



Note1: Current measurement technology prevents measurements below –75 dBm in a one MHz bandwidth.

Figure 7: Proposed UWB slope masks (a- indoor, b-outdoor)

<u>Note :</u> These masks were not taken into account in the conclusions of the report, but were used in certain parts of the study.

6.3 Methodology

6.3.1 Victim receiver categories

Different types of interference scenarios may be identified depending on the type of considered victim receiver.
It was however expected that many similarities can be found between the relevant methodologies and UWB deployment scenarios to be used for different general categories of victim receiver.
It was therefore proposed to distinguish 3 general categories of victim receivers as shown in Table 4.

Category	Description	Examples of victim receivers	Dominant interference scenarios
Category A	Mobile and portable stations	• Mobile handsets (GSM, DCS1800, IMT-2000, MSS, RNSS) • Portable broadcasting receiver (T-DAB, DVB-T) • RLAN • Indoor FWA terminal	Single-entry interference
Category B	Fixed outdoor stations	• FS stations (P-P, P-MP) • MS base stations (GSM, DCS1800, IMT-2000) • RAS station • Earth stations (FSS, MSS…) • Broadcasting fixed outdoor receiver • Radar station	Aggregate interference from surrounding UWB Single-entry interference
Category C	Satellite/aeronautical on –board receivers	• Satellite receivers (EESS, MSS, FSS…) • Aircraft stations	Aggregate interference from large scale area

Table 4: Categories of victim receivers

6.3.2 Reference UWB deployment scenarios

Reference deployment scenarios have been established in order to provide operational characteristics of UWB communication applications to be used in the compatibility studies.
These scenarios are primarily applicable to aggregate interference analysis and consider three main parameters:

- density of UWB devices (/km²);
- activity factor (average peak hour);
- % of outdoor operation.

The activity factor reflects the effective transmission time ratio. It does not take into account reduction factors such as TDD and pulse duty cycle.
The reference values were selected for completion of the compatibility studies, as assumed to reflect a combination of use of different types of generic UWB communications applications. In particular, a 5% activity factor was assumed as a reasonable worst case assumption when averaging over a large scale area.

Different values from the references shown in the Table 5 below (ref. NTIA Special Publication 01-43) may be derived, taking into account potential aggregation from other UWB applications, when focusing on a specific UWB application.

Reference deployment scenario	Relevant for categories B & C, aggregate analysis		
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km²)	100	1000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
% Outdoor	20%	20%	20%
Deployment scenario 2	Average large scale		
UWB penetration rate over the population	80%		
Activity factor	5 %		
Percentage of active UWB transmitters over the population	4%		
% Outdoor	20%		
Deployment scenario 2bis			
Density of active UWB transmitters (/km²)	0.5		

Note: scenario 2bis is proposed as an alternative approach where density of UWB transmitters is calculated on the basis of a maximum number of UWB devices deployed over a large scale area. Assuming a total of $2*10^9$ UWB devices over a 200 Mkm², the density of UWB transmitters would be 10 UWB/km²

Deployment scenario 3	Home/Office environment - average building, for outdoor aggregation (3a)	Home/Office environment - desk premises, for indoor aggregation (3b)
UWB density (per floor)	1 per 10 m²	2 per 10 m²
Activity factor	20 %	4% to 50%
Density of active UWB transmitters	0.2 per 10 m²	0.08 to 1 per 10 m²

Note: specific mitigation factors may be considered in the relevant compatibility studies addressing “hot spot” deployment scenarios in Home/Office environment to reflect particular approach

Table 5: Reference UWB deployment scenarios

These scenarios will be applicable depending on the type of victim receiver that is considered.
Deployment scenarios 1 or 3 will hence be typically applicable to ‘Category B’ receivers, whereas Scenario 2 will most likely only be applicable to ‘Category C’ receivers.
Deployment scenario 3b may also be applicable to ‘Category A’ victim receiver for aggregate or possibly probabilistic analysis.

6.3.3 Single interferer

6.3.3.1 MCL methodology

UWB devices are characterized by an extremely large bandwidth compared with traditional radiocommunications transceivers and therefore may interfere simultaneously with several radiocommunications services. One of the main questions to be answered in any interference consideration is the geographical separation distance that is necessary to reduce the interference to the tolerable level, which is acceptable for a certain service if co-frequency operation is considered.

The first step of the procedure used to estimate the protection distance is to calculate the Minimum Coupling Loss (MCL) based on the sensitivity S_{RX} and the *C/I* value of the victim receiver on the one side and the UWB radiated power density $P_{UWB\text{-}RAD}$ on the other side:

$$\text{MCL (dB)} = P_{\text{UWB-RAD}} + 10*\log B_{\text{RX}} - S_{\text{RX}} + C / I$$

where:

$P_{UWB\text{-}RAD}$ is the radiated power density inside the victim bandwidth (dBm/MHz);
B_{RX} is the victim receiver's selectivity filter bandwidth (MHz), i.e. the IF bandwidth B_{IF};
S_{RX} is the victim receiver sensitivity (dBm);
C/I is the measured carrier to interference ratio (dB).

The second step is then to convert the MCL into the protection distance by using an appropriate propagation model (see section 6.1).

6.3.3.2 Methodology to assess interference from a single UWB emitter based on I/N criteria

This section outlines the model for the calculation of the maximum allowed EIRP as a function of distance between the UWB device and the system receiver, following the analysis in *NTIA Special Publication 01-43* ("Assessment of compatibility between ultra-wideband devices and selected federal systems") and *NTIA Report 01-383* ("The temporal and spectral characteristics of ultra-wideband signals"). In addition, this section provides definitions of *dithered* and *non-dithered* UWB signals.

This methodology has been used to assess interference from a single UWB emitter into a feeder link Earth Station receiver and MES terminals, and partly in the case of IMT 2000.

Calculation of interfering level

The maximum acceptable interfering EIRP may be determined using the following simple equation:

$$EIRP_{MAX} = + I_{MAX} - BWCF - G_R(\theta) + L_P + L_R$$

where:

$EIRP_{MAX}$ - max permitted EIRP of the interfering device, in dBm/B_{REF} . B_{REF} is normally taken 1 MHz;
I_{MAX} - maximum permissible interference level at the receiver input, normalised in dBm/B_{REF};
$BWCF$ - correction factor for the power of the UWB signal in the victim receiver's IF bandwidth (B_{IF}) relative to the PRF of the UWB emission;
$G_R(\theta)$ - victim receiver antenna gain in the direction of the UWB device, dBi;
L_P - propagation loss between transmitting and receiving antennas, dB;
L_R - insertion loss between the receiver antenna and receiver input, dB.

The initial step in determining the maximum permitted EIRP level and required minimum separation distance to ensure compatibility, is to establish a maximum permissible interference level I_{MAX}, which requires identification of the protection criterion for the victim system. Generally the protection criteria are specified in terms of an average or peak interference to noise ratio (*I/N*).

$$I_{MAX} = I/N + N$$

where:

I/N maximum permissible average or peak interference-to-noise ratio at the receiver IF output necessary to maintain the acceptable performance criteria, dB;
N receiver's inherent noise level at the receiver IF output referred to the receiver input, dBm.

For a known receiver's IF bandwidth and system noise temperature, the receiver inherent noise level is given by

$$N = KT_SB_{IF} = -198.6 \text{ dBm/°K/Hz} + 10\log T_S(\text{K}) + 10\log B_{IF}(\text{Hz})$$

where :

B_{IF} - the receiver IF bandwidth;
K - Boltzmann's constant, $1.38\text{x}10^{-20}$, in milliwatts/K/Hz;
Ts - the system noise temperature, in degrees Kelvin.

The following assumptions were made in the compatibility analysis:

- UWB transmit and receive antennas are isotropic with unity gains (0 dBi);
- UWB devices transmit at defined power levels, e.i.r.p. per a measurement reference bandwidth (B_{REF}), and these powers accumulate in the victim receiver;

For UWB communications systems, it was assumed that no obstructions are present between transmitter and the victim receiver;

When the victim receiver has an IF bandwidth (B_{IF}) different from the reference measurement bandwidth of the EIRP of the UWB transmitter (B_{REF}), a bandwidth correction factor ($BWCF$) is considered to normalize the average (rms) power level in a 1 MHz bandwidth, and to provide a correction for the UWB signal average (rms) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output in dB. It was assumed that UWB transmitter emissions are uniform across the victim receiver bandwidth.

Definition of non-dithered and dithered signals

i) non-dithered UWB signals are defined as a series of identical pulses emitted at fixed time intervals between pulses (constant PRF);

ii) dithered UWB signals consist of identical, time-hopped pulses, emitted one pulse per time slot whose duration is 1/PRF, with randomly varying time intervals between pulses that are uniformly distributed over at least one half of the time slot duration period.

$\text{BWCF}_{A/P}$ for non-dithered UWB signals

For non-dithered UWB emissions, the $BWCF$ for average power, $BWCF_A$, in dB, is given by the following expressions, where PRF≥10 kHz:

$BWCF_A = 0$, for $B_{RX} \leq PRF$ and $B_{REF} < PRF$;
$\text{BWCF}_A = 10 \log (\text{PRF}/\text{B}_\text{REF})$, for $\text{B}_\text{RX} \leq \text{PRF}$ and $\text{B}_\text{REF} \geq \text{PRF}$;
$\text{BWCF}_A = 10 \log (\text{B}_\text{RX}/\text{PRF})$, for $\text{PRF} \leq \text{B}_\text{RX}$ and $\text{B}_\text{REF} < \text{PRF}$;
$\text{BWCF}_A = 10 \log (\text{B}_\text{RX}/\text{B}_\text{REF})$, for $\text{PRF} \leq \text{B}_\text{RX}$ and $\text{B}_\text{REF} \geq \text{PRF}$.

For non-dithered UWB emissions, the $BWCF$ for peak power, $BWCF_P$, in dB, is given by the following expressions:

$\text{BWCF}_P = 0$, for $\text{B}_\text{RX} \leq 0.45$ PRF and $\text{B}_\text{REF} < \text{PRF}$;
$\text{BWCF}_P = 10 \log (\text{PRF}/\text{B}_\text{REF})$, for $\text{B}_\text{RX} \leq 0.45$ PRF and $\text{B}_\text{REF} \geq \text{PRF}$;
$\text{BWCF}_P = 20 \log [\text{B}_\text{RX}/(0.45\ \text{PRF})]$, for $0.45\ \text{PRF} \leq \text{B}_\text{RX}$ and $\text{B}_\text{REF} < \text{PRF}$;
$\text{BWCF}_P = 10 \log [(\text{B}_\text{RX})^2/(0.2\ \text{PRF}\ \text{B}_\text{REF})]$, for $0.45\ \text{PRF} \leq \text{B}_\text{RX}$ and $\text{B}_\text{REF} \geq \text{PRF}$.

$\text{BWCF}_{A/P}$ for dithered UWB signals

For dithered UWB emissions, the BWCF for average power, $BWCF_A$, in dB, is given by the following expressions, where PRF≥10 kHz:

$BWCF_A = 10 \log (B_{RX}/B_{REF})$, for any value of B_{RX} and B_{REF}.

For dithered UWB emissions, the BWCF for peak power, $BWCF_P$, in dB, is given by the following expressions:

$BWCF_P = 10 \log [(B_{RX})^2/(0.2\ PRF\ B_{REF})]$, for $0.2\ PRF < B_{RX}$ and any B_{REF}.

For $\boldsymbol{B_{RX} \leq 0.2\ PRF}$, the UWB signal's time waveform at the filter output with bandwidth B_{RX} will be noise-like and consequently, average (rms) power is more appropriate than peak power to assess receiver performance degradation. Therefore, to determine $BWCF_P$ for $B_{RX} \leq 0.2\ PRF$, the equation $BWCF_A = 10 \log (B_{RX}/B_{REF})$ should be used for any value of B_{RX} and B_{REF}.

6.3.3.3 Methodology to assess interference from Single UWB emitter into Aeronautical Systems

ICAO in their Standards and Recommended practices for non-radar based systems define a minimum power spectral density at the receive antenna. How an operator designs their receiver system is not taken into account, they simple have to guarantee receiving the minimum wanted signal. Assuming an ideal isotropic antenna this value can be translated to an equivalent receiver sensitivity at the receive antenna input.

Interference is deemed to have occurred when either the the minimum level of desired signal at the receive antenna minus the required signal-to-interference ratio or receiver sensitity level have been exceeded. In practice the value of the minimum level of desired signal at the receive antenna minus the required signal-to-interference ratio will be the most restrictive. Taking into account a safety-of-life factor, a value for the maximum level of aggregate interference can be calculated.

This aggregate protection level then has to be apportioned since a single interference system/network should not be able to claim the total aggregate protection margin. Knowing the apportioned aggregate protection level, the MCL required between a single UWB source and the victim receiver can be calculated:

$$MCL = P_{UWB-RAD} / MHz + 10 * \log BW_{victim} - P_{RXA} + S/I + SF + MTA$$

where:

$P_{UWB\text{-}RAD}$ is the radiated power density inside the victim bandwidth;
P_{RXA} is the equivalent victim receiver sensitivityat the antenna input;

S/I is the measured signal to interference ratio;
SF is an safety-of-life safety factor;
MTA is the multiple system/technology allowance.

For radar based systems the methodology given in section 6.3.1 can be used, provided that the safety factor and multiple system/technology allowance are taken into account.

The second step is then to convert the MCL into the protection distance by using an appropriate propagation model (see section 6.1).

6.3.4 Aggregate interference

The following methods have been used:

- Fantasma statistical method;
- NTIA aggregate airborne model;
- GSO satellite-based aggregate interference model.

Summation methodology: see Annex 4 on radio astronomy.

6.3.4.1 Fantasma statistical method

This aggregate model is applicable for an existing terrestrial device located at the center of a zone defined by minimum and maximum radii using free space propagation. Such method may be found in the NTIA Special Publication 01-43.

The average aggregate interference *A* in *W* per unit bandwidth can be expressed as:

$$A = 2\alpha\eta\rho\pi \ln(R_1 / R_0)$$

with

$\alpha = eirp \cdot (\lambda / 4\pi)^2 \cdot G_r$ - constant valid in the case of omni-directional emissions and free space propagation;

e.i.r.p. - average e.i.r.p. of the UWB transmitting device in W per unit bandwidth;
G_r - victim receiver antenna gain;
λ - wavelength in m;
ρ - average density of emitters (emitters per m^2);
η - fraction of time each emitter is transmitting, activity factor;
R_0 - minimum radius of the observed zone or minimum distance to the nearest UWB receiver;
R_1 - maximum radius of the observed zone.

While the above method does not consider a receiver antenna having directional characteristics, a logical extension to the method could include the effects of a directional receive antenna by simply replacing the fixed receiver gain with an average gain in the horizontal plane.

6.3.4.2 NTIA aggregate airborne model as in Special Publication 01-43

An NTIA airborne aggregate model has been developed and it can be directly used for satellite usage. Such method may be found in the NTIA Special Publication 01-43. It has been shown that this model is quite efficient and reliable as noted in the NTIA Report.

However, the limits of such a model are the following:

when satellite beams or corresponding coverage area are very limited, this model is not useful. In such case, averaging over the beam footprint using the same path loss provides satisfactory results. Concerning EESS (passive) systems, the generic equation provided in §6.3.4.4.2 is quite sufficient;

such method is quite useful when satellite beams cover large areas;

it seems that this method appears to be limited to nadir pointing beams. For instance, for many practical cases, EESS satellites in operation employ beams that are off-set by angles in the order of about 40° off nadir. In that case, alternative methods like the GSO satellite based aggregate interference model described below can be used.

The average aggregate interference A in W per unit bandwidth can be written as

$$A = \alpha\rho\pi R_e \ln\left(\left(2(R_e + h)H + h^2\right)/ h^2\right)/(R_e + h)$$

with

$\alpha = eirp \cdot (\lambda / 4\pi)^2 \cdot G_r$ - constant valid in the case of omni-directional emissions and free space propagation;

e.i.r.p. - average e.i.r.p. of the transmitting device in W per unit bandwidth;
G_r - victim receiver antenna gain;
λ - wavelength (m);
ρ - average density of emitters (emitters per m^2);
R_e - Earth radius;
h - satellite height (m);
R - radius of the observed zone (m);

$$H = R_e (1 - \cos(R / R_e))$$

6.3.4.2.1 NTIA interference assessment model including satellite antenna gain variation

The previous model can be extended to accommodate satellite antenna gain variation across the area from which interference is received. It is assumed that the coverage area can be approximated by a circular area and propagation between the satellite receiver and UWB transmitters is free-space. The geometry and the resulting integration are shown below in Fig. 9 and following formula.

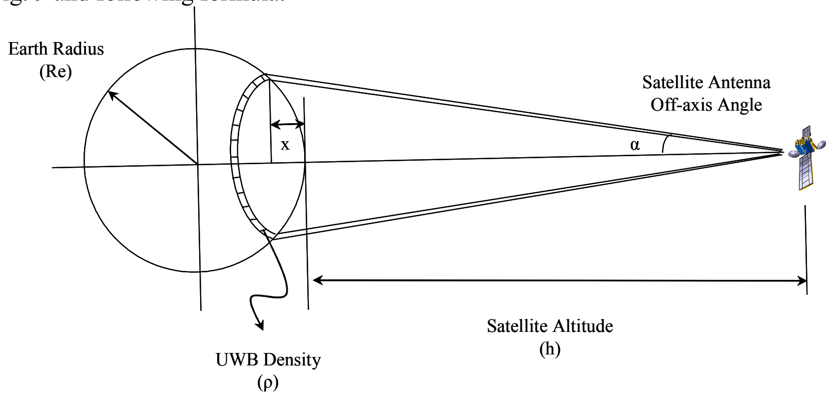


Figure 9: Aggregate UWB - FSS Satellite Interference Geometry

$$I := \int_0^{x\_max} \left[\left(10^{\frac{eirp}{10}} \right) \cdot \frac{1}{\left(\frac{4 \cdot \pi}{\lambda} \right)^2} \cdot \frac{1}{\left[\left(h^2 \right) + \left[\left[(2 \cdot Re) + (2 \cdot h) \right] \cdot x \right] \right]} \cdot \left[10^{\frac{G\left[acos\left[\frac{(h+x)}{\sqrt{h^2 + \left[\left[(2 \cdot Re) + (2 \cdot h) \right] \cdot x \right]}} \right] \right]}{10}} \right] \cdot \rho \cdot (2 \cdot \pi \cdot Re) \right] dx$$

where:

x is the distance between the satellite nadir point and the strip on the axis passing through the satellite and Earth's centre (m);
x_max is the maximum 'x', determined by the coverage area of satellite. It is expressed as:

$$x\_max := Re \cdot \left[1 - \left[\cos\left[\left[acos\left[\frac{\cos(\theta)}{\left(1 + \frac{h}{Re} \right)} \right] \right] - \theta \right] \right] \right]$$

where:

θ is the minimum elevation angle as seen from a point at the edge of the satellite coverage area (radians);
h is the satellite altitude (m);
Re is the Earth radius (m);
eirp is the UWB effective isotropic radiated power (dBW/MHz);
ρ is the UWB density (devices per m^2);

λ is the wavelength (m);
G(α) is the satellite receive off-axis gain (dBi).

The above expression is based on the assumption that the paths between UWB devices and the satellite receive antenna are unobstructed and all UWB devices transmit simultaneously. An interference correction factor, *ICF* (dB), may be applied to the aggregate interference levels calculated using the above equation to take account of clutter losses, building losses, activity factors and, to account for different UWB densities, the ratio of the total populated area and total satellite coverage area:

$$I_N = I - ICF$$

Using I_N, the maximum number of UWB transmitters allowed to operate within a satellite coverage area without causing harmful interference into an FSS satellite can then be calculated, see Annex 11.

6.3.4.3 GSO satellite-specific aggregate interference model

The receiving antenna of a GSO satellite will receive interference from a very large number of transmitting UWB devices. Because of this, the aggregate interference at the satellite receiver from UWB devices will be Gaussian in nature, not depending on the detailed characteristics of the UWB waveform or its duty cycle. The only UWB parameter of concern in this case is the total interference power at the satellite receiver input from these UWB devices located on the Earth's surface, weighted by the satellite's receiving antenna gain characteristics.

As specified in terms of the normal satellite link equation, the interference power I_j received from the j^{th} transmitting UWB device is:

$$I_j = P_j + G_j - 92.5 - 20 \log (d_j) - 20 \log (f) - L_A + G_{SAT}(j) + 10 \log (B_{MHz}) \qquad (1)$$

where:

P_j - power of the UWB device transmitter, averaged over its duty cycle (dBW/MHz);
G_j - gain of the j^{th} UWB antenna towards the satellite (dBi);
d_j - distance from the j^{th} transmitting UWB device to the satellite (km);
f - carrier frequency (GHz);
L_A - clear-air atmospheric attenuation (dB);
$G_{SAT}(j)$ - gain of the satellite's receiving antenna towards the j^{th} transmitting UWB device (dBi);
B_{MHz} - bandwidth of the interfered satellite receiver (MHz), within the bandwidth of UWB transmission.

