Report researched and prepared by:

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# Ultra-Wideband (UWB) Simulation Report

As a worldwide industry consortium with >100 members, FiRa® members are united in their support for the deployment of ultra-wideband technology, which enables high-precision tracking.
UWB devices designed to FiRa specifications operate on 500 megahertz channels with center frequencies between 6.0 GHz and 10 GHz.

UWB co-exists well with other technologies including governmental users. UWB transmission uses short duration pulses with large transmission bandwidths and extremely low power levels. It has been observed for more than 20 years that UWB devices consistently operate in real-world settings with no adverse effects to existing operations.

To prove that UWB is a "good neighbor" technology, the FiRa Consortium has contracted Roberson and Associates, LLC to do an UWB Interference Simulation Methodology using SEAMCAT that is provided in the respective report[1]. The report confirms that UWB applications are unlikely to cause harmful interference to four selected incumbent wireless systems between 6 and 10.6 GHz (Fixed Service, Fixed Satellite Service, Surface Movement Radar and Airborne Weather Radar). This study also includes new fixed outdoor and enhanced power indoor UWB applications not previously considered in spectrum studies. The lack of interference potential of UWB is also supported by the fact that there is no report published about interference caused by UWB so far, despite significant UWB deployment over the recent years.

To adequately assess the compatibly situation, the study focused on the current and planned UWB solutions for precise ranging, presence detection, and precise location finding between 6 and 10.6 GHz. It can be stated that in contrast to the originally assumed use cases 20 years ago, the deployment of UWB has mainly focused on location tracking and low data rate communications based on IEEE802.15.4z standards rather than the originally assumed high and ultra-high data rate systems.

Since the publication of the current rules in 2002 [2], such high and ultra-high data rate UWB systems did not materialize, and different wideband data communication technologies became dominant for high and ultra-high data rate transmissions. This leads to a significant reduction of the originally assumed duty cycle and activity factors in studies, reducing the impact of UWB as a potential source of interference.

A critical coexistence concern are the incumbent airborne and airport Radar services above 8.5 GHz. An important consideration is selection of the propagation model for simulation studies. The Longley Rice propagation model has been validated by decades of spectrum coexistence experience. Previous work on UWB coexistence is available in ECC Report 327[3] which used the ECO SEAMCAT tool[4] and ITU propagation models rather than the Longley Rice model used here.

The Methodology Report presents simulations of spectrum compatibility for large mixed UWB device populations with five incumbent services. ´ Since UWB signals have RF bandwidths of 500 MHz or more, their emissions are regulated on a power spectral density in a 1 MHz bandwidth. The simulation results present the probability distributions of the ratio (I/N) of aggregate received UWB interference power spectral density.

### Airborne Weather Radar (AWR)

UWB compatibility with Airborne Weather Radar receivers was demonstrated assuming an aircraft was flying over a worst-case Dense Urban environment. Millions of UWB devices are potentially in line-of-sight of the AWR receiver. A new AWR aircraft receiver antenna model was developed based on ITU Recommendations M.1796 and M.1851.

### Surface Movement Radar (SMR)

UWB compatibility was demonstrated for large and small airports in both Dense Urban and Suburban environments. An inverse Cosecant-Squared SMR receive antenna model was developed also based on ITU-R M.1796 and M.1851.

### Fixed Satellite Service (FSS)

UWB compatibility was demonstrated for Fixed Satellite Service ground station receivers. The simulations were based upon simulation files (workspaces) previously developed in the 327 Report.

### Fixed Service (FS)

UWB compatibility was demonstrated for Fixed Service or point-to-point link receivers. The simulations were also based on workspaces developed in the 327 Report.

### Surveillance/SAR Radar

UWB compatibility with Surveillance/SAR Radar receivers was demonstrated for all five system types studied. This study used conservative worst-case assumptions including operation in a very large dense urban environments.

## References


[1] Roberson and Associates, LLC; UWB Interference Simulation Methodology using SEAMCAT; 10 July 2024; Version 1.00

[2] Revision of Part 15 of the Commission's Rules Regarding Ultra WideBand Transmission Systems https://www.fcc.gov/document/revision-part-15-commissions-rules-regarding-ultra-wideband-7

[3] ECC Report 327, Technical studies for the update of the Ultra Wide Band (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz , 1 October 2021 (https://docdb.cept.org/download/3511)

[4] SEAMCAT - Spectrum Engineering Advanced Monte Carlo Analysis Tool (https://www.cept.org/eco/eco-tools-and-services/seamcat-spectrum-engineering-advanced-monte-carlo-analysis-tool)

Roberson and Associates, LLC
Technology and Management Consultants ®

# UWB INTERFERENCE SIMULATION METHODOLOGY USING SEAMCAT

This technical report has been generated based on a request by the NTIA. The goal is to provide sufficient background and simulation details to allow others to conduct identical or additional studies.

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# EXECUTIVE SUMMARY

Modern products and services using unlicensed Ultra-Wideband (UWB) devices solve problems competing wireless systems cannot, for example, offer precise and secure location, ranging, presence detection, and signaling. Devices implementing the IEEE 802.15.4z [11] UWB PHY layer operate on 500 MHz or wider channel spacing in two bands where the high band ranges from 6.0 to 10.6 GHz. As unlicensed systems, UWB devices must not cause interference to existing licensed services operating in the high band when those systems' frequencies overlap with the UWB channel. Currently, only portable, e.g. handheld, UWB devices are allowed outdoor, and indoor devices are held to the same power spectral density limit as outdoor devices.

In support of updating the regulations to allow 1) fixed outdoor low duty cycle UWB stations and 2) enhanced power low duty-cycle indoor UWB devices, Monte Carlo simulations were performed to understand the potential aggregate impact on existing receiver interference-to-noise (I/N) ratios. It is understood that the regulatory environment includes the current efforts supporting the National Spectrum Strategy (NSS) and that regulatory changes will need to be cognizant of changes to the Spectrum Strategy.

New fixed outdoor applications that exploit the unique ranging and location capabilities of new UWB technologies have been proposed. In addition, enhanced performance, higher transmit power indoor UWB devices have also been proposed. To ensure that these new types of UWB devices individually, and in the aggregate, do not cause interference with existing licensed services in the 6 to 10.6 GHz band, detailed simulations can be used to predict worst-case UWB power spectral density levels received by other co-channel systems. This document describes the methods and assumptions used in designing large scale simulations of UWB device interference with licensed receivers.

This report describes the procedures used to design the victim and interfering systems and scenarios for the SEAMCAT [Spectrum Engineering Advanced Monte Carlo Analysis Tool] spectrum compatibility simulation tool. The ECC recently published a report "ECC Report 327" titled "Technical studies for the update of the Ultra-Wideband (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz"[13]. This report described the results of simulations of UWB devices and potential co-channel compatibility with fixed, fixed satellite, space science, and radio astronomy receivers under a European regulatory environment. The upper frequency of 8.5 GHz reflected current European UWB regulations.

The procedures described in this paper give guidance on the design of spectrum compatibility simulations of new types of UWB devices operating from 8.5 GHz up to 10.6 GHz. Systems operating above 8.5 GHz include airborne weather radar, airport surface movement radar, and other radionavigation systems. With restrictions, UWB devices are currently allowed to operate in the United States up to 10.6 GHz.

The appendices include results of the interference simulations performed along with specific details for each interference scenario. Initial simulations included the following areas of investigation:

- Airborne Weather Radar (AWR)

  AWR systems are characterized by radar receivers on aircraft which are in line-of-sight with very large numbers of terrestrial UWB devices.

- Surface Movement Radar (SMR)

SMR systems use a ground-based radar receive antenna typically located on the top of airport control towers. The purpose of SMR is to search for the presence of vehicles or equipment that may interfere with airplane movements. Also known as ASDE (Airport Surface Detection Equipment)

- Fixed Satellite Service (FSS)

  Fixed Satellite Service (FSS) systems use high-gain directional antennas to connect terrestrial earth stations to orbiting satellites. Simulation results of the impact of UWB devices on Fixed Satellite Service earth station receivers were previously presented in ECC Report 327. The work presented here extends these results to use the NTIA-ITS propagation model.

- Fixed Service (FS)

  Fixed Service systems use high-gain directional antennas to connect terrestrial locations. Simulation results of the impact of UWB devices on Fixed Service receivers were previously presented in ECC Report 327. The contribution presented here is the modification of the simulations to use the NTIA-ITS propagation model.

- Surveillance/SAR Radar

  Surveillance/SAR radar refers to a collection of radar systems described in Table 1 of [5] as system A12. The full name of the collection is "Multipurpose surveillance, scanning, tracking, search, (imaging)" airborne radars.

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# 1 Technical Background

## 1.1 Monte Carlo Simulation: SEAMCAT[1]

The methodology used in this study is to perform Monte Carlo simulations to find the interfering signal levels received by various licensed systems receivers (a.k.a. victims) from large numbers of unlicensed UWB devices (a.k.a. interferers). The SEAMCAT simulation tool is used to perform Monte Carlo simulations [8].

SEAMCAT is a Monte Carlo based simulation tool for analyzing wireless systems for compatibility. The main focus of this tool is to perform co-existence studies between RF systems operating in the same or adjacent frequency bands. A primary output is the quantification of the probability of interference of one system upon another.

It provides a general-purpose simulation capability that can be applied to a variety of environments and scenarios. Figure 1 (from Figure 5(a) of [8]) illustrates the general system model and serves to introduce key terminology used by SEAMCAT.

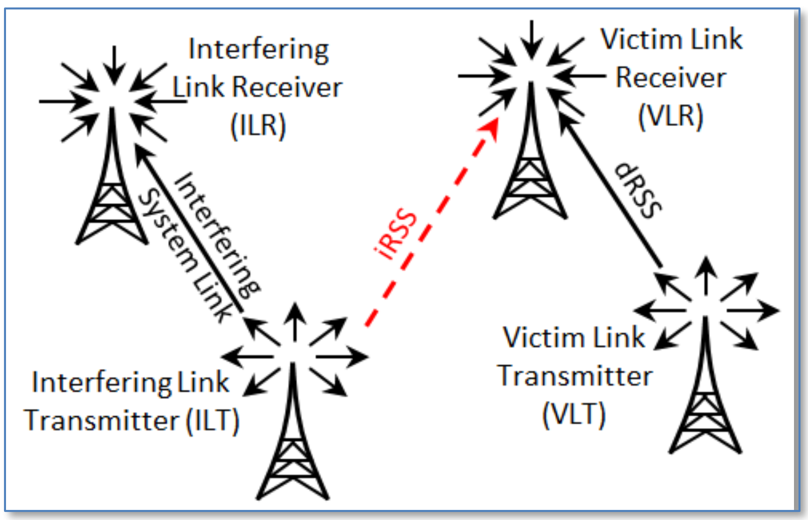


**Figure 1. General SEAMCAT System Model (SOURCE: SEAMCAT Manual)**

At minimum, any scenario simulated will have one victim system and one or more interfering systems. The victim system and each interfering system will consist of transmitters and receivers. Referring to Figure 1, the devices shown are defined as follows:

- Victim Link Transmitter (VLT) – The VLT represents the transmitting device within the victim system.
- Victim Link Receiver (VLR) – The VLR represents the receiving device within the victim system.

[1] Spectrum Engineering Advanced Monte Carlo Analysis Tool

- Interfering Link Transmitter (ILT) – The ILT represents the transmitting device(s) within an interfering system. Note that scenarios may include multiple interfering systems as well as multiple ILT devices associated with each interfering system. In this report these are the UWB transmitters.
- Interfering Link Receiver (ILR) – The ILR represents the receiving device(s) within an interfering system. Again, scenarios may include multiple interfering systems as well as multiple ILR devices associated with each interfering system.

In SEAMCAT, all of these devices are placed on a flat-earth surface.

Within the current study documented here, the interfering systems are representations of one or more UWB traffic classes. Thus, the ILT and ILR devices are UWB devices. This study considers different examples of victim systems, including victim transmitters (VLTs) and receivers (VLRs). Each different victim is fully described within the appendices.

Figure 1 also shows 3 RF link measurements of interest, defined as follows.

- desired Received Signal Strength (dRSS) – the dRSS refers to the RF link between the VLT and the VLR. For the victim receiver, this link provides the desired signal.
- interfering Received Signal Strength (iRSS) – the iRSS refers to the RF link between the ILT and the VLR. For the victim receiver, this is an interfering or undesired signal.
- interfering System Link – this is the RF link from the ILT to the ILR. For the receiver of an interfering system, this link provides its desired signal.

Through simulation of these various RF links, SEAMCAT is able to evaluate a variety of signal quality metrics, including carrier to interference plus noise ratio (C/(I+N)), interference to noise ratio (I/N), or interference-plus-noise to noise ratio ((I+N)/N). In this study, the I/N metric is used in the sense of comparing the interference power spectral density (PSD) to receiver thermal noise power spectral density to evaluate interference impacts. Thus, only the link measurement represented by iRSS is critical for calculating I/N, however, all the RF links must be configured within SEAMCAT.

Setting up a SEAMCAT Monte Carlo simulation involves multiple steps. The main steps are:

- Entering a victim transmitter and receiver system and configuring its frequency, transmit bandwidth and power level, receiver bandwidth and receiver performance parameters such as noise figure, transmit and receiver antenna types, antenna environment details such as height and clutter, relative placement of transmitter and receiver antennas, and the transmitter to receiver propagation model (represented by dRSS in Figure 1).
- Entering one or more interfering systems each configured with frequency, transmit bandwidth and power level, receiver bandwidth and receiver performance parameters such as noise figure, transmit and receiver antenna types, antenna environment details such as height and clutter, relative placement of transmitter and receiver antennas, and the transmitter to receiver propagation model (represented by Interfering System Link in Figure 1).
- Configuring the total population of interfering devices for their placement and number relative to the victim receiver and the propagation model (represented by iRSS in Figure

1) with its parameters for the path between the interfering transmitter and the victim receiver.

- Configuring the number of Monte Carlo trials (events) to simulate.
- Processing the results to obtain a statistical distribution of the I/N ratios between the simulated received interfering power spectral density I and the calculated receiver noise level N.

The interfering power (or PSD) level is the sum of the received powers (or PSDs) at the victim receiver from all the UWB devices that are transmitting during each simulation trial. Factors that affect the interference level are UWB transmitter maximum EIRP, local impairments such as clutter or building entry (exit) losses, propagation path loss, victim receiver antenna gain in the direction of the UWB transmitter, and local impairments near the victim receiver antenna.

In the sections that follow the general configuration for victim systems is described. Specifics details for specific victim systems are included in the appendices.

Details are next provided for the expected dense urban placement and numbers of both legacy and the new types of UWB devices.

Finally, the procedures for processing and displaying the simulation results is presented.

## 1.2 Power Scaling

SEAMCAT has been observed to operate well on the available platforms if the number of interfering transmitters is less than 50000. However, some scenarios of interest include interfering population numbers significantly higher than this limit. For these cases, power scaling is used to adjust (reduce) the number of UWB transmitters to not exceed SEAMCAT memory limits.

If the number of devices exceeds 50000 then the number is reduced by dividing the number of devices by a scaling factor and increasing the UWB transmitter power by a corresponding value so that the total sum of interfering powers remains unchanged. Typical scaling factors are 2X and 10X reductions with corresponding 3 dB and 10 dB power level increases, or multiples of these factors. This approach was validated by comparing the results of simulations with scaled and with un-scaled device numbers and device power levels. To obtain the results for the un-scaled simulations with large numbers of devices, results from multiple separate simulations were combined.

## 1.3 Runtime Notes

When large numbers of interferers (e.g. approaching 50000) are present, the simulations may take an hour or more for 20000 simulation trials. Computing platforms with 16 GB or more of memory are strongly recommended.