The aggregate power at the satellite receiver is the power addition of the *N* individual interfering elements $\{I_j\}$. The result of that power addition, in dB, is:

$$I_{AGG} = 10 \log\{ \Sigma 10^{(Ij/10)} \} \qquad (2)$$

The number *N* over which this power sum is theoretically done is expected to be a very large number, too large to evaluate Eq. 2 on an element-by-element basis. Different types of simplification can be made to Eq. 1, depending on a specific application, to make estimation of the aggregate interference at the satellite receiver more tractable. One application of Eq. 1 is the estimation of interference into a GSO satellite, to estimate whether interference from UWB devices is potentially harmful in uplink path of the satellite network.

Based on six approximations considered in this study, Eq. 1 can be re-written as:

$$I_{AGG} = 10\log(N) + P - 92.5 - 20 \log (d_o) - 20\log(f) - L_A + G_{SAT}(-3 \text{ dB}) + 10\log(B_{MHz}) \qquad (3)$$

The only new UWB parameter in the right hand side of the Eq. 3 is *N*, the number of simultaneously active UWB devices within the service area of the satellite antenna beam.

The level of aggregate interference caused by a given number of simultaneously emitting UWB devices into the satellite receiver can also be expressed in terms of $\Delta T/T$ ratio.

6.3.4.4 General formula to assess compatibility between UWB devices and EESS (passive)

6.3.4.4.1 Description of an EESS (passive) system

Passive satellite-based sensors are measuring natural transmitted radiation in the microwave spectrum and have a global coverage. Radiometric imaging of a scene of interest is accomplished by scanning the object with the main beam of sensor antenna. For a moving platform, scanning in the cross-track plane is sufficient to produce an image.

Both mechanical and electronic (beam-steering) scanning techniques are used in microwave radiometry. In mechanical scanning, the direction of antenna beam is changed by mechanical rotation or angular movement of the radiating aperture of the antenna system. Alternatively, phased array antennas can be used to steer the direction of the antenna beam electronically (no mechanical antenna motion in the scanning process).

Various types of radiometer instruments are operated in space depending on the requirements:

- ⇨ Atmospheric sounders, which provide information about vertical profiles of temperature and molecular constituent concentrations in the atmosphere by making measurements near the molecular resonance frequencies (resonance method with nadir pointing);
- ⇨ Surface imaging sensors, which operate primarily at “window” frequencies where atmospheric absorption is low and surface features can be imaged or measured quantitatively. The nadir viewing technique is employed for surface imaging. Radiometric measurements are affected to some extent by water vapour, clouds and rainfall. Hence, most surface sensing radiometers include frequency channels sensitive to atmospheric water vapour and liquid water, to measure global distributions of these parameters and to correct for their effects on the measurement of the surface parameters.

These two types of passive observations can be performed either using a conical scan sensor or a nadir sensor. Differences between these two sensor types are explained below.

Conical scan passive sensors

Fig. 10 below shows a typical geometry of conical scan sensors.

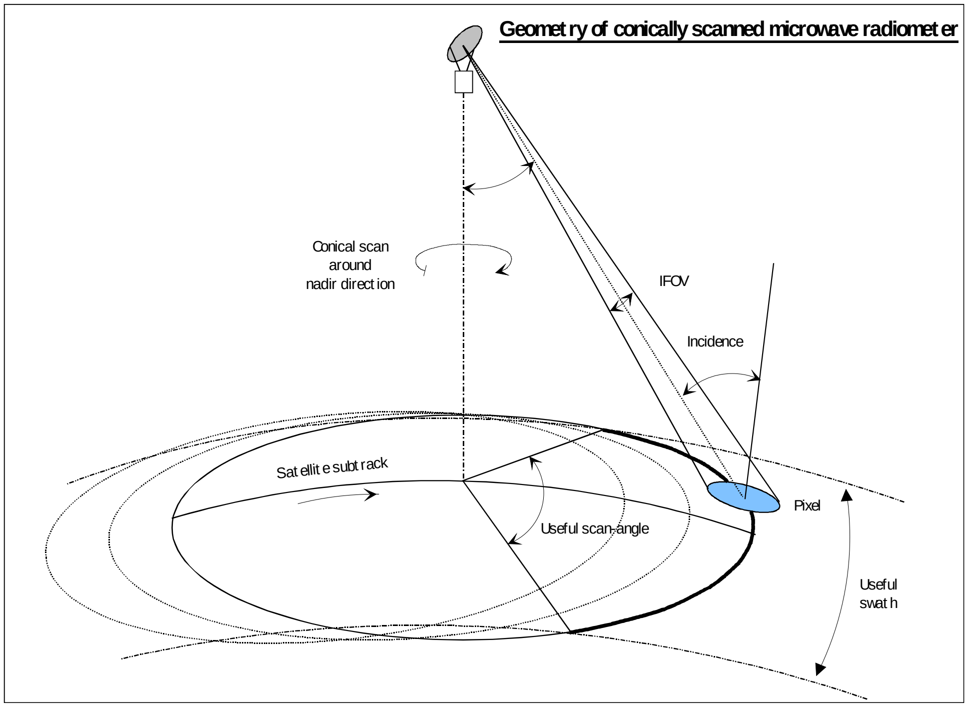


Figure 10: Geometry of conical scan passive microwave radiometers

Typical geometrical parameters of this kind of instruments are the following (for an altitude of about 850 km):

- Ground incidence angle *i* at footprint centre: around 50°;

EESS off-set angle to the nadir, or half cone angle α to the nadir direction (also called antenna off-set angle or off-nadir angle): about 44°;
Useful swath of about 1600 km;
The scanning period is chosen so as to ensure full coverage and optimum integration time (radiometric resolution).

Cross track passive nadir sensors

The Fig. 11 below shows a typical geometry of a nadir sounder that uses a mechanical scan.

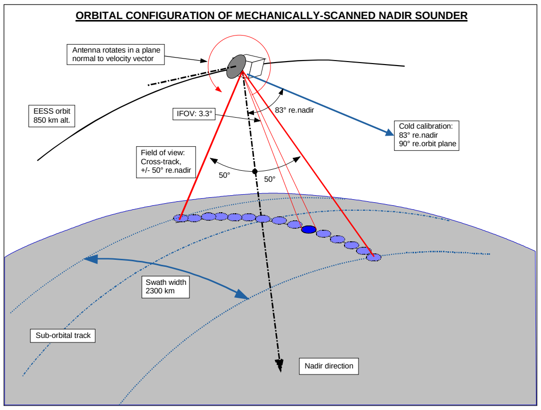


Figure 11: Geometry of mechanical scan passive nadir microwave radiometers

The following Fig. 12 shows a nadir sounder using an electronic scan, which means that it is possible for the radiometer to see at the same time the whole line of pixels within a single swath, because all the beams are simultaneously in operation.

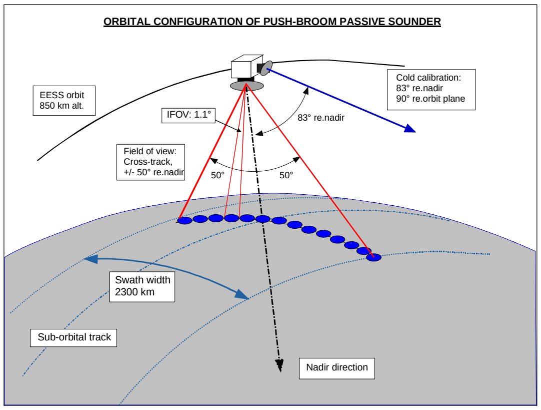


Figure 12: Geometry of electronic scan passive nadir microwave radiometers

6.3.4.4.2 General equation to determine the maximum number of UWB devices within the beam of an EESS (passive) radiometer

The main features of this formula are the following:

- The sensor antenna gain and distance between the sensor and the interferer are eliminated from the final formula. They are first combined in the formula, which expresses the link budget and then eventually expressed through the pixel surface area, which in turn can be eliminated, provided that the interfering radiated power is expressed in terms of **radiated power density per unit of surface area within the pixel (dBW/m^2)**;
- The radiometer bandwidth is also disregarded, such that the interfering radiated power can finally be expressed in terms of **radiated power spectral density per unit of surface area within the pixel (i.e. dBW/Hz/m^2)**.

The purpose of this formula is to get a single equation following the rationale described above, in the most simple configuration where vertical interfering paths are considered.

Standard formulas for radiometry:

$$\Delta T_r = T_s \big/ \sqrt{B * \tau} \qquad (1)$$

$$\Delta Ti = \Delta T_r / 5 \qquad (2)$$

where: ΔT_r (K) – the smallest temperature increment detectable by the radiometer;

ΔTi (K) - the greatest temperature equivalent interfering signal;

T_s (K) - system temperature of the radiometer receiver;

B (Hz) - receiver bandwidth;

τ (s) - integration time of the radiometer.

$$\Delta \mathrm{Pr} = k * \Delta T_r * B \qquad (3)$$

$$\Delta Pi = \Delta \mathrm{Pr} / 5 \qquad (4)$$

where: k = 1.38*10^{-23} (J/K) - the Boltzman constant;

$\Delta \mathrm{Pr}$ (W/Hz) - the smallest power increment detectable by the radiometer;

ΔPi (W/Hz) - the maximum acceptable received interfering power (interference threshold).

Standard link budget for interference analysis:

The general formula is the following:

$$\Pr = (EIRP)i * Gr * \left(\lambda/(4*\pi*R)\right)^2 * \left(1/A\right) \tag{5}$$

where: Pr - power received by the radiometer;

$(EIRP)i$ - interfering radiated power in the direction of the radiometer;

Gr - isotropic gain of the radiometer antenna in the direction of the pixel;

λ - wavelength;

R - distance between the radiometer and the interferer;

$A(\geq 1)$ - absorption coefficient of the atmosphere along the path *R* considered.

Note that if addressing a nadir satellite, the distance *R* = *H* = altitude of the satellite. If it is a conical scan passive radiometer, then:

$$R = R_T \frac{\sin(i-\alpha)}{\sin(\alpha)}, \text{ and } \sin(\alpha) = \frac{\sin(i)}{1+\dfrac{H}{R_T}} \tag{6}$$

where: R_T - Earth radius = 6371 km;
i - ground incidence angle;
α - antenna off-set angle;
H - altitude of the satellite.

The Eq. 5 above can be written as follows:

$$(EIRP)i = \Pr * \left(1/G_r\right) * \left((4*\pi*R)/\lambda\right)^2 * A \tag{7}$$

Now, noting that the maximum value for Pr is the interference threshold defined in Eqs 3 and 4, the following condition can be written, which define the maximum acceptable interfering EIRP (W) in direction of the sensor, in the receiver bandwidth:

$$(EIRP)i \leq \left((k*\Delta T_r*B)/5\right) * \left(1/G_r\right) * \left((4*\pi*R)/\lambda\right)^2 * A \tag{8}$$

Application of the new approach:

Suppressing the parameter B (bandwidth) in the Eq. 8 would provide for calculation of the maximum EIRP density ΔEi radiated from the sensor's pixel in *W/Hz*, if the bandwidth of the UWB device is higher than the passive sensor bandwidth:

$$\Delta Ei(W/Hz) \leq \left((k*\Delta T_r)/5\right) * \left(1/G_r\right) * \left((4*\pi*R)/\lambda\right)^2 * A \tag{9}$$

It is also possible to combine the sensor antenna gain Gr and the distance *R* such that these two parameters can be replaced in Eq. 9 by the surface area of the pixel. This is done below:

$$Gr = \left(\eta*4*\pi*s/\lambda^2\right) = \eta*(\pi*d/\lambda)^2 = \eta\left(k*\frac{d}{2}\right)^2 \tag{10}$$

where: *s* is the surface area of the sensor's antenna;
d is the sensor antenna diameter;

$$k = \frac{2\pi}{\lambda};$$

η (<1) is the aperture gain factor;

<u>Note:</u> *s*, *λ* and *d* should be expressed in the same unit.

The “-3dB” aperture (°) of the sensor antenna is given by the following expression:

$$\theta_{\deg} = (C * \lambda)/d \qquad (11)$$

where *C* is a factor which depends on the illumination efficiency of the antenna reflector. Radiometer antennas are designed for the highest possible beam efficiency (>95%).
Converting *θ* from degree to radian gives:

$$\theta_{rad} = (\pi/180) * (C * \lambda)/d \qquad (12)$$

$$d/\lambda = (\pi/180) * (C/\theta_{rad}) \qquad (13)$$

Replacing d/λ in Eq. 9 gives:

$$Gr = \eta * ((\pi^2/180) * (C/\theta_{rad}))^2 \qquad (14)$$

Replacing *Gr* in Eq. 9 gives:

$$\Delta Ei(W/Hz) \leq (k * \Delta T_r)/5 * \left((180 * \theta_{rad})/(\pi^2 * C)\right)^2 * (4 * \pi * R/\lambda)^2 * A/\eta \qquad (15)$$

Noting that, it is possible to get a good estimate of the size of the cross track (normal to the satellite track trajectory) and instantaneous field of view of a pixel (spatial resolution of the sensor):
$\theta_{rad} * R = D$ = pixel diameter, Eq. 15 becomes:

$$\Delta Ei(W/Hz) \leq (k * \Delta T_r)/5 * \left(180/(\pi^2 * C)\right)^2 * \left((16 * \pi)/\lambda^2\right) * \pi * D^2 * A/\eta \qquad (16)$$

The pixel surface area is: $S = (\pi * D^2)/4$, and ($\pi * D^2$) in the Eq. 16 above can be replaced by *4*S*:

$$\Delta Ei(W/Hz) \leq (k * \Delta T_r)/5 * \left((180)^2/\pi^3\right) * \left(16/\lambda^2\right) * 1/(C)^2 * 4 * S * A/\eta \qquad (17)$$

$$\Delta Ei(W/Hz/m^2) \leq \left((k * \Delta T_r)/\lambda^2\right) * A/\eta * \left(13375/C^2\right) \qquad (18)$$

or, expressed in MHz/km^2 the final formula takes the following form:

$$\Delta Ei(W/MHz/km^2) \leq (k * \Delta T_r)/\lambda^2 * A/\eta * \left(13375/C^2\right) * 10^{12} \qquad (19)$$

where:
Ei (W/MHz/km2) - the maximum acceptable UWB radiated power spectral density in the sensor’s direction per unit of surface area within the pixel, all effects included;

- $k = 1.38 \times 10^{-23}$ *J/K* - the Boltzman’s constant;
- ΔT_r *(K)* - radiometric resolution of the passive sensor;
- λ*(m)* - wavelength;
- *A(>=1)* - total atmospheric opacity (absorption) along the considered path;
- *η*- aperture gain factor of the passive sensor antenna;
- *C* is the sensor antenna factor depending on the illumination.

6.4 Measurements

6.4.1 Scope of the measurement campaign

An experimental campaign was carried out to rerform single/aggregated UWB interferer measurements in the victim radiocommunications services bands, including:

- Average (PSD) and peak interferer measurements;
- UWB propagation effects in the narrow band receiver domains with LOS.

This measurement campaign has been set up by using specimens of UWB transmitters and measurement (frequency and time domain) test equipment (spectrum analysers, signal acquisitions). No measurements were carried out on victim receivers.
The main purpose of this measurement campaign was to characterise UWB signals and prepare measurement tools, procedures and baseline to be re-used during the future measurement campaigns. Another target was to collect and analyse data in order to obtain characteristics for available UWB transmitters in some victim bands, in single-entry and aggregate interference office conditions, noting the fact that these are not representative of devices on the market. Qualitative conclusions were needed to assess behaviour of these devices.

The detailed description of the used equipment and measurement goals are provided in Annex 16 of the report.

6.4.2 Incumbent radiocommunications services

During the campaign, UWB emissions have been measured in the operating frequency bands of the following radiocommunications services:

- Fixed Service (FS);
- Mobile Service (MS);
  - IMT-2000: GSM900, DCS1800, PCS1900, UMTS-FDD;
  - Wireless Access Systems – RLANs;
- Radionavigation Satellite Services (RNSS);
- Terrestrial Broadcasting Services (T-DVB, T-DAB**).**

All radio characteristics used as reference for definition of measurement conditions are described in Annex 16.

6.4.3 Description of UWB interferer measurement

6.4.3.1 Definition of UWB Interferer measurement in incumbent service bands

The drawing in Fig. 13 defines the receiver Bandwidth (BW) and the channel BW (carrier BW) of the incumbent radiocommunications service receivers. These receiver BW and channel BW are specific to each radiocommunications service and have been specified in order to allow the definition of the test conditions for the measurement campaign.

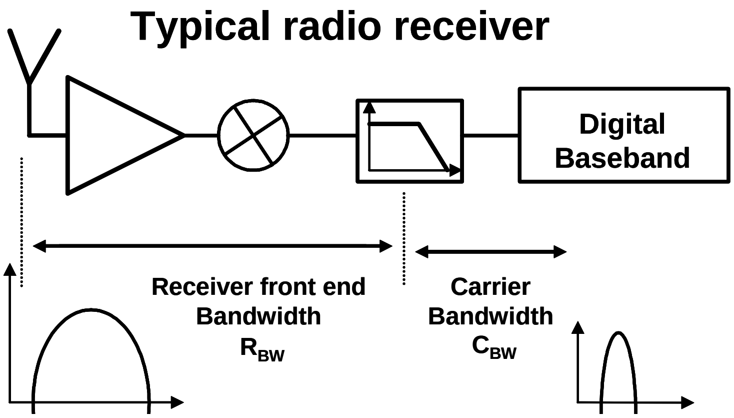


Figure 13: Definition of receiver and channel bandwidths for victim receivers

The used values of these parameters are given in Annex 16.
For each incumbent radiocommunications services' band investigated, two UWB interferer measurements have been conducted:

- Average UWB interferer in the Channel BW resolution, defined as PSD measurement;
- Average UWB interferer in the total Receiver BW resolution, defined as the Peak Power measurement (maximum interferer level seen by the incumbent receiver's front-end).

A data file has been created for each measurement (one file for the PSD and one file for the peak power).

6.4.3.2 Description of UWB transmitters

Two types of UWB transmitters were used in measurements. These UWB transmitters were based on UWB pulse generators producing UWB signals with large spectrum bandwidth from D.C. to 6 GHz.
Throughout the measurement campaign, the UWB transmissions were continuous, no traffic transmission patterns were applied. This is equivalent to an UWB transmitter activity factor of 100%.
Detailed description of used UWB transmitters is given in annex 16.

6.4.3.3 Description of the measurement campaign scenarios

During the measurement campaign, the following four main UWB interference measurement scenarios were used to summarise the results:

- **Scenario 1:** Ambient interference measurements (without any UWB Tx active) and UWB single interferer measurements in all selected incumbent radiocommunications services' bands, without band-pass filter on the UWB transmitter for wired and wireless configurations. For wireless configuration, 3 distances have been considered: 36 cm, 1 m, and 2 m;
- **Scenario 2:** Single UWB interferer measurements with a band-pass filter (3.1 to 4.8 GHz) on the UWB transmitter: in this case measurements were performed at 36 cm distance only, and only for the following radiocommunications services' bands: GSM900, DCS1800, UMTS 2100 MHz, WLAN 2.4 and 5 GHz;
- **Scenario 3:** Aggregated UWB interference measurements in a limited number of MS bands: GSM900, DCS1800 and UMTS 2100 MHz. These aggregated interference measurements have been conducted for 1, 2, 4 and 8 active UWB transmitter configurations for each distance case of 36 cm, 1 m, and 2 m;
- **Scenario 4:** Aggregated UWB interference measurements in the continuous band from 900 MHz to 2.5 GHz. This limited frequency range was selected so as to have a band, which would allow getting better resolution of the records. These aggregated interference measurements have been conducted for 1, 2, 4 and 8 active UWB transmitter configurations for each distance case of 36 cm, 1 m, and 2 m.

In all these measurement scenarios UWB transmitters have operated with an activity factor of 100% (on/off switch), as the prototypes had no capability of working in burst mode.

The UWB interference measurements have been performed in an indoor environment, at open space room conditions (i.e. not in anechoic chamber).

6.4.3.4 Conclusion on the test range of the campaign

Based on the characteristics of used UWB transmitters, test equipment BW and antenna BW, the UWB interference measurements in incumbent radiocommunications services' bands have been conducted in a frequency range from 470 MHz to 6 GHz. Results of this first measurement campaign are detailed in Annex 16 (Informative).