# 2 VICTIM SYSTEMS

## 2.1 Overview

Licensed services sharing spectrum with UWB devices between 6 and 10.6 GHz often use highly directional antennas to compensate for the greater propagation losses at these frequencies vs. the comparable loss at lower frequencies. Accurate simulations of the power received by licensed service receivers must include accurate models for the antenna gain patterns and realistic values for antenna heights and antenna clutter. Since the beamwidths are narrow as a result of the high gains employed many trials are needed to obtain an accurate sample of the statistical distribution of received interference power.

## 2.2 Victim Receivers (VLR)

Modeling the received interference power spectral density for each class of victim system involves understanding the peak gain and gain pattern of the receive antenna, the distribution of likely antenna placements and pointing directions relative to the UWB devices, the statistical distributions describing the local environment including clutter surrounding the victim receive antenna, the receiver bandwidth and noise figure, and the maximum acceptable interference power spectral density to noise density (I/N) ratio.

The antenna peak gain is entered in the receiver system description panel separately from the gain pattern. The antenna gain pattern can be selected from one of the available standard patterns included with SEAMCAT such as Recommendation ITU F.1245 or a custom pattern can be entered or imported as either spherical or elevation-azimuth gain tables. The maximum gain in a custom gain table must not exceed 0 dB.

The antenna height is entered as a constant value or as a statistical distribution as part of configuring the local environment of the victim system receiver. The local environment of the victim receiver antenna is also used to specify local clutter if desired. Various clutter models are available. In many cases the receiver clutter models are implemented as part of the propagation model described in the interference scenario section.

UWB devices are currently limited by FCC rules to a maximum power spectral density of –41.3 dBm/MHz averaged over 1 millisecond. For convenience, victim receiver bandwidth can be fixed at 1 MHz, allowing maximum UWB transmit power levels to be set to –41.3 dBm. For Fixed Service simulations a 30 MHz bandwidth was used. For the Fixed Satellite Service a 1.2 MHz bandwidth was used.

The receiver noise floor for terrestrial links is determined by adding the receiver noise figure in dB to the thermal noise in one MHz (-114 dBm at 290 K). Antenna noise temperatures may need to be used when calculating receiver noise levels for Fixed Satellite System (FSS) earth stations or other Space-to-Earth system earth station receivers. When appropriate, the use of antenna noise temperature to determine the receiver noise floor will be discussed in the relevant use case-specific appendix.

## 2.3 Victim Transmitters (VLT)

The victim transmitter antenna, bandwidth, and power level also need to be specified. The configuration of victim transmitters is not critical since only received interference power spectral density to noise density I/N ratios are used to evaluate interference, i.e. the RF link (dRSS) from VLT to VLR does not factor into the interference evaluation. For simplicity the power level in this study is left at the default level (33 dBm) and the antenna is the default isotropic design. The transmit bandwidth should match the victim receiver bandwidth, i.e. 1 MHz.

## 2.4 Victim Transmitter to Victim Receiver Propagation

The choice of victim transmitter to victim receiver propagation model, impacting dRSS in Figure 1, is arbitrary since it does not impact the final I/N ratio. The free space model is recommended as it is computationally the simplest model.

For this study, the positioning of the victim transmitter is set using the SEAMCAT correlated position feature. The victim transmitter is placed at a fixed offset along the x-axis. This has proved helpful in verifying the relative placement of victim and UWB devices post-simulation in the Outline and Event Results tabs of an open simulation result file in SEAMCAT.

# 3 UWB Systems and Devices

## 3.1 Overview

UWB systems (the interfering systems in SEAMCAT) are implemented as transmit-receive pairs. These pairs are randomly placed around the victim receiver. The number of devices is set by the expected device densities and the total area or radius where the devices are expected to be deployed. Worst case assumptions are followed such as placing devices to completely encircle the victim receiver extending out to ranges that include zero, or nearly zero, degree elevation angles for the UWB path towards the victim receiver. The important device characteristics to model are the transmit power levels and the clutter or building entry environmental details.

## 3.2 UWB Transmitters (ILT)

The UWB interfering link transmitters (ILT) are usually modeled as continuously transmitted signals with 1 MHz of Bandwidth (30 MHz for FS) radiating from a 0 dB gain isotropic antenna. This aligns the simulation results with the FCC power spectral density emission limits for UWB. Two power levels are considered for UWB transmitters corresponding to (1) devices in line with current UWB regulations and (2) indoor devices with a proposed enhanced power level. For devices aligned with current UWB regulations, the nominal, un-scaled, transmitter power level of the UWB transmitters is -41.3 dBm and the bandwidth is set to 1 MHz. For new enhanced power indoor UWB transmitters the nominal power level is increased to -31.3 dBm in a 1 MHz bandwidth

The UWB transmitter antenna heights are entered as either a constant value or drawn from a specified statistical distribution. For some victim systems (AWR) the UWB antenna heights used for UWB transmitters were fixed:

- Outdoor portable and vehicle: 1.5 meters
- Outdoor fixed: 6 meters
- Indoor: 5 meters

For other victim systems, various distributions of antenna heights were used.

## 3.3 UWB Clutter and Building Entry Loss

Two additional environmental effects to include are clutter for outdoor transmitters and building entry loss (BEL) for indoor transmitters. These are specified in SEAMCAT under the local environments tab. The Recommendation ITU-R P.2108 [9] models are used for outdoor clutter and the Recommendation ITU-R P.2109 [10] model is used for building entry loss. In SEAMCAT as of version 5.5.1-ALPHA, both the Recommendation ITU-R P.2108 model and the Recommendation ITU-R P.2109 model may be applied together. The Recommendation ITU-R P.2109 building entry loss is parameterized via a percentage named probability of Not Exceeding. In this study, the (nominal) building entry loss parameter is set to draw from a uniform distribution between 1% and 99%. There are three Recommendation ITU-R P.2108 clutter models available. The first, labeled Ref. 3.1, is intended for systems operating below 3 GHz and is not used in this study. The second, labeled Ref. 3.2, is valid for all terrestrial links operating between 0.5 and 67 GHz. The third, labeled Ref, 3.3, is intended for links where one device is terrestrial, and the other is located on either an airborne or spaceborne platform. This model also specifies a valid frequency range of 10 to 100 GHz but will be used in this study also for earth to airborne links in the 9 to 10 GHz range. The Recommendation ITU-R P.2108 is parameterized with a Percentage of Locations parameter for both the 3.2 and 3.3 models. In this study the parameter is usually set to draw from a uniform distribution between 1% and 99%.

## 3.4 UWB Receivers (ILR)

The UWB interfering link receiver (ILR) parameters, including receive antenna characteristics, receive antenna placements, statistical distributions describing the local environment, receiver bandwidth and noise figure, must also be specified in the SEAMCAT model. The configuration of the UWB receivers is not critical since only interference power spectral density to noise density I/N ratios at the victim receiver are used to evaluate interference.

## 3.5 UWB Devices

The simulations in this study consider two populations of UWB devices. The first population is composed of legacy devices operating under the existing regulations. The second population is composed of devices supporting new deployments and new applications that have been proposed but are not currently allowed under FCC regulations. Each population of UWB devices is composed of multiple device classes. Within SEAMCAT, each class of UWB device is represented as a separate interfering system since each class may have independent traffic characteristics.

### 3.5.1 Legacy UWB Device Classes

There are two classes of currently allowed UWB devices that were used in the Monte Carlo simulations to understand the baseline interference levels that could arise from modern (post 2001) UWB devices operating under the existing regulations. These are referred to as legacy devices and the two classes are legacy outdoor vehicle devices and legacy indoor devices. Simulations including only legacy device populations are referred to as baseline simulations.