Further measurements are planned and a separate report should be developed within CEPT on that subject.

7 SUMMARY OF COMPATIBILITY STUDIES

7.1 Fixed Service (FS)

7.1.1 Summary table

Victim Radiocommunications Service	Fixed Service						
Application	Fixed Wireless Access (FWA)				• Public fixed access and mobile networks' infrastructure (medium to high capacity for trunk, regional, local connections) • Private utilities networks (low to medium capacity connections) • Military (National/NATO) networks		
System description	Point-to-multipoint				Point-to-point		
Frequency band[8]	3.5 GHz			3.5 GHz	4/5/6 GHz	7/8 GHz	10.5 GHz
Approximate number of links (ECC Report 3 – February 2002[9])					16470	16989	4375
Receiver station							
Station description	CS and TS (Category B outdoor)			TS (Category A indoor)	←-------------Category B-------------→		
Receiver characteristics							
Bandwidth (MHz)	< 50			< 50	< 50	< 50	< 50
Noise figure (dB)	5			5	4+ 3 (feeder)	6	7
Signal model	←-------Digital (e.g. n-QAM, QPSK, FSK etc.) ------→						
Receiver antenna							
Type	Omni	90° Sect	Dir.	Omni	Directional (dish)		
Gain (dBi)	8	16	16	0	41	40	40
Model	ITU-R F. 1336				Φ=3.7 m ITU-R F. 699	Φ=3 m ITU-R F. 699	Φ=1.2 m ITU-R F. 699
Protection requirement							

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[8] Some bands below 3 GHz are still allocated on primary bases to FS and are extensively used for particular applications in many countries; ERC Report 25 indicates several cases of such bands. In terms of system characteristics, performance objectives and scenarios, that might be relevant to the co-existence with UWB devices, there are no significant differences with the corresponding applications in 3.5 and 4 GHz; only antennas might have slight different characteristics, but the expected reduced directivity and gain would somehow compensate each other. Therefore the r.m.s. PSD objectives for UWB below 3 GHz should be considered very similar to those evaluated for the higher bands and they would be retained valid unless a more detailed study would be required.

[9] Values are for civil use only, in addition, trunk and regional links might comprise multi-channel systems; actual number of equipment is then larger.

Criteria	I/N(rms/1MHz) = – 20dB Ipk/Nrms (50 MHz) = + 5 dB (Note 1)	I/N(rms/ 1MHz) = –6 dB min distance = 1 m (Note 2)	I/N(rms - 1MHz) = – 20dB Ipk/Nrms (50 MHz) = + 5 dB (Note 1)
Reference	r.m.s: ITU-R Rec. F.1094 and WP9A LS peak: test results	t.b.d.	r.m.s.: : ITU-R Rec. F.1094 and WP 9A LS peak: test results

Note 1: It corresponds to a peak interference lower that the peak of Raleigh noise (both evaluated in 50 MHz) at probability 0.4%
Note 2: the I/N=-6 dB criteria is pending confirmation by ITU-R WP9A of the assumed I/N objectives

Interference scenario & methodology

UWB characteristics	
PSD limit	Reference value for initial evaluation: r.m.s. = –41.3 dBm/MHz peak = – 0 dBm/50 MHz
Activity factor:	
Category A – Single entry	100%
Category B – Single entry	100%
Category B – aggregate	5% (uniform density distribution of scenario 1) 20% (hot-spot office of scenario 3a)
Single interferer	
Methodology:	
– Indoor FWA terminals (Category A)	Minimum distance requirement
– Outdoor FS stations (Category B)	Worst case interference level from the surrounding territory
Propagation model	
– indoor	Siwiak 2-slope
– outdoor	Free space
Mitigation techniques	Not applicable
Aggregate interference	
Methodology	Power Integration
Propagation model:	
– Scenario 1	Free space
– Scenario 3	P.1238 (indoor open space office) + wall + free space (outdoor)
Indoor-to-outdoor attenuation	
– P.1238 + outer walls (Note 1)	10 dB
– roofs (Note 2)	16 dB/floor

Note 1: Intended as the attenuation incremental to the free-space, using P.1238 defined open-space propagation exponent ~2 and metal-glass building structure (see also next mitigation technique). This is also the default value in SEAMCAT® program.
Note 2: additional to the indoor path attenuation

Mitigation techniques	– 2/3 of all indoor or outdoor UWB devices, assumed in deep shade conditions, are excluded = –5 dB – UWB Polarisation uncorrelation at victim antenna = – 3dB
Enhancement for multi-scenario aggregation	+5 dB
Reference deployment scenario	Relevant for categories B & C, aggregate analysis

Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km^2)	100	1000	10000
Activity factor (busy hours)	5 %	5 %	5 %
Density of active UWB transmitters (/km^2)	5	50	500
% Outdoor	20%	20%	20%

Deployment scenario 3 (Note)	Home / Office environment
UWB density (per floor)	1 per 10 m^2
Activity factor (busy hours)	20 %
Density of active UWB transmitters	0.2 per 10 m^2

Note: this scenario reflects deployment of UWB devices in indoor environment; it may be used for reference in the evaluation of interference to indoor as well as to outdoor receivers.

Results of theoretical compatibility studies

Single interferer

Calculation 1: required UWB PSD emission limit to ensure given protection distance(s) For indoor UWB to indoor Category A FWA TS

Protection distance:	1 m 3.4 – 3.8 GHz		Not applicable above 6 GHz
UWB PSD limit (dBm/MHz)	–68 [10]		Not applicable
Minimum PRF (MHz)		Not relevant	

Note: Justification for the protection distance is for indoor FWA terminal on a desk closest to window

Calculation 2: **separation distances** associated with different UWB PSD emission limit (as per calculation 1) **For indoor UWB to indoor Category A FWA TS**

	FCC limits (–41.3 dBm/MHz)	Slope mask (.. dBm/MHz)	–57 [10] dBm/MHz
Separation distance (m) 3.4-3.8 GHz Indoor FS	> 10 m (Different room)	Not applicable	3 m

Calculation 3: **required UWB PSD emission limit** to ensure given protection **For UWB outdoor to outdoor Category B station** (LoS and positions aligned to the link direction)

Freq range (GHz) Outdoor FS	3 to 7	7 & 8	10.5
UWB PSD limit (dBm/MHz)	–57	–52	– 49
Minimum PRF (MHz)		Not relevant	

Aggregate interference category B outdoor FS stations

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits – scenario 1

	FCC limits (–41.3 dBm/MHz)
Maximum density of active UWB transmitters	0 UWB/km^2 (Note)

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[10] Pending confirmation by ITU-R WP9A of the assumed I/N objectives

Note: There is no compatibility mentioned with any density due to the fact that a single UWB entry with FCC eirp already exceeds the objectives

Calculation 2: **required UWB PSD emission limit** to ensure compatibility Scenario 1 and scenario 3a (Note 1)

Density of UWB transmitters (/km^2)		Required UWB PSD limit (dBm/MHz)	Minimum PRF(MHz)	Wide-band Peak PSD limit (dBm/50 MHz)	
Deployed	Active				
100 (Scenario 1a)	5	−57		−15	Note 2
1000 (Scenario 1b)	50	−61.5		−19.5	
10000 (Scenario 1c)	500	−71.5	Not relevant	−29.5	
1/10m^2 (Scenario 3a Indoor “hot spots”)	0.2/10m^2	−62		−20	

Note 1: Values are referred to the more sensitive bands below 7.125 GHz.
Note 2: The required PSD for compatibility does not raise above that derived from compatibility in single UWB entry (calculation 3).

7.1.2 Conclusions

The study within this report has been focused on the FS bands between 3-10.6 GHz used by both P-P and FWA systems. Although it is recognised that frequency bands lower than 3 GHz and above 10.6 GHz are also used for FS systems; for bands lower than 3 GHz, however, qualitative considerations leading to very close objectives and PSD requirements for compatibility are presented.

A requirement for wide-band peak has also been defined.

The Summary Table in 7.1.1 above details the assumptions and results (in terms of both average and 50 MHz peak) for all UWB deployment scenarios considered in this report.

From these UWB deployment scenarios, the PSD limits for coexistence of any generic UWB application considered in this report with FS systems below 10.6 GHz are:

➢ E.i.r.p PSD (r.m.s.)	≤ −71.5 dBm/MHz
➢ E.i.r.p. PSD (wide-band peak)	≤ −29.5 dBm/50MHz

NOTE 1: These values are referred to bands up to 7.125 GHz; according to the study, there might be a relaxation of 2.5 dB up to 8.5 GHz and of further 2.5 dB for the 10.5 GHz Band.

NOTE 2: Also the PSD limit (−68 dBm/MHz) derived from single entry indoor UWB interferer to indoor FWS TS (Calculation 1) is very close to the above. Therefore, the above values are provisional, pending the confirmation by ITU−R WP9A of the I/N objective for FWA TS indoor applications; if objectives for FWA TS indoor applications would be defined as being more than 3.5 dB tighter than the −6 dB provisionally assumed in this report, then the aforementioned PSD limits should also be tightened accordingly; otherwise the above PSD limits would remain valid.

A number of assumptions have been made in the study concerning future deployment and scenarios of UWB applications. It is considered that the given limits will only apply to UWB systems that are intended for continuous (or systematic throughout most part of the day) emissions. A number of different aggregation scenarios have been explored in order to find the most severe cases. However, in actual deployment all these scenarios will be additive and not “alternative” to each other and therefore their further potential aggregation has also been taken into account.

The FCC regulation (i.e. −41.3 dBm/MHz r.m.s. and 0 dBm/50MHz Peak) was also studied, but found to lead to a potentially large incompatibility (up to ~ 30 dB above margin) with the FS in the bands below 10.6 GHz.

It should finally be underlined that the “single entry” study has also shown that a single UWB device that appears at an unfavourable (which could happen) location (i.e. in outdoor location, placed along a FS link direction, in LoS of the FS receiver antenna), would already exceed the FS interference objectives by an amount up to ~15/20 dB.

7.2 Mobile Satellite Service (MSS)

7.2.1 Summary table

7.2.1.1 Service Links of GSO MSS Systems

Radiocommunications Service	**Service Links of GSO MSS Systems**	
Application		
System description	Inmarsat-3 satellites are currently used to provide different types of services in land, maritime and aeronautical environments. Inmarsat-4 satellites will be used in the near future to continue the existing and evolved services in land, maritime and aeronautical environments. In addition, these satellites will be used for enhanced data services up to 432 kbps from small portable MES terminals.	
Frequency band		
Service Links	Uplink: 1626.5-1660.5 MHz Downlink: 1525-1559 MHz	
Feeder Links	Uplink: 6425-6575 MHz Downlink: 3550- 3700 MHz	
Receiver station	**Mode-2 (1.5 GHz) compatibility analysis – service downlink**	
Station description	Mobile Earth Station Terminals: Type-1 and Type-2	
Receiver characteristics		
Bandwidth	Type-1: 200 kHz; Type-2: 60 kHz	
System Noise Temperature	Type-1: 355 ^{o}K; Type-2: 316 ^{o} K	
Receiver antenna gain	Gain pattern (dB)	
Type-1 MES Terminal (Land based)	**Off-Axis angle (degrees)**	
	$\theta \le 13^{o}$	17
	$13^{o} < \theta \le 21^{o}$	14
	$21^{o} < \theta \le 76^{o}$	$44-25 \log \theta$
	$\theta > 76^{o}$	-3
Type-1 Aero MES terminal	0 dBi for aggregate interference analysis	
Type-2 MES Terminal (Land based)	**Off-Axis angle (degrees)**	
	$0^{o} < \theta \le 30^{o}$	18.0
	$30^{o} < \theta \le 63^{o}$	$41-25 \log(\theta)$
	$\theta > 76^{o}$	-4.0
Type-2 Aero MES terminal	0 dBi for aggregate interference analysis	
Protection requirement		
Criteria	1% of the thermal noise, i.e., I/N = -20 dB.	
Maximum Permissible Interference Level	Type-1: -140.09 dBm Type-2: -145.82 dBm	
Receiver station	**Mode-4 (1.6 GHz) compatibility analysis- service uplink**	
Station description	Inmarsat-3 /Inmarsat-4 satellite receiver	
Receiver characteristics		
Bandwidth	Inmarsat-3 Global/spot beam: 34 MHz Inmarsat-4 Global/Narrow Spot beam: 34 MHz	

System Noise Temperature	Inmarsat-3 Global beam: 562 °K; Spot beam: 708° K Inmarsat-4 Global beam: 501°K; Spot beam: 501°K
Receiver antenna gain	Gain pattern (dB)
Inmarsat-3 Global	Peak: 18.5 dBi; Edge of Coverage: 16 dBi
Inmarsat-3 Spot	Peak: 27.0 dBi; Edge of Coverage: 23 dBi
Inmarsat-4 Global	Peak: 22.0 dBi; Edge of Coverage: 17 dBi
Inmarsat-4 Narrow Spot Beam	Peak: 41.0 dBi; Edge of Coverage: 37 dBi
Protection requirement	
Criteria	1% of the thermal noise, i.e., I/N = -20 dB.
Maximum Permissible Interference Level	Inmarsat-3 Global beam: -115.79 dBm Inmarsat-3 Spot beam: -114.78 dBm Inmarsat-4 Global beam: -116.29 dBm Inmarsat-4 Narrow spot beam: -116.29 dBm

Interference scenario & methodology

UWB characteristics	As currently considered in the compatibility study
PSD limit	**Mode-2 (1.5 GHz) Compatibility Analysis**
FCC	-75.3 dBm/MHz at 1542 MHz
Slope I/D	-77.7 dBm/MHz at 1542 MHz
Slope O/D	-87.7 dBm/MHz at 1542 MHz
PSD limit	**Mode-4 (1.6 GHz) Compatibility Analysis**
FCC Indoor devices	-53.3 dBm/MHz at 1642.5 MHz
FCC Outdoor Devices	-63.3 dBm/MHz at 1642.5 MHz
Slope I/D	-75.3 dBm/MHz at 1642.5 MHz
Slope O/D	-85.3 dBm/MHz at 1642.5 MHz
Activity factor	
Category A	Type-1 and Type-2 MES terminal – No activity factor (Mode-2)
Category C Aggregate	Aero Type-1and Type-2 MES Terminal: 4 % (Mode-2) Inmarsat-3/4 Satellite Receiver: 4% (Mode-4)
Single interferer	
Methodology	Compatibility with a single device (Section 6.3.1.1)
Propagation model	Free space propagation model for Type-1 and Type-2 Land based MES terminals deployed in rural areas ITU-R Recommendation P1411 for Type-1 and Type-2 Land based MES terminals deployed in urban areas
Aggregate interference	
Methodology	Aero Type-1 and Type-2 MES terminal (Mode-2) The NTIA air borne aggregation model (Section 6.3.2.2) Inmarsat 3 and Inmarsat-4 Satellite Receiver (Mode-4) The NTIA airborne aggregation model (Section 6.3.2.2) GSO satellite based aggregate interference methodology (Section 6.3.2.3)
Propagation model	Free space propagation model
Mitigation techniques	

Reference deployment scenario	Aero Type-1 and Type-2 MES terminal (Mode-2) (Mode-2) Deployment Scenario-2 Average Large Scale UWB Density: 10 devices/km^2 Percentage of active UWB transmitters: 4% Percentage of outdoor devices: 20% Inmarsat 3 and Inmarsat-4 Satellite Receiver (Mode-4) Deployment Scenario-2 Average Large Scale UWB Density: 10 devices/km^2 Percentage of active UWB transmitters: 4% Percentage of outdoor devices: 20%

Results of theoretical compatibility studies

Single interferer Type-1 and Type-2 Land based MES terminals
Calculation 1: **required UWB PSD emission limit** to ensure given protection distance/reference distance
Protection/reference distance: **20 meters**

UWB PSD limit (dBm/MHz)	Type-1 MES terminal	Type-2 MES terminal
Non dithered signals- average emissions	-91.65 dBm	-98.39 dBm
Non dithered signals- peak emissions	-91.65 dBm	-98.39 dBm
Dithered signals- average emissions	-84.66 dBm	-86.17 dBm
Dithered signals- peak emissions	-84.66 dBm	-86.17 dBm
Minimum PRF (MHz)	1 MHz	

Note:Values for other PRFs are given in Annex 2

Calculation 2: **separation distances** associated with different UWB PSD emission limit

Separation distance (m) (With 1 MHz PRF)	Type-1 MES Terminal		Type-2 MES Terminal	
	FCC Limit -75.3 dBm/MHz	Slope mask limit -77.7 dBm/MHz	FCC Limit -75.3 dBm/MHz	Slope mask limit -77.7 dBm/MHz
Non dithered signals- average emissions	132	32	286	69
Non dithered signals- peak emissions	132	32	286	69
Dithered signals- average emissions	59	14	70	17
Dithered signals- peak emissions	59	14	70	17

Note: Separation distances for low PRFs are considerably higher than the above distances. These distances are given in Annex 2

Aggregate interference Type-1 and Type-2 Aero MES Terminals (Mode-2)
Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

FCC limits: -75.3 dBm/MHz

	Altitude	Type-1	Type-2
Maximum density of active UWB transmitters **(/km²)** With 80% outdoor	High	25,629	22,853
	Medium	19,950	17,780
	Low	11,878	10,591

Calculation 2: **required UWB PSD emission limit** to ensure compatibility
Required UWB PSD limit

Density of total UWB transmitters per sq km	Density of active UWB transmitters per sq km	High Altitude		Medium Altitude		Low Altitude	
		Type-1	Type-2	Type-1	Type-2	Type-1	Type-2
25	1	-75.3	-75.3	-75.3	-75.3	-75.3	-75.3
250	10	-75.3	-75.3	-75.3	-75.3	-75.3	-75.3

Note: The density of active UWB transmitters per sq km is based on deployment scenario 2

Aggregate interference	Inmarsat-3/Inmarsat-4 Satellite Receiver (Mode-4) GSO based aggregation model

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

FCC limit: -53.3 dBm/MHz

Maximum density of active UWB transmitters **(/km²)** With 80% outdoor	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Wide Spot Beam	Inmarsat-4 Narrow Spot Beam
	3,539	7,075	2,506	22,230	5,011

Slope Mask Limit: -75.28 dBm/MHz

Maximum density of active UWB transmitters **(/km²)** With 80% outdoor	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Wide Spot Beam	Inmarsat-4 Narrow Spot Beam
	558,250	1,116,700	395,312	3,507,034	790,569

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of total UWB transmitters per sq km	Density of active UWB transmitters per sq km	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Wide Spot Beam	Inmarsat-4 Narrow Spot Beam
25	1	-53.3	-53.3	-53.3	-53.3	-53.3
250	10	-53.3	-53.3	-53.3	-53.3	-53.3

Note: The density of active UWB transmitters per sq km is based on deployment scenario 2

Required UWB PSD limit (below the Slope Mask Limit)

Density of total UWB transmitters per sq km	Density of active UWB transmitters per sq km	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Wide Spot Beam	Inmarsat-4 Narrow Spot Beam
25	1	-75.28	-75.28	-75.28	-75.28	-75.28
250	10	-75.28	-75.28	-75.28	-75.28	-75.28

Note: The density of active UWB transmitters per sq km is based on deployment scenario-2

Aggregate interference	Inmarsat-3/Inmarsat-4 Satellite Receiver (Mode-4) NTIA Methodology

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

Slope Mask : -75.28 dBm/MHz

Maximum density of active UWB transmitters **(/km²)** With 80% outdoor	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Spot Beam
	106,639	187,042	75,464	129,998

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of total UWB transmitters per sq km	Density of active UWB transmitters per sq km	Inmarsat-3 Global Beam	Inmarsat-3 Spot Beam	Inmarsat-4 Global Beam	Inmarsat-4 Spot Beam
25	1	-75.28	-75.28	-75.28	-75.28
250	10	-75.28	-75.28	-75.28	-75.28

Note: The density of active UWB transmitters per sq km is based on deployment scenario 2

7.2.1.2 Service and Feeder Links of LEO and GSO Search and Rescue MSS Systems

Victim Radiocommunications Service	Service and Feeder Links of LEO and GSO Search and Rescue MSS Systems