It should be noted that that in contrast to the high and ultra-high data rate systems use cases assumed in the original UWB rule today's UWB has mainly focused on location tracking and low data rate communications based on IEEE802.15.4z standards. Since the completion of the original studies in the early 2000s, such high and ultra-high data rate UWB systems did not materialize. Rather, Wide Area Networks (4G LTE and 5G) and Wireless LAN (WLAN/Wi-Fi) systems became the dominant technologies for high and ultra-high data rate transmissions. This leads to a significant reduction of the assumed activity factors.

### 3.5.2 New Fixed Outdoor-Vehicle and New Enhanced Power Indoor

These new types of fixed UWB applications are currently not allowed without waivers in the FCC rules. The incremental increase in interference from these devices over that from the currently approved classes of devices is a subject of the simulation study. These devices are included in the new population labeled New Applications in the results appendices.

#### 3.5.2.1 New Fixed Outdoor to Vehicle

A new application for UWB is fixed outdoor transceivers that connect to vehicles. The applications include parking support.

#### 3.5.2.2 New Applications Outdoor Vehicle

In conjunction with the new Fixed Outdoor to Vehicle devices are additional new applications running on the pre-existing vehicle UWB devices. For example, some new applications involve communications from vehicles to fixed outdoor UWB terminals. This is accounted for in simulations by increasing the activity factor for the legacy vehicle UWB devices in accordance with the activity factor assumed for the new applications.

#### 3.5.2.3 New Enhanced Power Indoor

A new class of indoor devices is under consideration. These new enhanced power indoor devices are proposed to operate with an enhanced power density of -31.3 dBm/MHz which is 10 dB greater than the currently allowed level.

### 3.5.3 Other New Fixed Outdoor

An additional three new fixed outdoor UWB systems have been proposed to operate with very low duty cycles. In cases where the victim receiver may be in close proximity these systems may be very important to include in simulations. However, for some victim receivers considered in the current study, these very low duty cycle devices were not included because their impact on the total interference was expected to be very small.

#### 3.5.3.1 Outdoor Logistics

The new UWB outdoor logistics application involves new outdoor fixed UWB transceivers arranged around and within an area containing equipment or materials that need to be accurately located. The application involves the fixed transceivers sending interrogation signals to precisely locate a specific unit. The urban UWB devices densities can be as great as 1000 UWB devices per $km^{2,}$ but the deployment is confined and limited to specific storage sites. The activity factors are given in ECC Report 327[13] as 0.3%.

In wide area simulations the impact of outdoor logistics UWB will be a small contributor to the overall UWB interference power.

#### 3.5.3.2 Parking Management

The parking management application is another new fixed outdoor UWB application. The urban device density used in ECC Report 327[13] was 400 devices per $km^2$. The activity factor was 0.05%.

#### 3.5.3.3 Physical Access Control

The new fixed outdoor access control UWB application involves transponders at building entrances that allow access when certain portable UWB devices are nearby. The urban UWB device density used the ECC Report 327[13] was 200 UWB devices per $km^2$. The activity factor was 0.006%.

## 3.6 Interfering UWB Systems Propagation

The choice of UWB transmitter (ILT) to UWB receiver (ILR) propagation model, impacting the Interfering System Link in Figure 1, is arbitrary since it does not affect the final victim receiver I/N ratio. Since the level of the UWB signal received by the UWB receivers is not used in the spectrum compatibility analysis, simple propagation models are used. For outdoor UWB to UWB systems the free space propagation model is used. For indoor UWB-to-UWB system links the 802.11 rev3 (Model C) propagation model is used. SEAMCAT had issued warnings when free space propagation was selected for indoor UWB-to-UWB links.

# 4 INTERFERENCE MODELING

## 4.1 Overview

A visualization of a large UWB interference simulation is shown in Figure 2 where an airplane operating an airborne weather radar (the VLR) is flying over a large urban area. There are many indoor and outdoor fixed and mobile UWB devices (ILT and ILR) operating beneath the airplane.

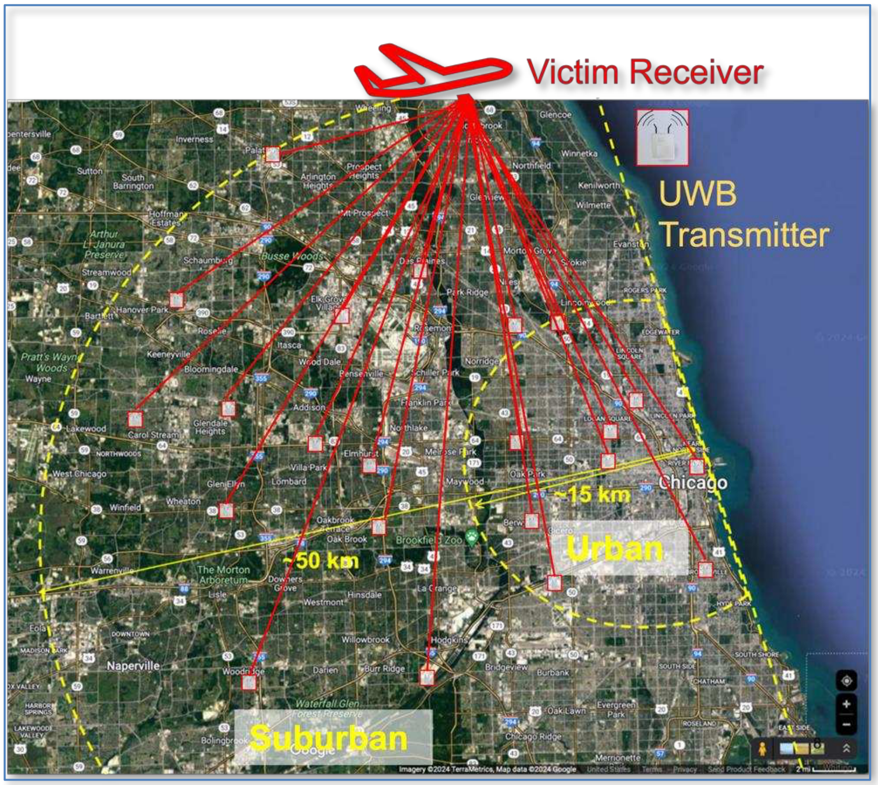


**Figure 2. System Model Example**

Modeling a specific scenario involves two key considerations:

1. Configuring SEAMCAT to randomly place interfering link transmitters (UWB devices) in the environment with the appropriate density of devices per square kilometer.
2. Defining the propagation model for the link from the UWB interfering link transmitter to the victim link receiver (VLR).

For terrestrial victim systems the local device densities and potential proximity of UWB devices need to be modeled in more detail.

## *4.2 UWB Device Density Modeling*

The development of UWB device density models took place in two phases. Initially, the information in Tables 6 and 7 of the ECC Report 327 was used to derive Phase 1 UWB device densities and activity factors for vehicle and fixed outdoor devices and legacy and enhanced power indoor devices.

Later, the values in Table 18 of the ECC Report 327 were used to derive Phase 2 device densities and activity factors for the same set of devices.

The main differences are that the densities and activity factors for legacy Indoor UWB devices and legacy vehicle devices were determined to be lower and more accurate in the latter Table. The values derived from Tables 6 and 7 used total device densities based on the earlier proposed high data rate UWB deployment concepts. The Table 18 values were constructed bottom-up from the expected modern (new applications) low duty cycle applications.

### 4.2.1 Overview

The random placement of UWB devices is based on an expected UWB device density in devices-per-square-kilometer and the total area where devices are to be placed. In this study, this is an area specified by a maximum radius around the victim receiver. The maximum radius is chosen to be the distance to the radio horizon where elevation angle including curvature of earth effects of the direct path between the UWB transmitter and the victim receiver is zero degrees. Additionally, a keep-out or protection radius can be specified when appropriate for a specific use case.

UWB device densities are determined based on general environmental considerations and specific traffic characteristics of each device class. In addition, the IEEE 802.15.4z UWB PHY standard [11] identifies up to 8 channels of 500 MHz between 6 and 10.6 GHz. However, taking a conservative approach, the devices in a specific class are assumed to be distributed evenly across only 5 channels. This choice also aligns with the results in [13] where UWB systems in Europe are limited to 5 channels of 500 MHz between 5 and 8.5 GHz.

Activity factors taken from various publications and ECC Reports were treated as probabilities of transmission in this study. For example, if a class of devices has a 5% activity factor, then only 5% of the devices are assumed to transmit during any individual Monte Carlo simulation event or trial.

### 4.2.2 UWB Urban Device Density Details

The Urban UWB density details are based on the values found in Table 18 of the ECC Report 327 (see Table 1). For indoor devices the overall density is 10 active devices per $km^2$ with half at the legacy -41.3 dBm/MHz maximum power density and half with the enhanced indoor -31.3 dBm/MHz maximum power density.

The overall density for UWB outdoor devices is just over 7 UWB active devices per $km^2$. All outdoor devices have a maximum power density of -41.3 dBm/MHz. The main differences are in the antenna heights.

| Table 18 | | Table 18 over Five Channels | | Active Transmitters per $km^2$ |
|---|---|---|---|---|
| | | Modified Phase 2 Density per-channel | Phase 2 AF | |
| Indoor Urban | Other Indoor | 500 | 1% | 5 |
| | New App Enhanced Power | 500 | 1% | 5 |
| Outdoor Urban | Other Outdoor | 80 | 1% | .8 |
| | Parking | 80 | 0.25% | .2 |
| | Outdoor Logistics | 10 | 0.30% | .03 |
| | PACS | 40 | 0.01% | .004 |
| | New App Vehicle Fixed | 80 | 5% | 4 |
| | New App Vehicular Mobile | 200 | 1% | 2 |

**Table 1. ECC Report 327 Table 18 UWB Device Densities**

## 4.3 UWB Device Placement

When placing UWB interfering links there are several options available in SEAMCAT. In this study the "None" (also labeled Standard in version 5.5) option for Relative Placement was used. With this option selected, both the Path Distance Factor probability distribution and the number of active devices are specified. A uniform polar distribution was used for the Path Distance Factor where the maximum radius from the victim receiver to the UWB transmitters is entered to set the distribution.

## 4.4 Interferer to Victim Propagation

The parameters of the interfering system link (see Figure 1) must be specified for each distinct type of interferer (see 3.5 UWB Devices). Setting up the interfering links of the SEAMCAT simulation scenario includes specifying the propagation model to use for the link from the UWB transmitter (ILT) to the victim receiver (VLR). Available propagation models are the Longley-Rice (NTIA/ITS) Irregular Terrain Model (ITM), the Recommendation ITU-R P.452-17 terrestrial model, the Recommendation ITU-R P.525 (i.e. free space model), and the Recommendation ITU-R P.528-5 earth to aircraft or space platform model.

### 4.4.1 Longley-Rice (NTIA/ITS)

The Longley-Rice ITM is used for terrestrial links. The Longley-Rice model includes clutter effects. The main parameter that can be varied in the simulation is the terrain irregularity parameter. Values of 0, 30, and 90 meters have been used in this study.

Other key parameters used to configure the Longley-Rice model include time variability, location variability and situational variability. For the Fixed Service (FS) and Surface Movement Radar (SMR) the following propagation variabilities were used.

#### 4.4.1.1 Time Variability

> "Time variability accounts for variations of hourly median values of attenuation due to, for example, slow changes in atmospheric refraction or in the intensity of atmospheric turbulence. The computed field strength value is an hourly median value; the actual field strength at the receiver location would be expected to be above that value during half of each hour and below that value for half of each hour. Time variability describes the effects of these changes over time. The time variability for the calculation is expressed as a percentage from 0.1% to 99.9%. This value gives the fraction of time during which actual received field strength is expected to be equal to or higher than the hourly median field computed by the program." [12]

#### 4.4.1.2 Location Variability

> "Location variability accounts for variations in long-term statistics that occur from path to path due to, for example, differences in the terrain profiles or environmental differences between the paths. The location variability for the calculation is expressed as a percentage from 0.1% to 99.9%. This value gives the fraction of locations where actual received field strength is expected to be equal to or higher than the median field computed by the program."[12]

#### 4.4.1.3 Situational Variability

> "Situation variability accounts for variations between "like appearing" systems with the same system parameters and environmental conditions, including differences in the ability of individuals to accurately take field strength readings. The situation variability for the calculation is expressed as a percentage from 0.1% to 99.9%. This value gives the fraction of "identical" paths on which actual received field strength is expected to be equal to or higher than the field computed by the program."[12]

#### 4.4.1.4 FSS Variability Parameters

The fixed Satellite Service (FSS) results were completed using time, location, and situation variability percentages fixed at 50%. These simulations were performed before the variabilities were updated.

### 4.4.2 Recommendation ITU-R P.452-17

Recommendation ITU-R P.452-17 is used to evaluate interference between terrestrial systems at frequencies from about 0.1 GHz to 50 GHz, accounting for both clear-air and hydrometeor scattering interference mechanisms. Clear-air propagation estimation includes five types of propagation modeling: line-of-sight, diffraction, tropospheric scatter, anomalous propagation, and height-gain variation in clutter. For hydrometeor-scatter interference prediction, the transmission loss between two stations is determined based on the interfering and victim antenna radiation patterns for each station. The Recommendation ITU-R P.452-17 model is also a component of the blended model discussed in the ECC Report 327 for distances greater than 1 km.

### 4.4.3 Recommendation ITU-R P.525 Free Space Propagation Model

The free space propagation model is appropriate for direct line of sight paths between the UWB transmitters and the victim system receivers. Modeling airborne victim receivers can use free space models.

### 4.4.4 Recommendation ITU-R P.528-5

Recommendation ITU-R P.528-5 is a propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands. The Recommendation ITU-R P.528 propagation model is intended for use in analyzing ground to air and earth to space propagation. In this study the median value from Recommendation ITU-R P.528-5 is used, which gives results similar to free space for airborne scenarios.

### 4.4.5 Winner II

The Winner II model is used in the ECC Report 327 blended model for distances below 1 km.

# 5 Result Generation and Assessment

## 5.1 SEAMCAT Output Files

The SEAMCAT tool produces result files of the total unwanted power at the victim receiver from all the placed UWB transmitters active during each simulation trial. The calculation of received power includes the UWB device and victim antenna gains, any clutter or building entry losses, and propagation losses. The format of the files is a zipped .xml archive with a *.swr suffix.

These files are converted to text files where the columns include the results the all the simulated victim and interferer power levels for each trial.

## 5.2 Histogram and plotting

Result vectors in text form are extracted from the binary result files using a conversion feature of the SEAMCAT tool. These vectors are processed in a post-processing tool to generate histograms of the power spectral I/N ratios. The total sum interference power density I/N ratio histograms or the individual interferers I/N ratio histograms can be generated. These are plotted as inverse CDF graphs.

# 6 Minimum Coupling Loss

A minimum coupling loss (MCL) calculation is included for each system in the appendices. The MCL was calculated as

$$MCL = P_{tx} + G_{tx} + G_{rx} - (N_{dBm} + \frac{I}{N})$$

Where

- MCL Minimum Coupling Loss is minimum loss to ensure that I/N is not exceeded
- $P_{tx}$ is the UWB transmit power in a specified bandwidth in dBm
- $G_{tx}$ is the maximum UWB device antenna gain (0 dB outdoor, -16.6 dB indoor representing building exit loss)
- $G_{rx}$ is the maximum Victim device antenna gain
- $N_{dBm}$ is the victim device noise level at the antenna terminals
- $\frac{I}{N}$ is the specified maximum allowed Interference to Noise ratio in dB, here -6 dB

The power level of the victim receiver input noise in 1 MHz using 290 K as the reference temperature is given by

$$N_{dBm} = -173.97\, dBm + dB(1MHz) + NF$$

Where *NF* is the noise figure as seen at the antenna connection. The noise figure NF is the sum of receiver noise figure in dB and the line loss between the antenna and the receiver in dB. If the antenna noise temperature is not 290K then the noise figure is modified as

$$NF_A = 10\log_{10}\left(10^{(\frac{NF}{10})} + \frac{T_{Ant}}{290} - 1\right) dB$$

This situation exists for the FSS receiver antennas which point towards the satellites in the sky above.