Application		
System description	The Cospas/Sarsat (C/S) system provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation and land users in distress. The band 1 544-1 545 MHz is a Space to Earth link to LEOLUTs (non-GSO Local User Terminal: earth station for non-GSO satellites) and GEOLUTs (GSO Local User Terminal: earth station for GSO satellites) for the two kinds of satellites (LEO and GSO). This band is limited to distress and safety operations only. For the C/S system, this band is used for feeder links of satellites needed to relay the emissions of satellite emergency position indicating radiobeacons to earth stations. There are currently about 39 C/S earth stations or LEOLUT located in more than 20 countries in the world.	
Frequency band		
Service links	Uplink: 406.0 - 406.1 MHz	
Feeder links	Downlink: 1544 - 1545 MHz	
Receiver station	For the service links	For the feeder links
Station description	Satellite on-board receiver Category C receiver	Satellite ground station Category B receiver
Receiver characteristics		
Bandwidth	100 kHz	1 MHz
Receiver antenna		
Type	Omni directional	Dish antenna having diameters of 3 m for LEO system and of 5 m for GSO systems
Gain	3.9 dBi	
Model	-	
Protection requirement		
Criteria	For the LEO case at 1544 MHz: -113.2 dBm/MHz For the GSO case at 1544 MHz: -133.2 dBm/MHz At 406 MHz: -120.1 dBm/MHz	
Reference (e.g. ITU-R Rec.)	-	

Interference scenario & methodology

UWB characteristics	
PSD limit	Feeder links
FCC indoor and outdoor	-75 dBm/MHz at 1544 MHz

Slope mask indoor	-77.6 dBm/MHz at 1544 MHz
Slope mask outdoor	-87.6 dBm/MHz at 1544 MHz
PSD limit	Service links
FCC indoor and outdoor	-41.3 dBm/MHz at 406 MHz
Slope mask outdoor	-138.1 dBm/MHz at 406 MHz
Slope mask indoor	-128.1 dBm/MHz at 406 MHz
Single interferer	N/A
Aggregate interference	
Methodology	NTIA air borne aggregation model at 406 MHz for satellite receivers FANTASMA method to compute protection distances at 1544 MHz for satellite ground station
Propagation model	Free space propagation model and additional parameter for indoor usage
Mitigation techniques	

Reference deployment scenario	Relevant for categories B & C, aggregate analysis.		
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km^2)	100	1000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km^2)	5	50	500
% Outdoor	20%	20%	20%

Note: some of the calculations are provided for densities of active UWB transmitters per km^2 ranging from 1 to 10000

Results of theoretical compatibility studies

Aggregate interference — Service links at 406 MHz

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

PSD limits in dBm/MHz	Maximum density of active UWB transmitters **(/km^2)**	Maximum density of active UWB transmitters **(/km^2)** for both outdoor and indoor usage
FCC: -41.3 outdoor	5	12
FCC: -41.3 indoor	18	12
Slope mask outdoor	2.10^{10}	10^{10}
Slope mask indoor	8.10^{10}	10^{10}

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of active UWB transmitters per km^2	Required UWB Power spectral (both indoor and outdoor) density in dBm/MHz	Required UWB Power spectral density in dBm/MHz	
		Outdoor limit (dBm/MHz)	Indoor limit (dBm/MHz)
1	-30	-38	-28
10	-40	-48	-38
100	-50	-58	-48
1000	-60	-68	-58
10000	-70	-78	-68

Aggregate interference — **Feeder links** at 1544 MHz

Calculation 1: **minimum protection distances** associated with different densities of active UWB transmitters and with standard UWB PSD emission limits

	UWB density (UWB/km²)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	FCC - outdoor -75	FCC - indoor -75	Outdoor slope mask -87,6	Indoor slope mask -77,6
LEO case	100	Protection distance	10 m	10 m	10 m	10 m
	1000	Protection distance	10 m	10 m	10 m	10 m
	10000	Protection distance	2000 m	10 m	10 m	10 m
GSO case	100	Protection distance	5000 m	100 m	10 m	10 m
	1000	Protection distance	9300 m	6000 m	3000 m	4000 m

Calculation 2: **minimum protection distances** associated with different densities of active UWB transmitters and with different UWB PSD emission limits

Computation of the protection distance for a maximum radius of 10 km for the LEO case

Density of active UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = - 75	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = - 85	Required UWB Power spectral density in dBm/MHz Outdoor = -75 Indoor = -65	Required UWB Power spectral density in dBm/MHz Outdoor = -85 Indoor = -75
1	10 m	10 m	10 m	10 m
10	10 m	10 m	10 m	10 m
100	10 m	10 m	10 m	10 m
1000	10 m	10 m	10 m	10 m
10000	100 m	10 m	3 km	10 m

Computation of the protection distance for a maximum radius of 10 km for the GSO case

Density of active UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = - 75	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = - 85	Required UWB Power spectral density in dBm/MHz Outdoor = -75 Indoor = -65	Required UWB Power spectral density in dBm/MHz Outdoor = -85 Indoor = -75
1	10 m	10 m	10 m	10 m
10	10 m	10 m	100 m	10 m
100	1 km	10 m	5.5 km	100 m
1000	8 km	1 km	9.5 km	5.5 km
10000	9.8 km	8 km	9.95 km	9.5 km

7.2.2 Conclusions

The following conclusions can be drawn from the results of the compatibility analysis with regard to interference from a single UWB emitter, with **PRF not less than 1 MHz,** into MES terminals in the 1.5 GHz band.

7.2.2.1 Land based MES terminals

Separation distances

- A minimum separation distance ranging from 14 m to 286 m, depending on the PRF, is required for both average power and peak power UWB emissions to protect land based MES terminals.

Maximum permissible EIRP density in 1 MHz at 20 m distance

- The permissible EIRP density is equal to –98.39 dBm/MHz from non-dithered UWB emissions with PRF not less than 1 MHz;
- The permissible EIRP density is equal to –86.17 dBm/MHz from dithered UWB emissions with PRF not less than 1 MHz.

7.2.2.2 Aero MES terminals

The aggregate interference into the aeronautical MES terminal is unlikely to be problematic.

7.2.2.3 Maritime MES Terminals

It is not expected that there may be any problems with regard to interference from single UWB device into a maritime MES terminal deployed on board the ships in international waters.

7.2.2.4 Aggregate interference in 1.6 GHz band

The aggregate interference into the satellite receiver is unlikely to be problematic.

7.2.2.5 Search and rescue

The results for MSS Search and rescue are independent of the PRF value.
At 406 MHz, using the slope mask, it is unlikely to have compatibility problems.
A protection distance of 6 km is required around each Earth Station in the band 1544-1545 MHz.

7.3 EESS

7.3.1 Summary table

Victim Radiocommunications Service	Earth Exploration Satellite Service
Application / System	The EESS systems are divided into three kinds of systems:
EESS (passive)	- where on-board satellite receivers (radiometers) are able to observe natural emissions of the Earth and its atmosphere
EESS (active)	- where radar signals are sent towards the Earth in order to get an accurate mapping of Earth surface
EESS	- where signals are sent from the Earth to satellites to control them in orbit, and from satellites to the Earth to collect on-board information
Frequency band	
EESS (passive)	1400-1427 MHz around 6.9 GHz 10.6-10.7 GHz
EESS (active)	5250-5570 MHz
EESS	2025-2110 MHz (Earth to Space) 2200-2290 MHz (Space to Earth) 8025-8400 MHz (Space to Earth)
Receiver station	
Station description	Satellite on-board receiver for EESS (passive), EESS (active) and for EESS for Earth to Space links Ground satellite station for EESS for Space to Earth links
Receiver characteristics	
Bandwidth	Depending on the above frequency bands
Receiver antenna	
EESS (passive):	in many cases, directional antennas having high beam efficiency. Antenna gains vary from 9 to 45 dBi for the above frequency bands.
EESS (active):	directional antennas, having gains from 32 to 43 dBi.
EESS:	For on-board receivers at 2 GHz, antennas are omni directional with low antenna gains (close to 0 dBi). For ground stations, antennas are directional: dishes having antenna gains from 46 dBi (2 GHz) to 55 dBi (8 GHz).
Protection requirement	

EESS (passive):	1400-1427 MHz: -158.3 dBm/MHz according to ITU-R 1029-2 for a radiometer sensitivity of 0.05 K, future systems currently planned will have lower sensitivity (0.01 K of resolution) which results in an interference criteria of -165.3 dBm/MHz. Around 6.9 GHz: -159 dBm/MHz according to ITU-R 1029-2. 10.6-10.7 GHz: -156 dBm/MHz according to ITU-R 1029-2.
EESS (active):	-113 dBm/MHz for spaceborne altimeters, -115.3 dBm/MHz.
EESS:	-117 dBm/MHz at the antenna level of the spaceborne receiver in the band 2025-2110 MHz, -172 dBm/MHz for the band 2200-2290 MHz band (already includes the station antenna gain), -124 dBm/MHz for the band 8025-8400 MHz band (already includes the station antenna gain).

Interference scenario & methodology

UWB characteristics	
PSD limit - EESS (passive)	
FCC indoor / outdoor	-75 dBm/MHz at 1400 MHz -41.3 dBm/MHz around 6.9 GHz -51.3 dBm/MHz at 10.6 GHz indoor usage -61.3 dBm/MHz at 10.6 GHz outdoor usage
Slope mask indoor	-80.9 dBm/MHz at 1400 MHz -41.3 dBm/MHz around 6.9 GHz -51.3 dBm/MHz at 10.6 GHz
Slope mask outdoor	-90.9 dBm/MHz at 1400 MHz -41.3 dBm/MHz around 6.9 GHz -61.3 dBm/MHz at 10.6 GHz
PSD limit - EESS (active)	
FCC indoor / outdoor, slope mask indoor / outdoor	-41.3 dBm/MHz at 5 GHz
PSD limit - EESS	
FCC indoor	-52 dBm/MHz at 2025 MHz -52 dBm/MHz at 2200 MHz -41.3 dBm/MHz at 8 GHz
FCC outdoor	-62 dBm/MHz at 2025 MHz -62 dBm/MHz at 2200 MHz -41.3 dBm/MHz at 8 GHz
Slope mask indoor	-66 dBm/MHz at 2025 MHz -66 dBm/MHz at 2200 MHz -41.3 dBm/MHz at 8 GHz
Slope mask outdoor	-76 dBm/MHz at 2025 MHz -76 dBm/MHz at 2200 MHz -41.3 dBm/MHz at 8 GHz
Activity factor	
Category B aggregate	For ground station receivers: 5 %
Category C aggregate	For satellite receivers: 5 %
Single interferer	N/A
Aggregate interference	
Methodology	NTIA air borne aggregation model FANTASMA method to compute protection distances for satellite ground station
Propagation model	Free space propagation model and additional parameter for indoor usage
Mitigation techniques	-

Reference deployment scenario	Relevant for categories B & C, aggregate analysis.		
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km²)	100	1000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
% Outdoor	20%	20%	20%

Results of theoretical compatibility studies	Aggregate interference analysis only

- *EESS (passive) in the band 1400-1427 MHz*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

PSD limits in dBm/MHz	Maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage
FCC mask	6
Slope mask	62

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral (both indoor and outdoor) density in dBm/MHz	Required UWB Power spectral density in dBm/MHz	
		Outdoor limit (dBm/MHz)	Indoor limit (dBm/MHz)
1	-68	-74	-64
10	-78	-84	-74
100	-88	-94	-84
1000	-98	-104	-94
10000	-108	-114	-104

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km^2: the corresponding PSD in dBm/MHz is:
-88 for both indoor and outdoor if no distinction is made between outdoor and indoor usage
or -94 for outdoor and -84 for indoor if a distinction is made between outdoor and indoor usage

- *EESS (passive) around 6.9 GHz*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits
For the FCC or slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 1.

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral (both indoor and outdoor) density in dBm/MHz
1	-42
10	-52
100	-62
1000	-72
10000	-82

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km²: the corresponding PSD in dBm/MHz is:
-62 for both indoor and outdoor if no distinction is made between outdoor and indoor usage

- *EESS (passive) at 10.6 GHz*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits
For the FCC or slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 194.

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz		Required UWB Power spectral density in dBm/MHz
	Indoor and indoor limit	Outdoor limit (dBm/MHz)	Indoor and outdoor limit (dBm/MHz)
1	-30	-40	-37
10	-40	-50	-47
100	-50	-60	-57
1000	-60	-70	-67
10000	-70	-80	-77

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km²: the corresponding PSD in dBm/MHz is:
-57 if no distinction is made between outdoor and indoor usage

- *EESS (active) at 5 GHz: spaceborne radar altimeter*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits
For the FCC or slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 83000.

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral (both indoor and outdoor) density in dBm/MHz
1	7
10	-3
100	-13
1000	-23
10000	-33

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km²: the corresponding PSD in dBm/MHz is:
-13 for both indoor and outdoor if no distinction is made between outdoor and indoor usage

- *EESS (active) at 5 GHz: synthetic aperture radar*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits
For the FCC or slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 12000.

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral (both indoor and outdoor) density in dBm/MHz
1	-1
10	-11
100	-21
1000	-31
10000	-41

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km2: the corresponding PSD in dBm/MHz is:
-21 for both indoor and outdoor if no distinction is made between outdoor and indoor usage

- *EESS in the band 2025-2110 MHz*

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits
For the FCC or slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 22000.
For the slope mask, the maximum density of active UWB transmitters (/km²) for both outdoor and indoor usage is 500000.

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

Density of UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz	Required UWB Power spectral density in dBm/MHz	
	Outdoor and indoor limit	Outdoor limit (dBm/MHz)	Indoor limit (dBm/MHz)
1	-15	-19	-9
10	-25	-29	-19
100	-35	-39	-29
1000	-45	-49	-39
10000	-55	-59	-49

Calculation 3: **required UWB PSD emission limit** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km^2: the corresponding PSD in dBm/MHz is
-35 if no distinction is made between outdoor and indoor usage

- *EESS in the band 2200-2290 MHz*

Calculation 1: **minimum protection distances** associated with different densities of active UWB transmitters and with standard UWB PSD emission limits

UWB density (UWB/km²)	UWB spectrum mask e.i.r.p. limit (dBm/MHz)	FCC outdoor mask -62	FCC indoor mask -52	slope outdoor mask -76	slope indoor mask -66
10	Protection distance, maximum radius of 30 km	13 km	8 km	10 m	10 m
100	Protection distance, maximum radius of 30 km	28 km	27 km	5 km	1 km

Calculation 2: **minimum protection distances** associated with different densities of active UWB transmitters and with different UWB PSD emission limits

Computation of the protection distance for a maximum radius of 30 km

Density of UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = - 70	Required UWB Power spectral density in dBm/MHz Outdoor = -52 Indoor = - 42	Required UWB Power spectral density in dBm/MHz Outdoor = -62 Indoor = -52	Required UWB Power spectral density in dBm/MHz Outdoor = -72 Indoor = -62	Required UWB Power spectral density in dBm/MHz Outdoor = -82 Indoor = -72
1	10 m	29 km	20 km	1 km	10 m
10	10 m	29.9 km	29 km	20 km	1 km
100	4 km	29.99 km	29.9 km	29 km	20 km
1000	25 km	30 km: **NO UWB** possible	29.99 km	29.9 km	29 km
10000	29.9 km	30 km: **NO UWB** possible	30 km: **NO UWB** possible	29.99 km	29.9 km

Calculation 3: **required UWB PSD emission limit and protection distance** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km²: the corresponding PSD in dBm/MHz is -70 if no distinction is made between outdoor and indoor usage.
The corresponding protection distance equals 4 km.

- *EESS in the band 8025-8400 MHz*

Calculation 1: **minimum protection distances** associated with different densities of active UWB transmitters and with standard UWB PSD emission limits

UWB density	UWB spectrum mask	FCC/CEPT outdoor mask	FCC/CEPT indoor mask
(UWB/km²)	e.i.r.p. limit (dBm/MHz)	-41,3	-41,3
1000	Protection distance for a maximum radius of 10 km	10 m	10 m
10000	Protection distance for a maximum radius of 10 km	4 km	10 m

Calculation 2: **minimum protection distances** associated with different densities of active UWB transmitters and with different UWB PSD emission limits

Computation of the protection distance for a maximum radius of 10 km

Density of UWB transmitters per km²	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = -41.3	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = -51.3	Required UWB Power spectral density in dBm/MHz Outdoor and Indoor = -61.3
1	10 m	10 m	10 m
10	10 m	10 m	10 m
100	10 m	10 m	10 m
1000	10 m	10 m	10 m
10000	4 km	10 m	10 m

Calculation 3: **required UWB PSD emission limit and protection distance** in accordance with the deployment scenario
For a rural deployment, the density equals 100 UWB per km²: the corresponding PSD in dBm/MHz is:
-41.3 for indoor and -41.3 for outdoor if no distinction is made between outdoor and indoor usage. The corresponding protection distance equals 10 m.

7.3.2 Conclusion

The above summary table highlights the main results for each EESS frequency band considered. Taking into consideration the emission limits as given by the FCC and Slope masks, the following can be concluded on the use of the following bands by generic UWB devices:

- 1400-1427 MHz: use of UWB devices is not compatible;
- 6.9 GHz: UWB devices are required to have lower eirp than those already planned in order to achieve compatibility;
- 10.6-10.7 GHz: UWB devices are required to have lower eirp than those already planned in order to achieve compatibility;
- 5 GHz: compatibility can be achieved;
- 2025-2110 MHz: compatibility can be achieved;
- 2200-2290 MHz: a protection distance of 4 km is required around each Earth station;
- 8025-8400 MHz: compatibility can be achieved around each Earth station.

Based on the analysis provided in this study, it is proposed to use the following generic UWB PSD limits:

- 1400-1427 MHz: -88 dBm/MHz
- 6425-7250 MHz: -62 dBm/MHz
- 5250-5570 MHz: -21 dBm/MHz
- 2025-2110 MHz: -35 dBm/MHz
- 2200-2290 MHz: -70 dBm/MHz with a 4 km exclusion zone
- 8025-8400 MHz: -41.3 dBm/MHz
- 10.6-10.7 GHz: -57 dBm/MHz

7.4 Radio Astronomy Service

7.4.1 Summary table

Victim Radiocommunications Service	Radio Astronomy

Application	
System description	Radio telescope (receiver): single dish, connected element interferometry, Very Long Baseline Interferometry (VLBI). Observations are done as continuum observations (broad band) and spectral line observations (narrow band). The conclusions apply to the issue of the compatibility between UWB transmissions and single dish radio telescopes.
Frequency band	Frequency bands allocated to the Radio Astronomy Service, and their protection requirements

Frequency band (MHz)	Detrimental spfd (Rec. ITU-R **RA.769**) $(dB(Wm^{-2}Hz^{-1}))$
608 - 614 [3]	-253 [2]
1330.0 - 1400.0 [3]	-239 [1], -255 [2]
1400.0 - 1427.0 [4]	-239 [1], -255 [2]
1610.6 - 1613.8 [3]	-238 [1]
1660.0 - 1670.0 [3]	-237 [1], -251 [2]
1718.8 - 1722.2 [3]	-237 [1]
2655.0 - 2690.0 [3]	-247 [2]
2690.0 - 2700.0 [4]	-247 [2]
3260.0 - 3267.0 [3]	-230 [1]
3332.0 - 3339.0 [3]	-230 [1]
3345.8 - 3352.5 [3]	-230 [1]
4800.0 - 4990.0 [3]	-230 [1], -241 [2]
4990.0 - 5000.0 [3]	-241 [2]
6650.0 - 6675.2 [3]	-230 [1]

Notes to the Table	1: spectral line observations (narrow band) [2]: continuum observations (broadband) [3]: RR No. 5.149 applies [4]: RR No. 5.340 applies
Receiver station	Category B receiver
Station description	Single dish, connected element interferometry, Very Long Baseline Interferometry (VLBI)
Receiver characteristics	See Recommendation ITU-R RA.769
Bandwidth	
Noise figure / Noise temperature	
Signal model	
Receiver antenna	See Recommendations ITU-R SA.509, RA.769
Type	
Gain	0 dBi (for sidelobes of RA antenna)
Model	
Protection requirement	
Criteria	
Reference (e.g. ITU-R Rec.)	See Recommendation ITU-R RA.769

Interference scenario & methodology

UWB characteristics	
PSD limit	Impact of -41.3 dBm/MHz PSD limit has been evaluated
Activity factor	
Single interferer	N/A
Methodology	
Propagation model	
Mitigation techniques	
Aggregate interference	
Methodology	Summation methodology, assuming all UWB emitters located on equally spaced concentric rings with the victim receiver at the centre of the distribution.
Propagation model	Clear-air propagation models given in Recommendation ITU-R P.452 were used. This involves several propagation mechanisms: Line-of-Sight propagation; spherical-earth diffraction and tropospheric scatter: - For a time percentage of 10% and distances greater than approximately 100 km, the tropospheric scatter mechanism is typically dominant. - For distances between 20 and 100 km, the spherical-earth diffraction is typically dominant. - For distances shorter than 20 km Line-of-Sight dominates.
Mitigation techniques	N/A
Reference deployment scenario	Aggregate interference calculations based on 1-RAS scenario
Deployment scenario 1	(1a) Rural (1b) Suburban (1c) Dense Urban

UWB density (/km²)[11]	100	1000	10000
Activity factor	5%	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
% Outdoor	20%	20%	20%

Results of theoretical compatibility studies

Single interferer	Significant separation distances are necessary between a single UWB device transmitting towards a radio astronomy station and that radio astronomy station. For the proposed slope mask (outdoor) the separation distances range from a few km to about 100 km for continuum observations and to a few tens of km for spectral line observations, and similar ranges of separation distances are estimated for the proposed FCC mask (outdoor). For a flat mask of –41.3 dBm/MHz similar values are found.