# 7 REFERENCES

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[13] ECC Report 327, *Technical studies for the update of the Ultra Wide Band (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz*, Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT), October 2021.

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# APPENDICES

The following Appendices contain information on the specific victim receiver types modeled and simulated.

# A. Airborne Weather Radar

## Description

Airborne weather radars [4] are used to search for undesired weather patterns ahead of an aircraft in flight and on the ground prior to take-off. These radars use narrow pencil beams to scan horizontally and to tilt up or down as needed. In this report the downtilt is the important parameter since it determines if the UWB devices on the ground are in the main pencil beam. In this report the downtilt of the center of the pencil beam is limited to the edge of the earth, i.e. the radio horizon. Table 2 below lists the important system parameters for an Airborne Weather Radar system drawn from ITU-R M.1796-3, Table A5 [5].

| Parameters from M.1796-3 System A5 | |
|---|---|
| Frequency | 9.33 GHz |
| Antenna Main Beam gain | 34.4 dBi |
| Elevation and azimuth beamwidth | 3.5 degrees |
| Horizontal scan type, sector | ± 30 degrees |
| Antenna (First) Sidelobe | 3.4 dBi |
| Receiver Noise Figure | 4.0 dB |

**Table 2. Airborne Weather Radar and Wind Shear System Parameters**

## Antenna

The AWR simulation uses two antenna models. First, the transmitter is the reflected radar signal. The antenna used is a simple isotropic 0 dB gain design. The reflected signal power is set to 33 dBm although this is not a critical value since the radar signal receiver power is not used in the calculation of I/N power density ratios. Second, the radar receiver antenna is a high gain symmetric design.

## ITU-R M.1851-2 Antenna Design

The ITU recommendation M.1851-2 [6] provides a detailed procedure to calculate the gain function for various types of antennas. As shown in Table 3 below, the design based on a cosine-squared illumination pattern has performance values very close to those in ITU-R M.1796-3, table entry A5. As a result, the antenna pattern based on ITU-R M.1851-2 cosine-squared illumination is used in the SEAMCAT Monte Carlo simulations to model the AWR antenna.

| | ITU-R M.1796-3, Table Entry A5 | ITU-R M.1851-2 Cosine Squared Illumination |
|---|---|---|
| Horizontal Beamwidth (deg) | 3.5 | 3.5 |
| Vertical Beamwidth (deg) | 3.5 | Spherically symmetric |
| First sidelobe | -30 dB | -32 dB |
| Maximum off axis loss | Not specified | -60 dB |

**Table 3. Airborne Weather Radar Antenna Specifications**

The antenna pattern was implemented in SEAMCAT by entering the calculated normalized gain values at multiples of 1 degree up to 10 degrees. The Spherical model implements a circulatory symmetric receiver gain function by combining the peak gain and the normalized gain pattern. Figure 3 shows the values and Figure 4 shows the vertical gain pattern.

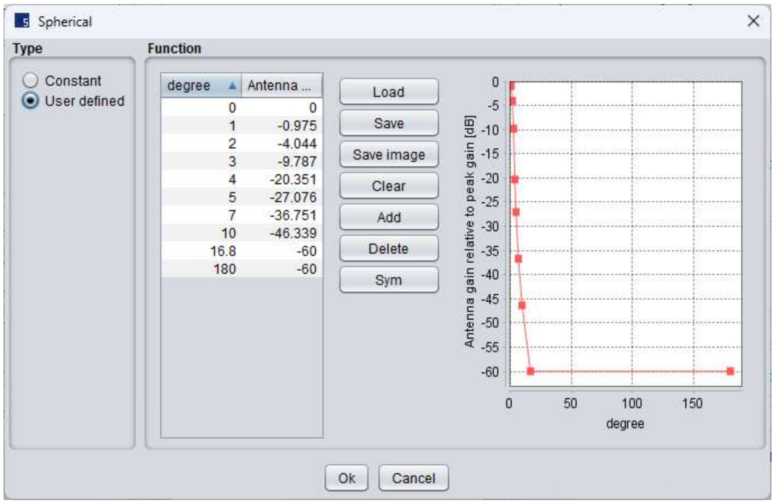



**Figure 3. Airborne Weather Radar M.1851-2 Antenna Gain Table**

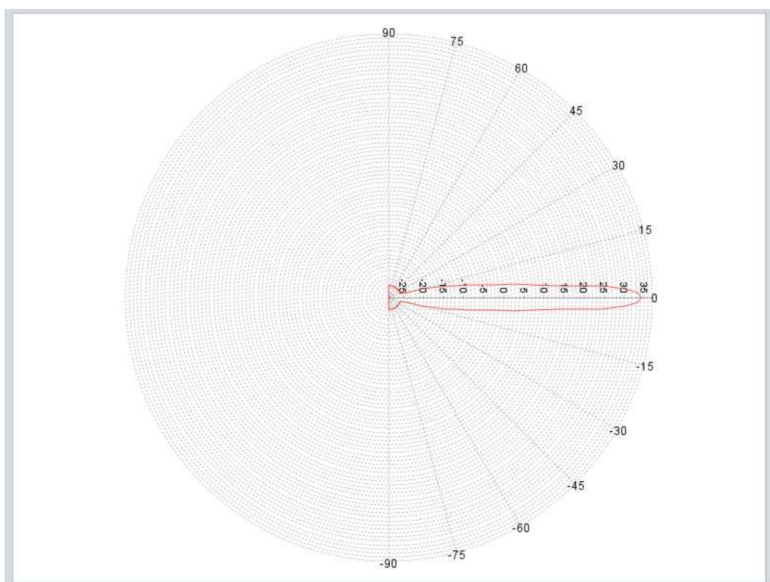


**Figure 4. Airborne Weather Radar M.1851-2 Vertical Gain Plot**

The calculated gain vs angle off-boresight for the 3.5-degree antenna is shown below in Figure 5. Note that the upper bound of the sidelobe levels is used in the simulations.