Aggregate interference

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

N/A

Calculation 2: **required UWB PSD emission limit** to ensure compatibility for different densities of transmitting UWB device per km^2, ρ

Protection distance: 30m

Note: The smallest distance between a radio telescope and the edge of the territory of a radio astronomy station. For European radio astronomy stations this ranges from about 30 meters to a few hundred meters. To ensure protection for all European radio astronomy stations a typical value of 30 meter was taken.

The table below gives some examples of the maximum tolerable e.i.r.p.$_{max}$ per UWB device as function of density of transmitting UWB device per km^2, ρ

Results for deployment scenario 1 are given in the table below:
Maximum tolerable e.i.r.p.$_{max}$ per UWB device as function of density of transmitting UWB device per km^2, ρ

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[11] Formulas were derived to estimate UWB e.i.r.p. and separation distances as function of density of UWB devices transmitting towards a radio astronomy station. Results were tabulated for the UWB densities of 1, 100 and 10000 km^{-2}.

frequency band (MHz)	Building attenuation (dB)	e.i.r.p$_{.max}$ (dBm/MHz)		
		Rural (1a)	Suburban (1b)	Dense urban (1c)
		$\rho = 5$ per km^2	$\rho = 50$ per km^2	$\rho = 500$ per km^2
608 – 614 [3]	5	-113.2 [2]	-123.2 [2]	-133.2 [2]
1330.0 – 1400.0 [3]	9	-95.4 [1], -111.4 [2]	-105.4 [1], -121.4 [2]	-115.4 [1], -131.4 [2]
1400.0 – 1427.0 [4]	9	-95.4 [1], -111.4 [2]	-105.4 [1], -121.4 [2]	-115.4 [1], -131.4 [2]
1610.6 – 1613.8 [3]	12	-90.6 [1]	-100.6 [1]	-110.6 [1]
1660.0 – 1670.0 [3]	12	-89.8 [1], -103.8 [2]	-99.8 [1], -113.8 [2]	-109.8 [1], -123.8 [2]
1718.8 – 1722.2 [3]	12	-90.2 [1]	-100.2 [1]	-110.2 [1]
2655.0 – 2690.0 [3]	12	-100.0 [2]	-110.0 [2]	-120.0 [2]
2690.0 – 2700.0 [4]	12	-100.0 [2]	-110.0 [2]	-120.0 [2]
3260.0 – 3267.0 [3]	12	-82.9 [1]	-92.9 [1]	-102.9 [1]
3332.0 – 3339.0 [3]	12	-82.9 [1]	-92.9 [1]	-102.9 [1]
3345.8 – 3352.5 [3]	12	-82.9 [1]	-92.9 [1]	-102.9 [1]
4800.0 – 4990.0 [3]	12	-82.4 [1], -93.4 [2]	-92.4 [1], -103.4 [2]	-102.4 [1], -113.4 [2]
4990.0 – 5000.0 [3]	12	-93.4 [2]	-103.4 [2]	-113.4 [2]
6650.0 – 6675.2 [3]	17	-77.9 [1]	-87.9 [1]	-97.9 [1]

Notes to the table:
[1]: spectral line observations (narrow band)
[2]: continuum observations (broadband)
[3]: RR No. **5.149** applies
[4]: RR No. **5.340** applies

In these calculations it was assumed that a fraction of 20% of the UWB devices is operating outdoors.

7.4.2 Conclusions

The calculated maximum tolerable e.i.r.p. per UWB device is several tens of dBs below the levels of the spectrum masks considered in this report. It is noted that this difference depends strongly on the aggregated impact of UWB devices emitting towards a RAS antenna. At this moment no accurate estimate of a realistic density of UWB devices is available. For any significant deployment of UWB devices, it is shown that significant separation distances must be needed for the protection of RAS stations. In any protection strategy, a major difficulty will be that outside the territory of a RAS station, the enforcement of such a condition is not practical.

From these results, it can be concluded that there is currently significant incompatibility between UWB emissions and the RAS, for any practical scenario. Whether dedicated mitigation techniques capable of bridging the calculated gap of several orders of magnitude between expected and tolerable e.i.r.p. levels can be implemented is uncertain.

As for the maximum allowable generic UWB PSD, it is proposed to use the limits derived from the sub-urban (1b) deployment scenario.

7.5 DVB-T

7.5.1 Summary table

Victim Radiocommunications Service	European Terrestrial Digital TV Broadcasting System

Application	
System description	The European Terrestrial Digital Television System, also known as (DVB-T), was developed under DVB project group. The system is based on COFDM (Coded Orthogonal Frequency Division Multiplex) modulation technique, which is ideally suited for systems operating in multi-path environments. The three types of modulation schemes (QPSK, 16QAM and 64 QAM) are allowed to suit different applications i.e. Fixed and mobile.
Frequency band	VHF bands: 174-230 MHz (band III) UHF bands: 470-582 MHz (band IV) 582-862 MHz (band V)
Receiver station	
Station description	Fixed and portable
Receiver characteristics	Fixed/Portable
Bandwidth	7,61 MHz
Noise figure / Noise temperature	7 / 290° K
Signal model	QPSK, 16QAM and 64 QAM
Receiver antenna	Fixed
Type	Directional
Height	10 m
Gain	9.15 dB (band III), 12.15 dBi (band IV), 14.15 dBi (band V)
Model:	
Diagram	Directive (opening angle at -3 dB=30)
Directivity discrimination	0-12 dB (VHF band), 0-16 dB (UHF band)
Polarisation Vertical/horizontal	Horizontal/vertical
Polarisation discrimination	3 dB
Receiver antenna	Portable
Type	Omni-directional
Height	1.5 m
Gain	0 dBi (VHF band), 2,15 dBi (UHF band)
Model:	
Diagram	Omnidirectional (no directivity discrimination)
Polarisation Vertical/horizontal	Vertical (no vertical/horizontal discrimination)

Protection requirement	
Criteria	C/N
Reference (e.g. ITU-R Rec.)	Rec. ITU-R BT.1368-3 and The Chester 1997 Multilateral Coordination Agreement

Interference scenario & methodology

UWB characteristics	Modulations: PPM Pulse width (PW): ≈500 ps Pulse peak amplitude: 8.5V/50Ω *Pulse train:* Time dithered (randomised pulse train) PRBS used for dithering: Unknown Pulse repetition frequency (PRF): 1 MHz, 5 MHz and 10 MHz f_{max_level}:≈1.38 GHz Band width (-15 dB below f_{max_level}): ≈3.8 GHz *Antenna height:* ≥ 1.5 m (depending on how and where the equipment is used)
PSD limit	FCC limits and slope emission mask
Activity factor	Not used
Single interferer	
Methodology	MCL
Propagation model	Free pace (Rec. ITU-R P. 525.2) and ITU-R P. 1411-1
Mitigation techniques	Not used
Aggregate interference	MCL
Methodology	Σ P_I=10logN (N= number of UWB interference; N_{max}=10)
Propagation model	Free pace (Rec. ITU-R P. 525.2) and ITU-R P. 1411-1
Mitigation techniques	Not used

Results of theoretical compatibility studies

Single interferer N/A for category C

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)

Protection distance (m):	0.5 (indoor to indoor interference)	3 (indoor/outdoor to outdoor interference)
UWB PSD limit (dBm/MHz)	-89 in the UHF band -94 in the VHF band	-86 in the UHF band -91 in the VHF band

Note 1: 0.5 m (in indoor to indoor interference): in this case the interfering UWB transmitter could be very close to the victim DVB-T receiver
3 m (indoor/outdoor to outdoor interference): this value corresponds to the half of a frequently encountered street width (6 m), in big and medium cities in Europe

Note 2: C/I values used for protection distance calculations were measured in the presence of an interfering UWB signal with PRF=10 MHz

Note 3: The use of the protection criterion *C/I=C/N* (*I/N*=0) does not adequately protect the existing digital broadcasting systems. To ensure an adequate protection an *I/N*=-10 dB is required. In this study a concession has been made by using the protection criterion *C/N*. Therefore, the UWB emission limits obtained according to this protection criterion constitute the less stringent limits which could be acceptable

Calculation 2: **separation distances** associated with different UWB PSD emission limit

	FCC limits	Slope mask (indoor/outdoor)	Flat limit
	.-40 dBm/MHz in the UHF band -42.5 in the VHF band	-102.48/-112.48 dBm/MHz at 800 MHz -120.24/-130.24 dBm/MHz at 500 MHz -154.86/--164.86 dBm/MHz at 200 MHz	-41,3 dBm/MHz (only a very limited number of scenarios were considered)
Separation distance (m)	12-460	0-0.09	5-119
Aggregate interference	Based on the methodology Σ P_I=10logN (N= number of UWB interference; Nmax=10)		
Separation distance (m)	12-1284	0-0.29	Not considered

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits: not considered

Calculation 2: **required UWB PSD emission limit** to ensure compatibility: not considered

7.5.2 Conclusions

A large number of interference scenarios have been simulated to assess the compatibility between the DVB-T and UWB systems in the VHF and UHF TV bands. For each of the considered scenarios, the protection distance (d_{min}) from the DVB-T receiver to the UWB transmitter has been calculated by assuming UWB radiated power density level alternatively from the FCC UWB emission limits in force and the UWB slope emission masks. The obtained distances have been compared with two threshold values $d_{\min}^{in}$=0.5 m and $d_{\min}^{out}$=3 m, which are respectively the protection distances required to ensure a high protection to the DVB-T receivers in indoor and outdoor environments, for fixed and portable reception.

The analysis of the results clearly shows that the FCC UWB emission limits do not guarantee the protection of the DVB-T receivers in presence of UWB emissions ($5 \text{ m} \leq d_{min} \leq 1284 \text{ m}$), while the UWB slope emission masks reduce significantly the interference probability ($d_{min} < 0.5$ m).

The following UWB PSD limits have been calculated to guarantee the protection of DVB-T receivers in presence of UWB emissions:

<u>In indoor environment</u>

- -89 dBm/MHz in the UHF band (470-862 MHz);
- -94 dBm/MHz in the VHF band (174-230 MHz).

<u>In outdoor environment</u>

- -86 dBm/MHz in the UHF band (470-862 MHz);
- -91 dBm/MHz in the VHF band (174-230 MHz).

From these results, a single generic UWB PSD limit can be selected to ensure the protection of the DVB-T in indoor as well as in outdoor environments:

- -89 dBm/MHz in the UHF band (470-862 MHz);
- -94 dBm/MHz in the VHF band (174-230 MHz).

7.6 T-DAB

7.6.1 Summary table

Victim Radiocommunications Service	European Terrestrial Digital Audio Broadcasting System
Application	
System description	The European terrestrial digital sound broadcasting (T-DAB) standard was developed under EUREKA project 147. The system is based on COFDM (Coded Orthogonal Frequency Division Multiplex) modulation scheme with fixed QPSK modulation for data carriers. COFDM modulation is designed to operate in multipath environment and has excellent immunity against narrow band interference. The bandwidth of a single T-DAB frequency block is 1.5MHz and provides 4-5 near CD quality program's per block.
Frequency band	VHF bands: 47-68 MHz (band I, this band was not considered in this study) 87,5-108 MHz (band II, this band was not considered in this study) 174-230 MHz (band III) UHF bands: 1452-1492 MHz (band L)
Receiver station	
Station description	Mobile and portable stations. Fixed stations not considered in this study.
Receiver characteristics	Mobile/Portable
Bandwidth	1.536 MHz
Noise figure / Noise temperature	7-6 / 290° K
Signal model	QPSK
Receiver antenna	Mobile/portable
Type	Omnidirectional
Height	1.5 m
Gain	0 dBi (VHF band), 2,15 dBi (UHF band)
Model:	
Diagram	Omni-directional (no directivity discrimination)
Polarisation	Vertical (no vertical/horizontal discrimination)
Protection requirement	
Criteria	C/N
Reference (e.g. ITU-R Rec.)	WIESBADEN 1995 Special Arrangement

Interference scenario & methodology

UWB characteristics	Modulations: PPM Pulse width (PW): ≈500 ps Pulse peak amplitude: 8.5V/50Ω *Pulse train:* Time dithered (randomised pulse train) PRBS used for dithering: Unknown Pulse repetition frequency (PRF): 1 MHz, 5 MHz and 10 MHz f_{max_level}:≈1.38 GHz Band width (-15 dB below f_{max_level}): ≈3.8 GHz *Antenna height:* ≥ 1.5 m (depending on how and where the equipment is used)
PSD limit	FCC limits and slope emission mask
Activity factor	Not used
Single interferer	
Methodology	MCL
Propagation model	Free pace (Rec. ITU-R P. 525.2) and ITU-R P. 1411-1
Mitigation techniques	Not used
Aggregate interference	MCL
Methodology	ΣP_I=10logN (N= number of UWB interference; N_{max}=10)
Propagation model	Free space (Rec. ITU-R P. 525.2) and ITU-R P. 1411-1
Mitigation techniques	Not used

Results of theoretical compatibility studies

Single interferer N/A for category C

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)

Protection distance (m):	0.3 (indoor to indoor interference)	1 (indoor/outdoor to outdoor interference)
UWB PSD limit (dBm/MHz)	-85 in the UHF band (band L) -97 in the VHF band	-75 in the UHF band (band L) -87 in the VHF band

Note 1: 0.3 m (in indoor to indoor interference): in this case the interfering UWB transmitter could be very close to the victim T-DAB receiver
1 m (indoor/outdoor to outdoor interference): this assumption takes into consideration the pedestrian use of portable PDA-T-DAB receivers

Note 2: C/I values used for protection distance calculations were measured in the presence of an interfering UWB signal with PRF=10 MHz

Note 3: The use of the protection criterion *C/I*=*C/N* (*I/N*=0) does not adequately protect the existing digital broadcasting systems. To ensure an adequate protection an *I/N*=-10 dB is required. In this study a concession has been made by using the protection criterion *C/N*. Therefore, the UWB emission limits obtained according to this protection criterion constitute the less stringent limits which could be acceptable

Calculation 2: **separation distances** associated with different UWB PSD emission limit

	FCC limits	Slope mask (indoor/outdoor)

	-75 dBm/MHz in band L -42.5 in the VHF band	-102.48/-112.48 dBm/MHz at 800 MHz -120.24/-130.24 dBm/MHz at 500 MHz -154.86/--164.86 dBm/MHz at 200 MHz
Separation distance (m)	0.79-159	0-0.55
Aggregate interference	Based on the methodology ΣP_I=10logN (N= number of UWB interference; Nmax=10)	
Separation distance (m)	0.79-520	0-1.75

7.6.2 Conclusions

A large number of interference scenarios have been simulated to assess the compatibility between the T-DAB and UWB systems, in the VHF/UHF bands. For each of the considered scenarios, the protection distance (d_{min}) from the T-DAB receiver to the UWB transmitter has been calculated by using UWB radiated power density levels alternatively from the FCC UWB emission limits and the UWB slope emission masks proposed for UWB applications in the band 3.1-10.6 GHz. The obtained protection distances have been compared with two threshold values $d_{\min}^{in}$ = 0.3 m and $d_{\min}^{out}$ = 1 m, which are respectively the protection distances required to ensure a high protection to the T-DAB receivers in indoor and outdoor environments, for mobile and portable reception.

The analysis of results clearly shows that the FCC UWB emission limits do not guarantee the protection of T-DAB receivers in the VHF band (33 m $\leq d_{min} \leq$ 520 m), while the UWB slope emission masks reduce the interference probability significantly (d_{min}.≈ 0 m). As for the UHF band (band L), in the majority of the considered scenarios the FCC UWB emission limits do not guarantee the protection of T-DAB receivers (0.79 m $< d_{min} <$ 5.66 m), while the UWB slope emission masks still ensure a better protection to T-DAB receivers ($d_{min} <$ 1.75 m).

The following UWB PSD limits have been calculated to guarantee the protection of T-DAB receivers in presence of UWB emissions:

In indoor environment
- -85 dBm/MHz in the UHF band (1452-1492 MHz);
- -97 dBm/MHz in the VHF band (174-230 MHz).

In outdoor environment
- -75 dBm/MHz in the UHF band (1452-1492 MHz);
- -87 dBm/MHz in the VHF band (174-230 MHz).

From these results, a single generic UWB PSD limit can be selected to ensure the protection of the T-DAB in indoor as well as in outdoor environments:
- -85 dBm/MHz in the UHF band (1452-1492 MHz);
- -97 dBm/MHz in the VHF band (174-230 MHz).

7.7 Bluetooth

7.7.1 Summary table

Victim Radiocommunications Service	Land Mobile Service
Application	Bluetooth: Global wireless connectivity standard
System description	

Frequency band	2.45 GHz ISM-band
Receiver station	
Station description	Cat A
Receiver characteristics	
Bandwidth	1-4 MHz
Noise floor	-100 dBm/MHz
Signal model	FH (for 1 MHz Bluetooth version)
Sensitivity (MUS)	<-80 dBm (for 1 MHz Bluetooth version)
Receiver antenna	
Type	Omni
Gain	0 dBi
Model	
Protection requirement	
Criteria	C/I = + 20 dB (based on measured performance)
Reference (e.g. ITU-R Rec.)	

Interference scenario & methodology

UWB characteristics	
PSD limit	- 41.3 dBm/MHz flat limit, FCC mask (22 April 2002), Slope mask.
Activity factor	N/A (Single interferer)
Single interferer	
Methodology	MCL
Propagation model	Free-space (ITU-R P.525-2) and Recommendations ITU-R P.1411-1 and ITU-R P.1238-2
Mitigation techniques	-

Results of theoretical compatibility studies

Single interferer	N/A for category C
Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)	
Protection distance:	36 cm
UWB PSD limit (dBm/MHz)	-75

Note: The above calculated limit is based on a Sensitivity of -80 dBm and a C/I ratio of +20 dB

7.7.2 Conclusion

This study took into account typical receiver sensitivity (below -80 dBm) of current Bluetooth devices and a protection distance of 36 cm. Outcome indicates that the required maximum permissible UWB PSD limit is -75 dBm/MHz, which is roughly 5 dB lower than the level proposed by the preliminary slope mask (outdoor).

7.8 RLAN in the 5 GHz range

7.8.1 *Summary table*

Victim Radiocommunications Service	Land Mobile Service
Application	
System description	IEEE 802.11a (and HIPERLAN-2) Measurement set-up for determination of tolerable C/I for IEEE 802.11a, Access point and ad-hoc network
Frequency band	5150-5350 and 5470-5725 MHz, centre frequency for measurement: 5250 MHz
Receiver station	
Station description	IEEE 802.11a: lap-top with adapter
Receiver characteristics	
Bandwidth	16.5 MHz
Sensitivity	-82 dBm for 6 Mb/s, -77 dBm for 18 Mb/s, -73 dBm for 36 Mb/s, -65 dBm for 54 Mb/s (HIPERLAN/2 is about 3 dB more sensitive)
Modulation	BPSK, ½ for 6 Mb/s, QPSK, ¾ for 18 Mb/s, 16-QAM, ¾ for 36 Mb/s, 64-QAM, ¾ for 54 Mb/s
Receiver antenna	
Type	Integrated Antenna
Gain	-
Model	-
Protection requirement	
Criteria	Measured C/I for about 10 % frame error (~ BER 10^{-5}): 6 dB for 6 Mb/s, 10 dB for 18 Mb/s, 24 for 36 Mb/s, 26 for 54 Mb/s
Reference (e.g. ITU-R Rec.)	-

Interference scenario & methodology	
UWB characteristics	As currently considered in the compatibility study
PSD limit	-41.3 dBm/MHz (FCC limit and proposed European sloped mask)
Activity factor	Single closest interferer: 100 % (Category A)
Single interferer	
Methodology	Minimum Coupling Loss (MCL)
Propagation model	Free space and ITU-R Rec. P.1238 (indoor)
Mitigation techniques	-

Results of theoretical compatibility studies	

Single interferer

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)

Protection distance:	36 cm
UWB PSD limit (dBm/MHz)	-68.2

Note: Protection distance as derived for IMT-2000 MS

Calculation 2: **separation distances** associated with different UWB PSD emission limit

	FCC limits (-41.3 dBm/MHz)	
Separation distance (m)		
Free space	4	6 Mb/s
	3.6	18 Mb/s
	8	36 Mb/s
	5.7	54 Mb/s
ITU-R P.1238, indoor	2.5	6 Mb/s
	2.4	18 Mb/s
	4	36 Mb/s
	3.2	54 Mb/s

7.8.2 Conclusions

The case of single interfering UWB device deployed in close vicinity of an RLAN terminal in the 5 GHz range was analysed and identified as the most critical case for Wireless Access Systems such as RLANs.

The required separation distances was computed for measured tolerable C/I ratios for RLANs (IEEE 802.11a). Assuming the UWB PSD limits from FCC mask or from the proposed European sloped mask, separation distances are required up to 8 m.
Assuming a reference distance of 36 cm between the UWB device and the RLAN terminal and free space propagation, the calculation of permissible UWB PSD results in -68.2 dBm/MHz. To ensure protection of HIPERLAN-2, this UWB PSD limit has to be reduced by 3 dB due to higher sensitivity of the HIPERLAN-2 receiver.

This result is in line with, and supplements, the theoretical study performed in ITU-R and reported in corresponding Annex 1.6 of the ITU-R TG1/8 Report. The ITU-R study used as interference criteria the system degradation of 1 dB. In this study, RLANs in the 2.4 GHz ISM-band and the effect of aggregate UWB interference on victim RLAN terminal were also considered.

7.9 IMT-2000

7.9.1 Summary table

7.9.1.1 Mobile Station (MS)

Victim Radiocommunications Service	Land Mobile Service
Application	IMT-2000
System description	
Frequency bands	1 710-1 885 MHz, 1 885-2 025 MHz, 2 110-2 170 MHz, 2 500-2 690 MHz
Receiver station	Category A
Station description	Mobile station
Receiver characteristics	IMT-2000/ W-CDMA Mobile station
Bandwidth	3.84 MHz
Noise figure / Noise temperature	9 dB
Signal model	W-CDMA
Receiver antenna	
Type	Omni-directional
Gain	0 dBi
Model	

Protection requirement	
Criteria	**Single interferer calculation** : I_{UWB} max = -115 dBm/MHz, based on simulation results contained in Annex 2.9 (section reference). The simulations considered a representative set of IMT-2000 service categories, from voice to high data rates transmission. This I_{UWB} max value is associated with a location of the considered IMT-2000 terminal at the edge of cell. It does take into account IMT-2000 intra- and inter-cell interference (characterised by geometry factor as defined in Annex 9 chapter 6.1.2.1).
Reference (e.g. ITU-R Rec.)	-

Interference scenario & methodology

UWB characteristics	
PSD limit	
Activity factor	N/A in the case of the single interferer methodology;

Single interferer	Reference scenario
Methodology	MCL : minimum UWB PSD to meet the protection criterion
Propagation model	Free space loss
Mitigation techniques	

Results of theoretical compatibility studies

Single interferer

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s) in the frequency band

Frequency band:	1710 – 1885 MHz	1885 - 2025 MHz	2110 - 2170 MHz	2500 - 2690 MHz
Protection distance:	36 cm (Note 1)			
UWB PSD limit (dBm/MHz)	-86.4 dBm/MHz	-85.9 dBm/MHz	-85 dBm/MHz	-83.1 dBm/MHz
Minimum PRF (MHz)	(Note 2)			

Note 1:	The separation distance of 36 cm, is felt appropriate to take into account a foreseen frequent scenario where a UWB may be on a desk in an office environment, not far from a potential victim IMT-2000 mobile station.
Note 2	UWB interference has been modelled as White Gaussian Noise, which is equivalent to assuming a PRF>3.84 MHz and perfect pulse dithering for pulsed UWB devices.

7.9.1.2 Base Station

Victim Radiocommunications Service	Land Mobile Service

Application	IMT-2000
System description	
Frequency bands	2 110-2 170 MHz
Receiver station	Category B
Station description	Base station
Receiver characteristics	IMT-2000/ W-CDMA Base station

Bandwidth	3.84 MHz
Noise figure / Noise temperature	5 dB
Cell load	75%
Signal model	W-CDMA
Receiver antenna	
Type	65° sectoral antenna downtilted by 4°
Gain	18 dBi
Model	to ITU-R Rec. 1336-1, k=0.7
Height	35 m
Protection requirement	
Criteria	I_{UWB}/N = -13 dB (urban areas), derived from the calculations as provided in A9.2, section <3.4.4.4.2> (Base stations).
Reference (e.g. ITU-R Rec.)	-

Interference scenario & methodology

UWB characteristics	
PSD limit	
Activity factor	As defined in following reference deployment scenarios 1c and 3a.
Single interferer	
Methodology	
Propagation model	
Mitigation techniques	
Aggregate interference	
Methodology	As described in Annex 2.9, section 2-9.6.2.2 (Multiple interferers into a single base station)
Propagation models	–15.3 – 37.6log(d) (HATA model) together with standard deviation for a log-normal distribution of 10 dB (urban outdoors), and -25.3-37.6log(d) together a standard deviation of 12 dB (urban indoors).
Mitigation techniques	

Reference deployment scenario	Relevant for categories B & C, aggregate analysis.		
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km²)	100	1000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
% Outdoor	20%	20%	20%

Deployment scenario 3	Home / Office environment - average building, for outdoor aggregation (3a)	Home / Office environment - desk premises, for indoor aggregation (3b)
UWB density (per floor)	1 per 10 m²	1 per m²
Activity factor	20 %	5% & 20%
Density of active UWB transmitters	0.2 per 10 m²	0.05 per m² & 0.2 per m²

Note: specific mitigation factors may be considered in the relevant compatibility studies addressing “hot spot” deployment scenarios in Home/Office environment to reflect WPAN approach.

Results of theoretical compatibility studies	

Aggregate interference	N/A for category A

Calculation 1: **maximum tolerable density of active UWB transmitters** associated with different UWB PSD emission limits

Calculation 2: **required UWB PSD emission limit** to ensure compatibility

	Density of active UWB transmitters (/km²)	Required UWB PSD limit (dBm/MHz)
Urban scenario 1c	500	-67 dBm/MHz
Average building (3a)	20,000 (0.2/10m²)	-81 dBm/MHz

Note: Values linearly interpolated from table A.9.24 in Annex 9

7.9.2 Conclusions

7.9.2.1 Mobile Station

The above tables contain the study results for the most critical reference scenario of interference from a single UWB interferer into IMT-2000 mobile station, which concludes that the maximum UWB PSD level that allows protecting IMT-2000 mobile stations at a reference distance of 36 cm is -85 dBm/MHz.

Results from a complementary probabilistic study show that for a typical UWB deployment scenario in a desk work area office environment, UWB devices transmitting at -85dBm/MHz with 20% activity factor would cause a 10% probability of interference to IMT-2000 mobile stations.

Note that compatibility studies of UWB emissions with IMT-2000 victim systems in the 1800 MHz band also ensure the protection of GSM/EDGE systems in this band since the I/N_{th} criterion for IMT-2000 is more critical.

7.9.2.2 Base Station

This sub-section summarises results of compatibility studies between UWB interferer and IMT-2000 base stations.

The results contained in the table of §7.9.1.2 are the maximum UWB PSD values to meet the protection requirements of IMT-2000 base stations in the more critical, urban case of UWB deployment. For the "average building" scenario (3a), the maximum acceptable UWB PSD is -81dBm/MHz. Values were interpolated from the studies contained in Annex 9. Note that in Annex 9 Table A9.24, which provides UWB PSD values needed to protect IMT-2000 base stations, used active UWB densities of 10,000 to 100,000 per km^2, not matching exactly the deployment scenarios 1c and 3a considered here.

7.10 Radio Navigation Satellite Service (RNSS)

7.10.1 Summary table

Victim Radiocommunications Service	Radio Navigation Satellite Service (RNSS)

Application	
System description	The purpose of RNSS is to provide accurate position for users using a constellation of MEO satellites. Three types of systems are recognized to operate in the Radio Navigation Satellite Service: GPS, GALILEO and GLONASS. This study considers the Galileo and GLONASS systems.
Frequency band	Detailed below are the frequency bands used by the 3 systems.

GPS	L5: 1164-1188 MHz L2: 1215-1239 MHz L1: 1563-1587 MHz
GALILEO	E5: 1164-1219 MHz E6: 1258-1300 MHz L1: 1559-1593 MHz
GLONASS	G3: 1189-1215 MHz G2: 1237-1254 MHz G1: 1593-1610 MHz
Receiver station	
Station description	Category A receiver
Receiver characteristics	
Bandwidth	-
Noise figure / Noise temperature	-
Signal model	ITU-R M 1477, basis of the current compatibility analysis.
Receiver antenna gain for Galileo system	
non “Safety of life” applications	0 dBi
“Safety of life” applications	5 dBi
Receiver antenna gain for GLONASS system	
non “Safety of life” applications	3 dBi
“Safety of life” applications	5 dBi
Protection requirement	
Criteria for Galileo	-111.3 dBm/MHz (Acquisition mode: receiver aggregate wideband interference threshold).
non “Safety of life” applications	I/N = -6 dB
“Safety of life” applications	For Galileo aeronautical “Safety of life” applications: ⇨An aeronautical safety margin of 5.6 dB is included as explained in ITU-R M.1477. ⇨A I/N of -20 dB. This value actually represents an error performance degradation of 1 % for all sources of interference.
Criteria for GLONASS	-112 dBm/MHz (Acquisition mode: receiver aggregate wideband interference threshold).
non “Safety of life” applications	I/N = -6 dB
“Safety of life” applications	For GLONASS aeronautical “Safety of life” applications: ⇨An aeronautical safety margin of 5.6 dB is included as explained in ITU-R M.1477. ⇨A I/N of -20 dB. This value actually represents an error performance degradation of 1 % for all sources of interference.
ITU-R Recommendations:	ITU-R M.1088 ITU-R M.1317 ITU-R M.1477 ITU-R M.1479 ITU-R M.1318

Interference scenario & methodology

UWB characteristics	
PSD limit	Maximum e.i.r.p. density calculated.
Activity factor	
Single interferer	Single interferer
Methodology	
Propagation model	Free space loss
Mitigation techniques	
Aggregate interference	Considered for GLONASS system.
Methodology	NTIA model
Propagation model	Free space loss
Mitigation techniques	

Results of theoretical compatibility studies

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)

	Non Safety-of life application	Safety-of-life application
Single interferer		
Protection distance:	1m	30m
Galileo (noise-like case)		
UWB PSD limit (dBm/MHz)	-83.5 dBm/MHz	-79 dBm/MHz
Minimum PRF (MHz)	-	-
GLONASS (noise-like case)		
UWB PSD limit (dBm/MHz)	-87.0 dBm/MHz	-79 dBm/MHz
Minimum PRF (MHz)	-	-
GLONASS (CW-like case)		
UWB PSD limit (dBm/MHz)	-102.0 dBm/kHz	-94 dBm/kHz
Minimum PRF (MHz)	-	-
Aggregate interferers		
GLONASS (noise-like case)		
UWB PSD limit (dBm/MHz)		-84.7 dBm/MHz
Minimum PRF (MHz)	-	-
GLONASS (CW-like case)		
UWB PSD limit (dBm/MHz)		-99.7 dBm/kHz
Minimum PRF (MHz)	-	-

Note: The analyses detailed in Annex 10 of this Report address primarily the noise-like effect of UWB emissions, based on Galileo protection criteria which needs to be further assessed. The current study will also need to be improved in order to properly assess the impact of CW like and pulse like interference on the Galileo system.

7.10.2 Conclusion

For the protection of the GALILEO and GLONASS stations from noise-like interference, the provisioning of safety-of-life and non-safety-of-life services have been considered in different scenarios.
For the protection of GALILEO:

- In the worst case for the Galileo non-safety-of-life applications a maximum UWB PSD limit of -83.50 dBm/MHz was obtained, assuming a 1 m protection distance;
- For safety-of-life services, a maximum UWB PSD limit of –79 dBm/MHz was obtained, assuming a 30 m protection distance.

For the protection of GLONASS:

- In the worst case for the GLONASS non-safety-of-life applications a maximum UWB PSD limit of -87 dBm/MHz was obtained, assuming a 1 m protection distance.
- For safety-of-life services, a maximum UWB PSD limit of –84.7 dBm/MHz was obtained, assuming a 30 m protection distance.

It is to be noted that the above protection criteria considers effect of single-source UWB signals at the input of navigation receivers. Actual operation of UWB devices would cause interference in the form of periodic or pseudo-periodic sequence of UWB pulses at a navigation receiver input to be similar to effect of narrow-band interference at the receiver front-end.
In that respect it would be appropriate to use the following UWB PSD limits to provide protection of navigation receivers from narrow-band interference:
For the protection of the GLONASS:

- In the worst case for the GLONASS non-safety-of-life applications a maximum UWB PSD limit of -102 dBm/kHz was obtained, assuming a 1 m protection distance.
- For safety-of-life services, a maximum UWB PSD limit of –99.7 dBm/kHz was obtained, assuming a 30 m protection distance.

It is worth noting that the proposed requirements did not consider interference produced by other stations in the radiocommunications services operating in the frequency bands under discussion.

7.11 Fixed satellite service (FSS)

7.11.1 Fixed satellite service - downlink

7.11.1.1 Summary table

Victim Radiocommunications Service	Fixed Satellite Service – downlink

Application
The fixed-satellite service has operated in the 4/6 GHz bands since commercial satellite services were initiated using the geostationary orbit during the 1960s. As a result, there is a large number of Earth Stations installed around the world, which are used on a continuous basis for transmitting telephony, Internet traffic and broadcast feeds. More particularly, these bands are heavily used in Europe for international telephony with other regions of the world or to enable Internet connectivity to regions that are far from the terrestrial Internet backbone (e.g. Africa, Middle-East, overseas territories of CEPT countries).

Frequency bands
3 400-4 200 MHz and 4 500-4 800 MHz, 7250-7750 MHz

Receiver station :	Category B

Typical FSS parameters at 4 and 7 GHz band

Downlink bands	3 400-4 200 MHz and 4 500-4 800 MHz, 7250-7750 MHz[4]					
Antenna reference pattern	Recommendation ITU-R S.465					
Earth station off-axis gain towards the local horizon (dBi)[1, 2]	Elev. Angle	5° [3]	10°	20°	30°	≥48°
	Off-axis gain	14.5	7.0	–0.5	–4.9	–10.0
Bandwidths (range)	40 kHz-72 MHz					
Polarization	Linear or circular					
Noise temperature of ES receiver system	100 K					
Deployment	All regions, in all locations (rural, semi-urban, urban)[5]					

[1] The values were derived by assuming a local horizon at 0° of elevation.

[2] The off-axis antenna gain is independent of the ES antenna diameter for the range of antennas considered.
It is recommended that the elevation angles and gain values provided be used to calculate the interference into the FSS ES.

[3] 5° is considered as the minimum operational elevation angle.

[4] These typical FSS parameters were assumed to also apply to the 7250-7750 MHz band and 7900-8400 MHz Note: it has to be confirmed for the European case

5 FSS antennas in this band may be deployed in a variety of environments smaller antennas (1.8-3.8 m) are commonly deployed on the roofs of buildings in urban or semi-urban locations, whereas larger antennas (4.5 m and above) are typically mounted on the ground and deployed in semi-urban or rural locations.

Typical MSS Feeder link Earth Stations parameters

Parameter	**Symbol**	**Inmarsat-3 Feeder link earth station**	**Inmarsat-4 Feeder link earth station**	**Units**
Downlink Frequency Band		3550-3700	3550-3700	MHz
Antenna Reference Pattern		RR. App 7	RR. App 7	
System noise temp	T_S	71	52.5	K
IF bandwidth	B_{IF}	40	40	MHz

Protection requirement
Recommendation ITU-R S.1432 contains the allowable degradations to the FSS below 15 GHz. The Recommendation states that for all sources of long-term interference that is neither from FSS systems, nor from systems having co-primary status, the allowable interference noise contribution is 1%.

Interference scenario &
methodology

UWB characteristics	
PSD limit	FCC mask , average power UWB emission, peak power UWB emission
Single interferer	
Methodology	Compatibility with single device (section 6.3.1.1)
Propagation model	Combination of generic UWB propagation model, smooth earth diffraction (IUT-R P.526) and Clutter model (ITU-R P. 452)
Aggregate interference	
Methodology	Cumulative distribution of I/N ratios 99% of the time
Propagation model	ITU-R P.452
Reference deployment scenario	Relevant for categories B & C, aggregate analysis.
Deployment scenario 1	(1a) Rural (1b) Suburban (1c) Dense Urban

UWB density (/km²)	100	1000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
% Outdoor	20%	20%	20%

Results of theoretical compatibility studies

Single interferer

Calculation 1: **required UWB PSD emission limit** to ensure given protection distance(s)

Protection distance:	10 m Average UWB emissions	10 m Peak UWB emissions
UWB PSD limit (dBm/MHz)	-63.56	-86.57
Minimum PRF (MHz)	1 MHz	1 MHz

Calculation 2: **separation distances** associated with different UWB PSD emission limit

	FCC limits (-41.3 dBm/MHz) Average UWB emissions	-41.3 dBm/MHz Peak UWB emissions
Separation distance (m) (With 1 MHz PRF)	592.5	990

Aggregate interference

Calculation 1: **required UWB PSD emission limit** to ensure compatibility

	Density of active UWB transmitters (/km²)	Required UWB PSD limit (dBm/MHz)	Associated exclusion zone (m)
Rural (1a)	5	- 53	100
Suburban (1b)	50	- 66	50
Dense Urban (1c)	500	- 77	10

7.11.1.2 Conclusions

The results of sharing studies indicate that due to the impact of aggregate effect of UWB interference, FSS Earth Station receivers can not be adequately protected without significant separation distances (1-3 km) and therefore the reduction in UWB PSD limits is proposed in order to fully protect the FSS downlink.

7.11.2 Fixed satellite service - uplink

7.11.2.1 Summary table

Victim Radiocommunications Service	Fixed Satellite Service – uplink

Application

The fixed-satellite service has operated in the 4/6 GHz bands since commercial satellite services were initiated using the geostationary orbit during the 1960s. As a result, there is a large number of Earth Stations installed around the world which are used on a continuous basis for transmitting telephony, Internet traffic and broadcast feeds. More particularly, these bands are heavily used in Europe for international telephony with other regions of the world or to enable Internet connectivity to regions that are far from the terrestrial Internet backbone (e.g. Africa, Middle-East, overseas territories of CEPT countries).

Frequency bands

5.725-7.075, 7.900-8.400 GHz

Receiver station : category C
Typical FSS parameters at 6/8 GHz (Uplink)

Parameter	**Unit**	**Typical geostationary satellite system**
Uplink band	GHz	5.725-7.075, 7.900-8.400[1]
Free-space loss	dB	199.5
Clear-air loss	dB	0.1
Satellite antenna gain	dBi	35
Noise temperature	K	600

[1] These typical FSS parameters were assumed to also apply to the 7250-7750 MHz band and 7900-8400 MHz [Note : it has to be confirmed for the European case]

Typical MSS Feeder link satellite parameters

Parameter	**Inmarsat-3**	**Inmarsat-4**	**Units**
Beam	Global	Global	
Frequency Band	6425-6575	6425-6725	MHz
System noise temperature	891	501	K
Bandwidth	32.7	150	MHz

Protection requirement

Recommendation ITU-R S.1432 contains the allowable degradations to the FSS below 15 GHz. The Recommendation states that for all sources of long-term interference that is neither from FSS systems, nor from systems having co-primary status, the allowable interference noise contribution is 1%.

Interference scenario & methodology

UWB characteristics	
PSD limit	FCC mask
Aggregate interference	
Methodology	NTIA methodology, GSO-aggregate methodology
Propagation model	Free space propagation model
Reference deployment scenario	Relevant for categories B & C, aggregate analysis.
Deployment scenario 2bis	Global beam scenario
Density of active UWB transmitters (/km²)	0.5

Note: scenario 2bis is proposed as an alternative approach where the density of UWB transmitters is calculated on the basis on a maximum number of UWB devices deployed over a large scale area.
Assuming a total of 2 billion UWB devices over a 200 Mkm², the density of UWB transmitters would be 10 UWB/km².

Results of theoretical compatibility studies

Aggregate interference

Calculation 1: maximum tolerable density/or number of active UWB transmitters

FCC limits
(-41.3 dBm/MHz)

Maximum active UWB transmitters	34 Millions in a area covered by a zonal beam	For FSS, GSO-satellite based methodologies
Maximum active UWB transmitters	400 Millions in a area covered by a global beam	For FSS, NTIA methodologies
Maximum density of active UWB transmitters	885 /km²	For MSS feeder links, GSO-satellite based methodologies
Maximum density of active UWB transmitters	1686/km²	For MSS feeder links, NTIA methodologies

7.11.2.2 Conclusions

Preliminary results indicate that the aggregate interference into the satellite receiver is unlikely to be problematic and no changes to UWB PSD limits are proposed.