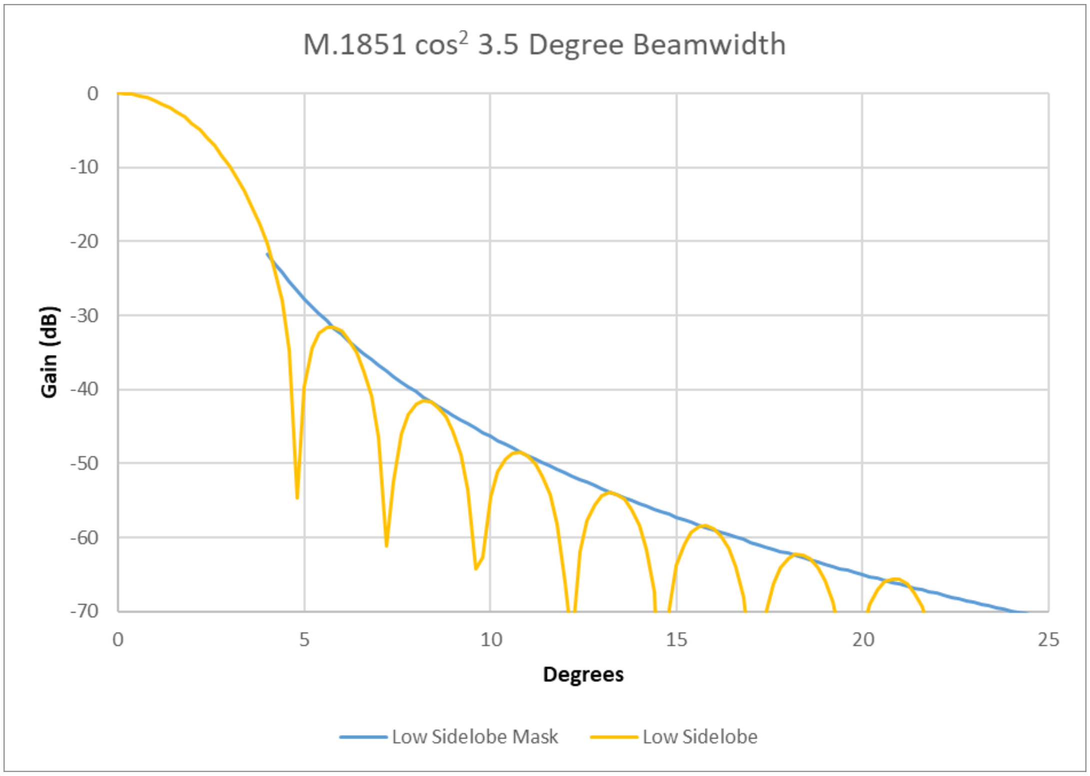



**Figure 5. Calculated Gain vs. Angle Off Boresight for the 3.5 Degree Antenna**

## *Airborne Platform Altitudes*

The Airborne Weather Radar systems were simulated for altitudes of 5000, 15000, 25000, and 35000 feet. These altitudes were selected to span both level flight conditions and take-off and approach altitudes.

The altitude is set as a constant receiver (VLR) and transmitter (VLT) antenna height in the configuration of the victim system. This parameter is found within the *Local Environments* definition for the receiver and transmitter tabs.

## *Downtilt and Scanning*

Airborne Weather Radar antennas are capable of being scanned left and right and tilted down to search for dangerous weather conditions. The maximum downtilt used in the analysis presented here was limited to the earth's edge. From the point of view of the UWB transmitters the elevation towards the Airborne Radar is zero degrees, i.e. there is no downtilt for UWB transmitters.

## *Propagation Model, Clutter, Building Loss*

The path between a ground base UWB transmitter and an airborne weather radar receiver is line-of-sight unless there is ground clutter present. Additionally, the indoor UWB device signals are impacted by losses known as building entry losses. Early simulation used the Recommendation ITU-R P.728 model with a 50% value for the Time percentage parameter. It was found that this model gave inconsistent results and was replaced with the Recommendation ITU-R P.525 Free space model.

The Recommendation ITU-R P.2108 Ref. 3.3 clutter model was used for the outdoor UWB transmitters and the Recommendation ITU-R P.2109 building loss model was used for the indoor UWB devices. For both, the parameter distribution was set to a uniform distribution from 1% to 99%.

## *Flat Earth Notes for Airborne Victim Modeling*

A flat earth model for the placement of victim receiver and the interfering transmitter receiver pairs is assumed. For the large ground area visible from airborne platforms the curvature of the earth needs to be considered.

The figure below shows a profile view of the path between a UWB transmitter at the radio horizon (Zero degrees of elevation) and an airborne receiver. The black line shows the flat earth profile for placing UWB devices based on extending the tangent of the earth surface beneath the airborne platform. If the downtilt angle to the radio horizon were used in simulations with this flat earth profile, then the radar receive antenna boresight would point directly to a point on the flat-earth ground about halfway to the radio horizon. Simulations of UWB devices placed near that point would introduce interference sources that would not correspond to the real 3D path between the UWB device and the airborne receiver. Simulation downtilt angles were calculated based on the flat earth model.

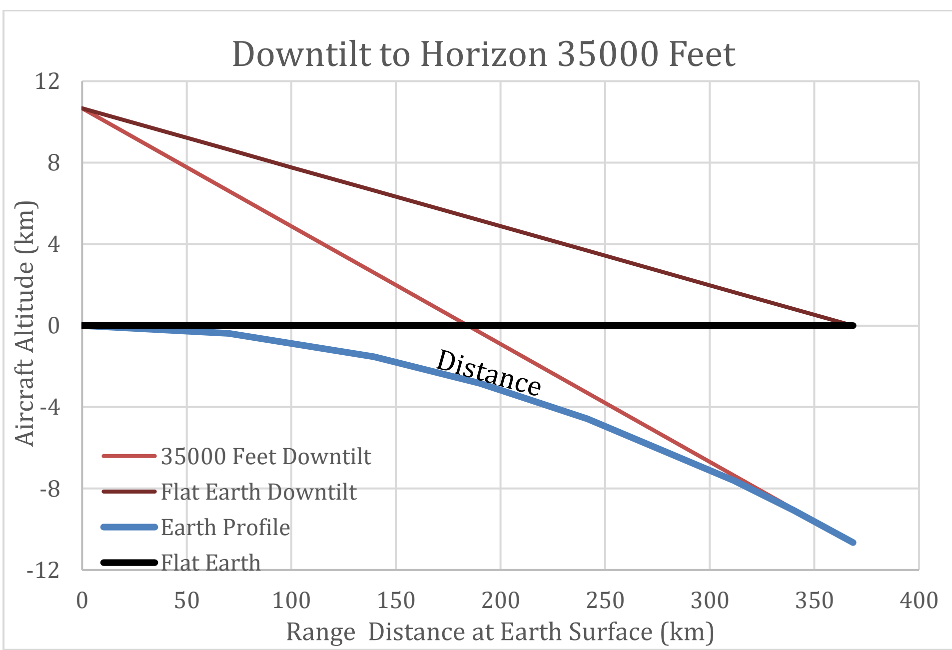



**Figure 6. Profile View of the Path Between a UWB Transmitter at the Radio Horizon**

Figure 6 shows the profile view of paths from the UWB transmitters showing downtilt from the airborne receiver with and without earth curvature and a flat earth. Note that the vertical scale is not the same as the horizontal.

The maximum downtilt angles are adjusted (reduced) to intercept the new radio horizon at a distance equal to the great circle distance along the surface of the earth.

The downtilt angles used are listed below in Table 4. The third column lists the downtilt angles to the radio horizon including the curvature of the earth.

| Altitude (ft.) | Altitude (m.) | Down-tilt Angle to Earth Curvature Edge, Radio Horizon (degrees) | New Flat Earth Down-tilt Simulation Angle (degrees) |
|---|---|---|---|
| 35,000 | 10,668 | 3.31 | 1.66 |
| 25,000 | 7,620 | 2.80 | 1.40 |
| 15,000 | 4,572 | 2.17 | 1.09 |
| 5,000 | 1,524 | 1.25 | 0.63 |

**Table 4. Base and Adjusted Down-tilt Angles.**

The downtilt angle (the rightmost column of Table 4) is set as a constant elevation offset for the receiver (VLR) and transmitter (VLT) antenna in the configuration of the victim system. This parameter, labeled *Elevation additional offset*, is found within the *Antenna pointing* parameters within the receiver and transmitter tabs.

For straight ahead, level flight simulation a 0-degree downtilt was used. In future work, the level flight downtilt will include a small uptilt to better model the flight path parallel to the surface of the earth.

The radius of operation was calculated by solving for the central angle between the ground point beneath the airborne radar and the horizon. An approximation for the cosine was used since the altitudes studied are small compared to the earth's radius. The radius of operation was found by multiplying the central angle by the radius of the earth or 6374.14 km. the drawing below shows the geometry involved. Note that the central angle is also the downtilt angle to the horizon point. The bold arc is the radius of operation.

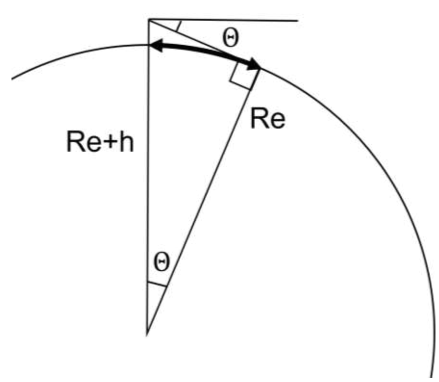



**Figure 7. Geometry to Calculate Operational Radius & Downtilt Angle Towards Horizon.**

Note that Re in the above figure is the radius of the earth and h is the altitude. In the figure above cosine of the central angle is given by $\cos(\theta) = \frac{R_e}{R_e+h}$ when the elevation angle to the airborne radar is zero degrees.