7.12 Amateur/Amateur Satellite Services

7.12.1 Summary table

Victim Radiocommunications Service	Amateur (Satellite) service
Application	
System description	Receiver stations in the Amateur (Satellite) Service
Frequency band	A. 5650-5850 MHz (taken as main example) B. 3400-3500 MHz C. 2300-2450 MHz D. 1260-1300 Mhz X. 10000-10500 MHz
Receiver station	
Station description	Low noise narrow band receiver
Receiver characteristics	
Bandwidth	3 kHz or 500 Hz
Noise figure / Noise temperature	1 dB
Signal model	Signals to be received are SSB-Telephony and/or morse telegraphy
Receiver antenna	
Type	Parabolic dish
Gain	A. 30 dBi boresight/ 0 dBi off boresight B. 27 dBi boresight/ 0 dBi off boresight C. 25 dBi boresight/ 0 dBi off boresight D. 22 dBi boresight/ 0 dBi off boresight X. 33 dBi boresight/ 0 dBi off boresight
Model	-
Protection requirement	
Criterion	The receiver systems noise shall not increase by more than 1 dB due to the interfering UWB signal The “reference/protection distance” between the UWB device is 10 meter

Interference scenario & methodology

UWB characteristics	As currently considered in the compatibility study
PSD limit	A and B. -41.3 dBm/MHz (FCC limit and sloped mask) C. –61.3 dBm/MHz outdoor D. –85.5 dBm/MHz outdoor X. –41.3 dBm/MHz
Activity factor	
Category B - Single entry	Single interferer; 100 % activity
Single interferer	
Methodology	Minimum Coupling Loss (MCL)
Propagation model	Free space
Mitigation techniques	-

Receiver antenna not directed towards UWB device

Result:

R**equired UWB emission limit** to ensure given protection distance(s)
Protection distance: 10 m

A. 5.65-5.85 GHz	Eirp max –51 dBm/MHz
B. 3.4 – 3.5 GHz	Eirp max – 55 dBm/MHz
C. 2.3 – 2.45 GHz	Above spectrum mask
D. 1.26 – 1.3 GHz	Above spectrum mask
X. 10 – 10.5 GHz	Eirp max –46 dBm/MHz

7.12.2 Conclusion

The interference criterion for Amateur Service receivers is <1 dB increase of the receiver noise level at a “protection distance” of 10 m.
The impact of a single UWB device deployed in close vicinity to the Amateur Station in the 5.7 GHz range was analysed. The separation distance was computed for an increase in the receiver noise level of 1 dB. Assuming the UWB PSD limits from FCC mask or the proposed European sloped mask, separation distances are required of at least 33 m. In order to arrive at the required protection level at a distance of 10 m the max UWB PSD of the UWB device shall be not more than –51 dBm/MHz. For the 10 GHz band the values were respectively 19 m and –46 dBm/MHz. For the 3.4 GHz band the values were respectively 55 m and –55 dBm/MHz. Due to the fall of the UWB spectrum mask below 3 GHz no interference in the 2.4 and 1.3 GHz amateur band will be encountered in the modelled situation.

7.13 Maritime mobile service and maritime radionavigation service including GMDSS

7.13.1 Summary table

The maritime radiocommunications and radionavigation systems used on ships and by shore stations, as shown in the following table, have been considered in compatibility studies. Cospas-Sarsat and Inmarsat systems, which are widely used on ships, have not however been included in this section as these are covered in other sections of this report. Similarly the RNSS, which is also widely used on ships, has not been included in this section, but is covered elsewhere. Two protection distances have been used: 10 m (in consideration of the case of UWB devices carried onboard a ship) and 300 m in consideration of UWB devices on the shore.

Equipment type/ Frequency band	Maximum UWB Power Into Receiver Antenna (dBm/MHz)	Maximum allowable UWB PSD for a single device at distances of: (dBm/MHz)		Maximum allowable UWB PSD for receiver height of 15 m and multiple UWB devices with 5% activity factor and at densities of: (dBm/MHz)		
				Rural (1a)	Sub-urban (1b)	Dense urban (1c)
		10 m	300 m	100/km^2	1000/km^2	10000/km^2
LORAN 0.09 – 0.11 MHz	-10.2	-57.7	-28.2	-38.9	-48.9	-58.9
DGNSS 0.285 – 0.325 MHz	-35.9	-53.7	-24.2	-34.9	-44.9	-54.9
NAVTEX 0.490 – 0.518 MHz	-7.6	-21.1	8.5	-2.2	-12.2	-22.2
MF radiotelephony 1.6 – 3.8 MHz	-46.0	-47.6	-18.0	-28.7	-38.7	-48.7
HF radiotelegraphy 4 – 27.5 MHz	-50.7	-39.8	-10.3	-20.9	-30.9	-40.9
HF radiotelephony 4 – 27.5 MHz	-58.5	-47.6	-18.0	-28.7	-38.7	-48.7
VHF DSC 156 – 163 MHz	-107.5	-74.1	-44.5	-52.1	-62.1	-72.1
VHF radiotelephony 156 – 163 MHz	-101.5	-68.1	-38.5	-46.1	-56.1	-66.1
UHF radiotelephony 457 – 467 MHz	-98.7	-56.0	-26.5	-34.1	-44.1	-54.1
S band radar 2900 – 3100 MHz	-144.0	-82.0	-52.5	-40.5	-50.5	-60.5
X band radar 9300 – 9500 MHz	-144.0	-72.1	-42.6	-30.6	-40.6	-50.6

7.13.2 Conclusions

For the case of UWB devices carried on board a ship, the most sensitive to interference communication system is the VHF, which requires a UWB PSD limited to –75 dBm/MHz at 158 MHz. This is less than the FCC limit of –41.3 dBm/MHz, but should be readily achievable by proposed slope masks, so there would not appear to be a problem to ship communication systems from UWB devices on board. In the case of navigation systems, the S band radar requires to limit UWB PSD to –82 dBm/MHz at 3000 MHz, and the X band radar requires –72 dBm/MHz at 9400 MHz. These limits are unlikely to be achievable, so preclude the use of UWB devices on board pending further study of the actual effect on ships radars.

For the case of UWB devices on shore, the required UWB PSD limit at VHF is –45 dBm/MHz and a limit of –72 dBm/MHz is required for an aggregate interference in the urban case of 10000 devices per km^2. Therefore there again does not appear to be a problem to ship communication systems assuming a proposed slope mask for UWB. For the radar systems, the required UWB PSD limits are –53 dBm/MHz for S band and –43 dBm/MHz at X band. These limits are not exceeded for aggregate interference until the density exceeds the suburban case. It is very unlikely that ships will be relying on radar systems in situations of such high density of UWB devices so the single interferer was considered being the dominant mechanism. Compared with the FCC limit of –41.3 dBm/MHz, the calculated here additional protection margin for the X band is insignificant, but for the S band it is in excess of 11 dB. Such additional loss can be achieved by increasing the assumed separation distance of 300 m to about 1 km. In many situations this may be acceptable, although the physical locations where this shore based interference might arise are subject to further study.

For the case of shore/port stations, the effect on communications receivers is similar to the case of ship-based stations, so there should not be a problem assuming a slope mask for USB PSD. In the case of shore-based radar systems associated with Vessel Traffic Services, these radars look towards sea and are sector blanked when scanning over the shore so they may not be affected by UWB devices as much as in the case of ship-based stations.

7.14 Aeronautical Mobile Service and Radiodetermination Service

7.14.1 Summary table

Victim Radiocommunications Service	Aeronautical systems
Application	
System description	Aeronautical Mobile (R) Service – air-ground communications systems (analogue and digital) operating in the HF, VHF and UHF bands. Aeronautical Radionavigation Services – ground-based and aircraft-based radio navigation systems. Radiolocation - aeronautical primary radar. Note: Brief technical description of the various systems is given in Annex 14.

Frequency bands

Frequency bands and intra-system protection requirements

System	Frequency band (MHz)	Rx Location	Intra-system S/I or required I/N (dB)
NDB	0.255 – 0.5265	Airborne	15
HF Comms	2.85 – 22	Ground	15
		Airborne	15
Marker Beacon	74.8 - 75.2	Airborne	20
ILS Localiser	108 - 112	Airborne	20
VOR	108 - 117.975	Airborne	20
GBAS	108 - 117.975	Airborne	26
VHF Comms, VDL Mode 4	108 – 137	Ground	20
		Airborne	20
VHF Comms, VDL Mode 2&3	117.975 – 137	Ground	20
		Airborne	20
VHF Comms, 8.33 kHz AM	117.975 - 137	Ground	20
		Airborne	20
VHF Comms, 25 kHz AM	117.975 - 137	Ground	20
		Airborne	20
ILS Glidepath	328.6 - 335.4	Airborne	20
50cm Radar	590 – 598	Ground	6
DME/ TACAN	940 - 1215	Ground	8
		Airborne	8
Secondary Surveillance Radar	1030 & 1090	Airborne	12
		Ground	12
23cm Radar	1215 – 1350	Ground	6
10cm Radar	2700 – 3100	Ground	10
Satellite Comms	1545 - 1559 & 1645.5 - 1660	Airborne	
		Satellite	
Radio Altimeters	4200 – 4400	Airborne	6
MLS	5030 – 5150	Airborne	25
Weather Radar	5 350 – 5470	Airborne	
Doppler Radar	8750 – 8850	Airborne	
3cm Radar	9000 - 9500	Ground	6

Notes to the Table:	Intra-system S/I figures or, in the case of radars, I/N figures are provided as an indicative value; S/I figures exclude the 6 dB aviation safety margin and 6 dB multiple technology allowance.		
Interference scenario & methodology			
UWB characteristics			
PSD limit	-41.3 dBm/MHz FCC limit Slope mask		
Single interferer			
Methodology			
Propagation model	Free-space basic transmission loss		
Mitigation techniques	N/A		
Aggregate interference			
Methodology	NTIA interference assessment model.		
Propagation model	Free-space basic transmission loss		
Mitigation techniques	N/A		
Reference deployment scenario			
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
UWB density (/km²)[12]	100	1000	10000
Activity factor	5%	5 %	5 %
Density of active UWB transmitters (/km²)	5	50	500
	In a typical aerodrome ground environment and on an aircraft in the vicinity of an aerodrome, the deployment scenario has been considered to equate to the suburban (1b) model.		
Results of theoretical compatibility studies			

Maximum Acceptable UWB PSD for Known Minimum Separation Distance

System	Frequency band (MHz)	Rx Location	Minimum Separation Distance (m)	Single-entry UWB PSD limit	Density of active UWB transmitters (/km^2)		
					5	50	500
				(dBm/MHz)	UWB PSD limit (dBm/MHz)		
NDB	0.255 – 0.5265	Airborne	300	-26	-34.5	-44.5	-54.5
HF Comms	2.85 – 22	Ground					
		Airborne	300				
Marker Beacon	74.8 - 75.2	Airborne	100	-16.5	-15.8	-25.8	-35.8
ILS Localiser	108 - 112	Airborne	50	-55.6	-49.1	-59.1	-69.1
VOR	108 - 117.975	Airborne	100	-44.5	-43.9	-53.9	-63.9
GBAS	108 - 117.975	Airborne	30	-52.5	-41.8	-51.8	-61.8
VHF Comms, VDL Mode 4	108 – 137	Ground	30	-54.1	-53.8	-63.8	-73.8
		Airborne	300	-27.2	-46.1	-56.1	-66.1
VHF Comms, VDL Mode 2&3	117.975 – 137	Ground	30	-60.9	-66.6	-76.6	-86.6
		Airborne	300	-31.9	-50.8	-60.8	-70.8
VHF Comms, 8.33 kHz AM	117.975 - 137	Ground	30	-59.4	-59.1	-69.1	-79.1
		Airborne	100	-45	-54.7	-64.7	-74.7
VHF Comms, 25 kHz AM	117.975 - 137	Ground	30	-63.9	-63.9	-73.9	-83.9
		Airborne	100	-49.5	-59.2	-69.2	-79.2
ILS Glidepath	328.6 - 335.4	Airborne	50	-37.4	-30.9	-40.9	-50.9
50cm Radar	590 – 598	Ground	400	-76.1	TBD	TBD	TBD
DME/ TACAN	940 - 1 215	Ground	30	-61.2	-48.7	-58.7	-68.7
		Airborne	100	-36.8	-34.3	-44.3	-54.3
Secondary Surveillance Radar	1030 & 1090	Airborne	100	-34.8	TBD	TBD	TBD
		Ground	30	-71.7	TBD	TBD	TBD
23cm Radar	1 215 – 1350	Ground	400	-82.4	TBD	TBD	TBD
10cm Radar	2700 – 3100	Ground	170	-82.6	TBD	TBD	TBD
Satellite Comms	1545 - 1559 & 1645.5 - 1660	Airborne					
		Satellite					
Radio Altimeters	4200 – 4400	Airborne	50	-47.3	-38.7	-48.7	-58.7
MLS	5030 – 5150	Airborne	50	-43.3	-34.7	-44.7	-54.7
Weather Radar	5350 – 5470	Airborne	300				
Doppler Radar	8750 – 8850	Airborne	300				
3cm Radar	9000 - 9500	Ground	20	-90.2	TBD	TBD	TBD

Notes to the Table: In systems that contain both airborne and ground receivers, the dominant interference is at the ground receiver. This is largely due to a lower minimum separation distance in the ground environment. The only exception to this is the VDL Mode 2 & 3 airborne receiver, which has greater typical bandwidth than the ground receiver.

For all ground victim receivers, the effect of multiple interferers becomes dominant over the single interferer case when UWB device density reaches (less than) 50/km^2. This is due to a minimum separation distance of 30 m being applied in all cases in the ground environment. It can be shown by calculation that this effect occurs at a density of approximately 26/km^2.

For systems that contain an airborne receiver only, the effect of multiple interferers always becomes dominant over the single interferer case at a density of less than 50/km^2.

Conclusions The results of calculations shown in the above table are indicative figures based on the intra-system protection criteria for each aeronautical system;

For all aeronautical systems, the effect of multiple UWB interferers becomes dominant (exceeds impact from single interferer) when density reaches (less than) 50 active devices/km^2;

The maximum acceptable density of active multiple UWB emitters for each proposed mask can be determined by reference to results in the above table.

7.15 Meteorological radars

7.15.1 Summary table

Victim Radiocommunications Service	Meteorological radars

Application	Meteorological radar
System description	Meteorological radars are designed to track particles in the atmosphere and utilize extensive processing to extract signals from received noise. The processing derives data on return pulse characteristics to determine factors such as precipitation intensity and type, wind velocity, wind shear and turbulence.
Frequency band	2700-2900 MHz (2.8 GHz) 5600-5650 MHz (5.6 GHz) 9300-9500 MHz (9.4 GHz)
Receiver station	
Station description	
Receiver characteristics	
Bandwidth	500 kHz to 2 MHz
Noise figure / Noise temperature	2 to 3 dB
Signal model	Pulse (0.5μs to 2 μs) with Doppler analysis
Polarisation	Linear (Vertical, Horizontal or bi-polarisation)
Receiver antenna	
Type	Parabolic
Gain	33 dBi in the 9.4 GHz band and 39 to 46 dBi in other bands
Model	ITU-R F.699 (for single entry) and ITU-R F.1245 (for aggregate)
Elevation	0.5°
Height	7 to 21 m, average 13 m in the 2700-2900 MHz band 9 to 29 m, average 16 m in the 5600-5650 MHz band 5 to 15 m, average 10 m in the 9300-9500 MHz band
Protection requirement	
Criteria	I/N = -10 dB
Reference (e.g. ITU-R Rec.)	Recommendation ITU-R M.1464 for the 2700-2900 MHz Recommendation ITU-R M.1638 for the 5600-5650 MHz

Interference scenario & methodology	

UWB characteristics	
PSD limit	FCC limit, as : - imaging applications, -41.3 dBm/MHz in the 2.8, 5.6 and 9.4 GHz bands - telecommunications applications (indoor) : -51.3 dBm/MHz in the 2.8 GHz and –41.3 dBm/MHz in the 5.6 GHz and 9.4 GHz bands - telecommunications applications (outdoor) : -61.3 dBm/MHz in the 2.8 GHz and –41.3 dBm/MHz in the 5.6 GHz and 9.4 GHz bands
Activity factor	Not used
Single interferer	

Methodology	– Deterministic approach. Allows to calculate the interference (I/N) from 1 UWB device (located on the ground) to a meteorological radar for a range of distances from the radar up to 9 km.
Propagation model	Free space
Mitigation techniques	Wall and ground attenuation for imaging systems and indoor/outdoor attenuation for Telecommunications devices

Aggregate interference

Methodology	Statistical approach. - Allows to calculate the interference (in dBm) from a deployment of UWB devices (with different UWB density) to meteorological radar. - Several parameters are randomly determined such as the location, the antenna height of each UWB device, as well as its possible outdoor deployment.
Propagation model	Free space
Mitigation techniques	Indoor/outdoor attenuation for Telecommunications devices

Reference deployment scenario	Relevant for categories B & C, aggregate analysis.		
Deployment scenario 1	(1a) Rural	(1b) Suburban	(1c) Dense Urban
Application to meteorological radars	Typical	Typical	Not Typical
UWB density (/km²)	20, 100 and 200	400, 1000 and 2000	10000
Activity factor	5 %	5 %	5 %
Density of active UWB transmitters (/km²)	1, 5 and 10	20, 50 and 100	500
% Outdoor	50%	20%	10%

Results of theoretical compatibility studies

Single interferer N/A for category C

Required UWB PSD emission limit to ensure given protection distance(s)

Protection distance: 0 m (absolute protection)	Imaging systems (low density applications)	Indoor communications applications	Outdoor communications applications
UWB PSD limit (dBm/MHz) in the **2.8 GHz band**	-51 dBm/MHz	-51 dBm/MHz	-51 dBm/MHz
UWB PSD limit (dBm/MHz) in the **5.6 GHz band**	-51 dBm/MHz	-51 dBm/MHz	-51 dBm/MHz
UWB PSD limit (dBm/MHz) in the **9.4 GHz band**	-54 dBm/MHz	-54 dBm/MHz	-54 dBm/MHz

Aggregate interference N/A for category A

Required UWB PSD emission limit to ensure compatibility (based on Rural and Suburban deployment, typical for meteorological radars)

Density of active UWB transmitters (/km²)	Imaging systems (low density applications)	Indoor communications applications	Outdoor communications applications
UWB PSD limit (dBm/MHz) in the **2.8 GHz band**	Not calculated	-71 dBm/MHz	-71 dBm/MHz
UWB PSD limit (dBm/MHz) in the **5.6 GHz band**	Not calculated	-65 dBm/MHz	-65 dBm/MHz

UWB PSD limit (dBm/MHz) in the **9.4 GHz band** or See note	Not calculated	-60 dBm/MHz	-60 dBm/MHz

Note: Provide results associated with 'Density' assumption from relevant UWB reference deployment scenario

7.15.2 Conclusions

The above theoretical analysis confirms that UWB devices operating at power density levels described by the FCC limits are not compatible with Meteorological radars.
The detailed simulations presented for both deterministic (single entry) and statistical (aggregate) approaches provided for determining the adequate PSD limits, given in the following table, that would allow UWB applications to operate in the 2.8 GHz, 5.6 GHz and 9.4 GHz frequency bands without producing harmful interference to Meteorological radars.

Frequency band	**UWB application type**	**Current US FCC PSD limit**	**PSD limit necessary to protect Meteorological radars**
2.8 GHz	Imaging (low density)	-41.3 dBm/MHz	**-51 dBm/MHz**
	Telecommunication (indoor)	-51.3 dBm/MHz	**-61 dBm/MHz**
	Telecommunication (outdoor)	-61.3 dBm/MHz	**-71 dBm/MHz**
5.6 GHz	Imaging (low density)	-41.3 dBm/MHz	**-51 dBm/MHz**
	Telecommunication (indoor and outdoor)	-41.3 dBm/MHz	**-65 dBm/MHz**
9.4 GHz	Imaging (low density)	-41.3 dBm/MHz	**-54 dBm/MHz**
	Telecommunication (indoor and outdoor)	-41.3 dBm/MHz	**-60 dBm/MHz**

8 OVERALL CONCLUSIONS OF THE REPORT

This ECC Report considered the protection requirements of radiocommunications systems below 10.6 GHz from Generic UWB Applications. The presented study was based mostly on theoretical analysis. The following conclusions are based on the currently available data on UWB technical characteristics and propagation models, bearing in mind that no specific mitigation techniques for UWB applications were taken into account as they were still under development at the time of writing this report.

The detailed results of the compatibility studies for various considered victim radiocommunications services are given in section 7 and are summarised in the table below. The graphical representation of results of the technical studies, with original FCC mask as a reference, is provided in Figure 14.

The required maximum Generic UWB PSD values to protect the existing radiocommunications services were shown to be more stringent than the values given in the FCC mask.

To reach a sufficient protection from UWB systems, especially for pulsed UWB emissions, it is necessary to set an average power limit and a peak power limit (alternatively to a peak limit, it is possible to limit the PRF to a minimum value).

Unless specially noted in the Comments column, the UWB PSD limits in the summary table below are valid for the assumption of AWGN-like interference effects, which is achievable with the following conditions:

- Scenarios with a sufficient number of interferers (>100);
- Pulse-based UWB emissions with a PRF-range of *PRF>VictimBandwidth*, and
- MB-OFDM (without Frequency Hopping).

Ref. Annex	**Victim Service/ Applications**	**Frequency bands**	**Victim Service protection criteria**	**Worst reference case analysis**	**Maximum generic UWB PSD to achieve protection (dBm/MHz)**	**Comments**
1	FS	1000-3000 MHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-74.5	Multiple FS sub-bands within 1-3 GHz, value extrapolated
	FS	3400-4200 MHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-71.5	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above PSD limit
	FS	4400-5000 MHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-71.5	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above PSD limit
	FS	5925-7125 MHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-71.5	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above PSD limit
	FS	7125-8500 MHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-69	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above PSD limit
	FS	10.15–10.65 GHz	ITU-R Rec. F.1094 and WP9A Liaison Statement (I/N = - 20 dB)	Aggregate, Urban (1c)	-66.5	Wide band peak protection limit in 50 MHz bandwidth was evaluated 42 dB above PSD limit
2	GSO MSS systems	1626.5-1660.5 MHz	I/N = - 20 dB	Aggregate, Global beam (2bis)	-75.3	Uplink
	GSO MSS systems	1525-1559 MHz	I/N = - 20 dB	Single interferer, 20 m separation	-98.4	Downlink. Assuming non-dithered UWB emission (Note 3)
	MSS Search & Rescue	406-406.1 MHz	I < -120.1 dBm/MHz (Cospas/Sarsat system)	Aggregate, Rural (1a)	-50	Satellite receivers
	MSS Search & Rescue	1544-1545 MHz	I < -133.2 dBm/MHz	Aggregate, Rural (1a)	-75	Earth Stations. Assuming an exclusion zone of 6 km
3	EESS	1400-1427 MHz	ITU-R Rec. SA.1029-2	Aggregate, Rural (1a)	-88	Satellite receivers. RR No 5.340 applies
	EESS	6425-7250 MHz	ITU-R Rec. SA.1029-2	Aggregate, Rural (1a)	-62	Satellite receivers
	EESS	5250-5570 MHz	I < -115 dBm/MHz	Aggregate, Rural (1a)	-21	Satellite receivers
	EESS	2025-2110 MHz	ITU-R. Rec. SA.609-1	Aggregate, Rural (1a)	-35	Satellite receivers. 100% devices outdoor
	EESS	2200-2290 MHz	ITU-R. Rec. SA.609-1	Aggregate, Rural (1a)	-70	Earth Stations. Assuming a 4 km

						exclusion zone
	EESS	8025-8400 MHz	ITU-R. Rec. SA.1027-3	Aggregate, Rural (1a)	-41.3	Earth Stations (Note 1)
	EESS	10.6-10.7 GHz	ITU-R Rec. SA.1029-2	Aggregate, Rural (1a)	-57	Satellite receivers. 100% devices outdoor
4	RAS	608 – 614 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-123.2	Continuum observations (broadband)
	RAS	1330.0 – 1400.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-121.4	Continuum observations (broadband)
	RAS	1400.0 – 1427.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-121.4	Continuum observations (broadband). RR No. 5.340 applies
	RAS	1610.6 – 1613.8 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-100.6	Spectral line observations (narrow band)
	RAS	1660.0 – 1670.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-113.8	Continuum observations (broadband)
	RAS	1718.8 – 1722.2 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-100.2	Spectral line observations (narrow band)
	RAS	2655.0 – 2690.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-110	Continuum observations (broadband)
	RAS	2690.0 – 2700.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-110	Continuum observations (broadband). RR No. 5.340 applies
	RAS	3260.0 – 3267.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-92.9	Spectral line observations (narrow band)
	RAS	3332.0 – 3339.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-92.9	Spectral line observations (narrow band)
	RAS	3345.8 – 3352.5 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-92.9	Spectral line observations (narrow band)
	RAS	4800.0 – 4990.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-103.4	Continuum observations (broadband)
	RAS	4990.0 – 5000.0 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-103.4	Continuum observations (broadband)
	RAS	6650.0 – 6675.2 MHz	ITU-R. Rec. RA.769	Aggregate, Suburban (1b)	-87.9	Spectral line observations (narrow band)
5	DVB-T	174-230 MHz (TV Band III)	C/N (see ITU-R Rec. BT.1368-3 & Chester 1997 Multilateral Coordination Agr.)	Single interferer, 50 cm separation	-94	Lower limit based on indoor scenario (Note 2)
	DVB-T	470-862 MHz (TV Bands IV & V)	C/N (see ITU-R Rec. BT.1368-3 & Chester 1997 Multilateral Coordination Agr.)	Single interferer, 50 cm separation	-89	Lower limit based on indoor scenario (Note 2)
6	T-DAB	170-230 MHz (Band III)	C/N (see Wiesbaden 1995 Special Arrangement)	Single interferer, 30 cm separation	-97	Lower limit based on indoor scenario (Note 2)
	T-DAB	1452-1492 MHz (band L)	C/N (see Wiesbaden 1995 Special Arrangement)	Single interferer, 30 cm separation	-85	Lower limit based on indoor scenario (Note 2)
7	Bluetooth	2400-2483.5 MHz	C/I = + 20 dB	Single interferer, 36 cm separation	-75	(Note 2)

8	RLAN	5150-5350 MHz	10 % frame error	Single interferer, 36 cm separation	-68.2	(Note 2)
	RLAN	5470-5725 MHz	10 % frame error	Single interferer, 36 cm separation	-68.2	(Note 2)
9	IMT-2000	1710-1885 MHz	(see Annex 9)	Single interferer, 36 cm separation	-86.4	
	IMT-2000	1885-2025 MHz	(see Annex 9)	Single interferer, 36 cm separation	-85.9	
	IMT-2000	2110-2170 MHz	(see Annex 9)	Single interferer, 36 cm separation	-85	
	IMT-2000	2500-2690 MHz	(see Annex 9)	Single interferer, 36 cm separation	-83.1	
10	RNSS	E5: 1164-1219 MHz E6: 1258-1300 MHz L1: 1559-1593 MHz	(see Annex 10)	Single interferer, separation distance1m	-83.5	
11	FSS	3400-4200 MHz	ITU-R Rec. S.1432	Aggregate, urban (1c)	-77	Downlink
	FSS	4500-4800 MHz	ITU-R Rec. S.1432	Aggregate, urban (1c)	-77	Downlink
	FSS	7250-7750 MHz	ITU-R Rec. S.1432	Aggregate, urban (1c)	-77	Downlink. Military band, FSS parameters extrapolated
	FSS	5725-7075 MHz	ITU-R Rec. S.1432	Aggregate, Global beam scenario (2bis)	-41.3	Uplink (Note 1)
	FSS	7900-8400 MHz	ITU-R Rec. S.1432	Aggregate, Global beam scenario (2bis)	-41.3	Uplink. Military band, FSS parameters extrapolated (Note 1)
12	Amateur	1260-1300 MHz	1 dB receiver noise level degradation	Single interferer, 10 m separation	-85.5	
	Amateur	2300-2450 MHz	“	Single interferer, 10 m separation	-61.3	(Note 1)
	Amateur	3400-3500 MHz	“	Single interferer, 10 m separation	-55	
	Amateur	5650-5850 MHz	“	Single interferer, 10 m separation	-51	

	Amateur	10-10.5 GHz	“	Single interferer, 10 m separation	-46	
13	Maritime	156 – 163 MHz	(see Annex 13)	Aggregate, Suburban (1b)	-73.5	VHF radiotelephony / DSC
	Maritime	457 – 467 MHz	(see Annex 13)	Aggregate, Suburban (1b)	-55.5	UHF radiotelephony
	Maritime	2900 – 3100 MHz	(see Annex 13)	Single interferer, 300 m separation	-58.5	S band radar. Preclude use of UWB devices on board pending further study of the actual effect on ships radars
	Maritime	9300 – 9500 MHz	(see Annex 13)	Single interferer, 300 m separation	-48.6	X band radar. Preclude use of UWB devices on board pending further study of the actual effect on ships radars
14	Aeronautical	0.255 – 0.5265 MHz		Aggregate, Suburban (1b)	-44.5	NDB (airborne)
	Aeronautical	2.85 – 22 MHz		Aggregate, Suburban (1b)	(Note 4)	HF Comms (ground)
	Aeronautical	74.8 – 75.2 MHz		Aggregate, Suburban (1b)	-25.8	Marker Beacon (airborne)
	Aeronautical	108 - 117.975 MHz		Aggregate, Suburban (1b)	-63.8	VDL Mode 4 (ground)
	Aeronautical	117.975 - 137 MHz		Aggregate, Suburban (1b)	-76.6	VHF Comms, Modes 2&3 (ground)
	Aeronautical	328.6 - 335.4 MHz		Aggregate, Suburban (1b)	-40.9	ILS Glidepath (airborne)
	Aeronautical	590 – 598 MHz		Single interferer 400m separation	-76.1	50cm Radar (ground)
	Aeronautical	940 - 1 215 MHz		Single entry 30m separation	-61.2	DME/ TACAN (ground)
	Aeronautical	1090 MHz		Single entry 30m separation	-71.7	Secondary Surveillance Radar (ground)
	Aeronautical	1 215 – 1350 MHz		Single entry 400m separation	-82.4	23cm Radar (ground)
	Aeronautical	2700 – 3100 MHz		Single entry 170m separation	-82.6	10cm Radar (ground)
	Aeronautical	1545 - 1559 & 1645.5 – 1660 MHz			(Note 4)	Satellite Comms
	Aeronautical	4200 – 4400 MHz		Aggregate, suburban (1b)	-48.7	Radio Altimeters (airborne)
	Aeronautical	5030 – 5150 MHz		Aggregate, suburban (1b)	-44.7	MLS (airborne)
	Aeronautical	5350 – 5470 MHz			(Note 4)	Weather Radar (airborne)
	Aeronautical	8750 – 8850 MHz			(Note 4)	Doppler Radar (airborne)
	Aeronautical	9000 – 9500 MHz		Single entry 20m separation	-90.2	3cm Radar (airborne)

15	Meteorological Radar	2700-2900 MHz	I/N = -10 dB	Aggregate, Suburban (1b)	-71	
	Meteorological Radar	5600-5650 MHz	I/N = -10 dB	Aggregate, Suburban (1b)	-65	
	Meteorological Radar	9300-9500 MHz	I/N= -10 dB	Aggregate, Suburban (1b)	-60	

Notes to the Table:

Note 1: limits provided in italic were taken from the FCC mask when the study did not evaluate the maximum generic UWB PSD to achieve protection, but just confirmed that the FCC limit would offer sufficient protection to the subject radiocommunications service;

Note 2: measurements were performed to take into account pulsed interference effects;

Note 3: *BWCF* of NTIA was used, the result is valid for pulsed UWB;

Note 4: this frequency band is not covered in this report and further work is needed.

In the compatibility study related to the protection of RAS stations, the derived maximum emission levels for UWB devices were stated to be below the thermal emission from a black body at 300 K. These levels are to be interpreted as the maximum allowed emission in excess of the thermal noise level at the impedance matching the antenna.

From the results shown in the above table, graphically depicted in Fig. 14, it can be seen that the FCC Indoor UWB PSD mask does not provide adequate protection to the existing radiocommunications services. Fig. 15 provides a generic consolidated UWB PSD limits necessary to protect existing services; this is obtained by drawing the line encapsulating the most stringent PSD limits required to protect each of the victim services.

The results show that:

- The majority of the considered radiocommunications services require up to 20-30 dB more stringent Generic UWB PSD limits than defined in the FCC masks, indoor as well as outdoor. Only a few EESS applications are sufficiently protected by FCC mask, whereas some RAS bands require 50-80 dB more stringent limits;
- The consolidated limits shown in Fig. 15 indicate that the allowed Generic UWB PSD limit increases with the frequency. The difference between PSD limit at 10 GHz and that at 200 MHz is about 20 dB;
- If the victim radiocommunications service is operated in an outdoor environment only, as is the case for e.g. FS, FSS, RAS, EESS etc, then the increase of noise due to the aggregate UWB interference determines the generic UWB PSD limit. In addition, if the victim radiocommunications service is (also) operated in the indoor environment, e.g. DVB-T, IMT-2000, RLAN, etc, then the closest UWB interferer becomes the determining interference factor due to small spatial separation (small path loss).

It can also be observed that for Services using narrow band receivers with higher sensitivity more protection is required.

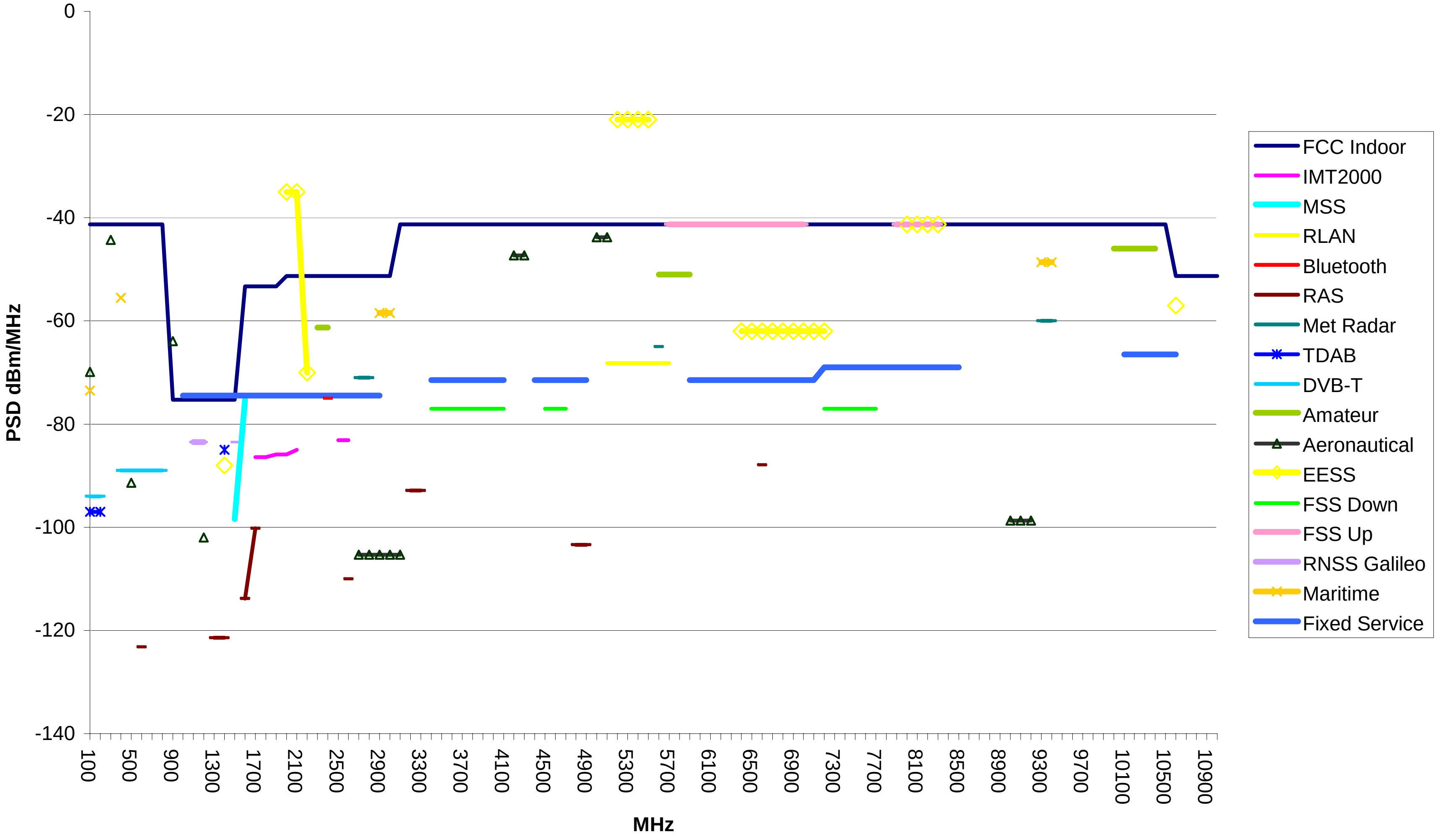

Figure 14: Generic UWB PSD limits required to protect all studied victim radiocommunications services

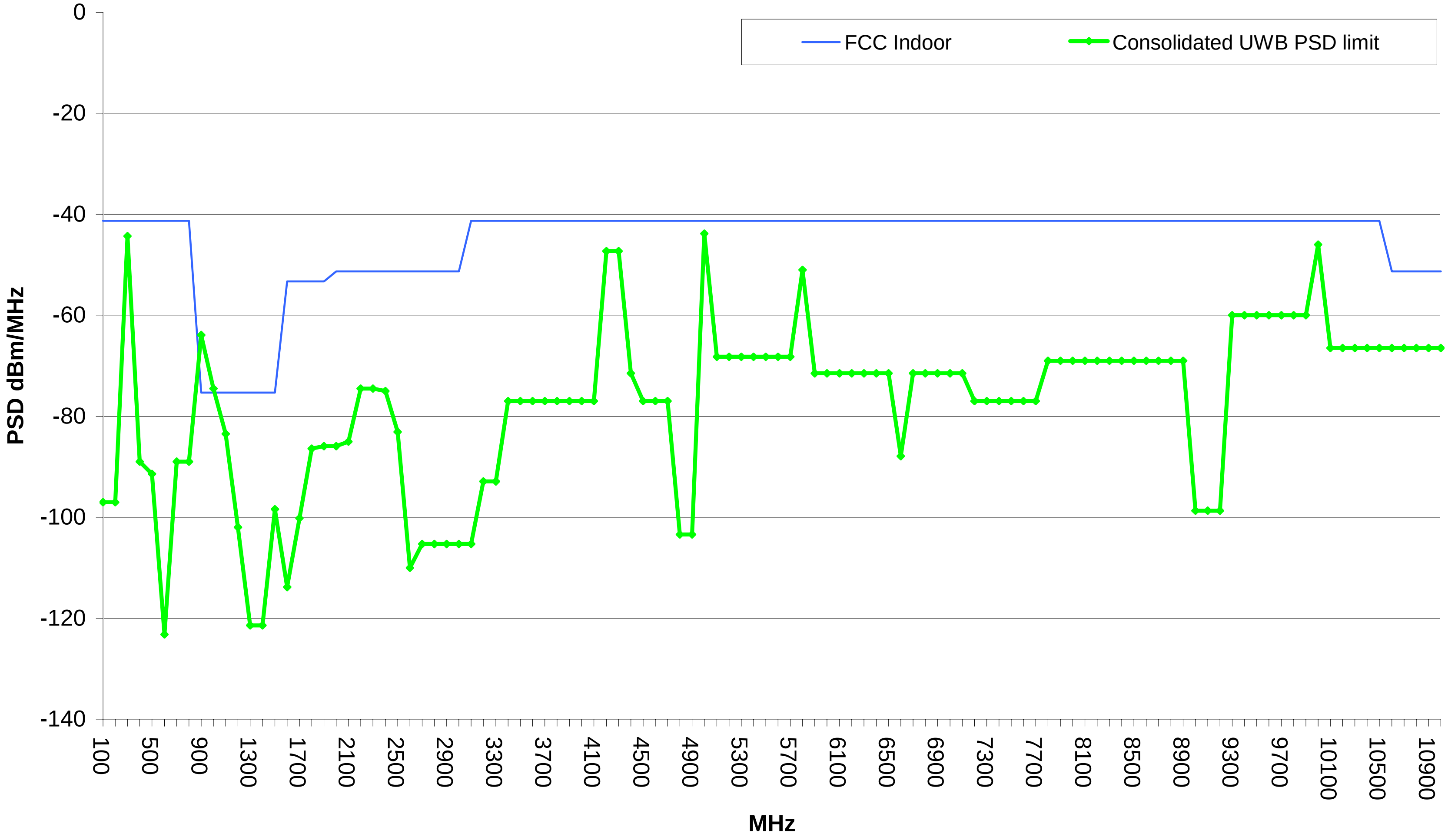

Figure 15: Resulting consolidated Generic UWB PSD limit and its comparison with FCC indoor UWB mask