## Device Detail

The number of active devices and the ground radius beneath the victim receiver are shown in the tables below. The first table shows the two baseline classes of UWB devices, vehicle and indoor, for the dense urban device density assumption. The second and third table shows the combined four classes of legacy and new UWB devices: indoor current power; combined vehicle; enhanced power indoor; and fixed-outdoor-to-vehicle.

| | | **Outdoor Vehicle** | | | **Legacy Indoor** | | |
|---|---|---|---|---|---|---|---|
| **Altitude (Feet)** | **Radius (km)** | **Number Active TX 206/km$^2$ @ 5%** | **Scaled Number Active TX** | **TX Power Scaled from -41.3 dBm** | **Number Active TX 1100/km$^2$ at 5%** | **Scaled Number Active TX** | **TX Power Scaled from -41.3 dBm** |
| 35000 | 368.5 | 4393305 | 21966 | -18.3 | 23459396 | 23459 | -11.3 |
| 25000 | 311.5 | 3139607 | 31396 | -21.3 | 16764893 | 16765 | -11.3 |
| 15000 | 241.3 | 1884715 | 18847 | -21.3 | 10064013 | 10064 | -11.3 |
| 5000 | 139.4 | 628800 | 6288 | -21.3 | 3357671 | 33577 | -21.3 |

**Table 5. AWR Baseline UWB Device Class Dense Urban**

| | | **Legacy Indoor 4m height** | | | **New Enhanced Power Indoor** | | |
|---|---|---|---|---|---|---|---|
| **Altitude (Feet)** | **Radius (km)** | **Number Active TX 1100 at 5%** | **Scaled Number Active TX** | **TX Power Scaled from -41.3 dBm** | **Number Active TX 500 at 1%** | **Scaled Number Active TX** | **TX Power Scaled from -31.3 dBm** |
| 35000 | 368.5 | 23459396 | 23459 | -11.3 | 2132672 | 21327 | -11.3 |
| 25000 | 311.5 | 16764893 | 16765 | -11.3 | 1524081 | 15241 | -11.3 |
| 15000 | 241.3 | 10064013 | 10064 | -11.3 | 914910 | 9149 | -11.3 |
| 5000 | 139.4 | 3357671 | 33577 | -21.3 | 305243 | 30524 | -21.3 |

**Table 6. AWR New UWB Application Class Dense Urban (1 of 2)**

| | | Legacy and New Vehicle Outdoor | | | New Fixed Vehicle Outdoor | | |
|---|---|---|---|---|---|---|---|
| Altitude (Feet) | Radius (km) | Number Active TX 205 at 6% | Scaled Number Active TX | TX Power Scaled from -41.3 dBm | Number Active TX 80 at 5% | Scaled Number Active TX | TX Power Scaled from -41.3 dBm |
| 35000 | 368.5 | 5246374 | 5246 | -11.3 | 1706138 | 17061 | -21.3 |
| 25000 | 311.5 | 3749240 | 37492 | -21.3 | 1219265 | 12193 | -21.3 |
| 15000 | 241.3 | 2250679 | 22507 | -21.3 | 731928 | 7319 | -21.3 |
| 5000 | 139.4 | 750897 | 7509 | -21.3 | 244194 | 24419 | -31.3 |

**Table 7. AWR New UWB Application Class Dense Urban (2 of 2)**

## Protection Ratios

The initial protection ratio used in this report is -6 dB I/N. The I/N protection ratio is compared with simulation results and can be modified if desired without the need to repeat simulations. The noise figure used is 4 dB and was taken from table 15 in ITU Rec. 1796. The noise floor (N) in 1 MHz, equal to the Thermal Noise (-114 dBm) plus the noise figure, is then calculated to be -110 dBm.

## Airborne Weather Radar Results with Table 18 UWB Density

Here, the results using the device densities form table 18 of the ECC Report 327 were used. The curves labeled T18 are from the Table 18 data. Note that common power scaling is assumed for each of the following two table's content.

| | | Legacy Indoor 5m Height | | | New Enhanced Power Indoor 5m Height | | |
|---|---|---|---|---|---|---|---|
| Altitude (Feet) | Radius (km) | Number Active TX 500 at 1% AF | Scaled Number Active TX | TX Power Scaled from -41.3 dBm | Number Active TX 500 at 1% AF | Scaled Number Active TX | TX Power Scaled from -31.3 dBm |
| 35000 | 368.5 | 2132672 | 8331 | -7.2 | 2132672 | 8331 | -7.2 |
| 25000 | 311.5 | 1524081 | 11907 | -10.2 | 1524081 | 11907 | -10.2 |
| 15000 | 241.3 | 914910 | 14295 | -13.2 | 914910 | 14295 | -13.2 |
| 5000 | 139.4 | 305243 | 9539 | -16.2 | 305243 | 9539 | -16.2 |

**Table 8. AWR Device Densities using Table 18 from ECC Report 327 (1/2)**

| | | Legacy and New Vehicle Outdoor 1.5m Height | | | New Fixed Vehicle Outdoor 6m Height | | |
|---|---|---|---|---|---|---|---|
| Altitude (Feet) | Radius (km) | Number Active TX 300 at 1% AF | Scaled Number Active TX | TX Power Scaled from -41.3 dBm | Number Active TX 80 at 5% AF | Scaled Number Active TX | TX Power Scaled from -41.3 dBm |
| 35000 | 368.5 | 1279603 | 4998 | -17.2 | 1706138 | 6665 | -17.2 |
| 25000 | 311.5 | 914449 | 7144 | -20.2 | 1219265 | 9526 | -20.2 |
| 15000 | 241.3 | 548946 | 8577 | -23.2 | 731928 | 11436 | -23.2 |
| 5000 | 139.4 | 183146 | 5723 | -26.2 | 244194 | 7631 | -26.2 |

**Table 9. AWR Device Densities using Table 18 from ECC Report 327 (2/2)**

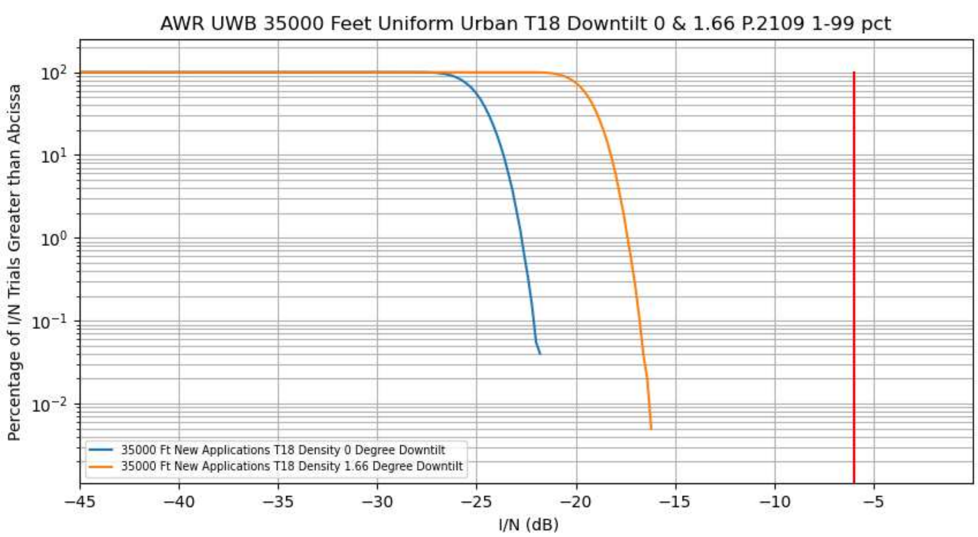



**Figure 8. Inverse I/N CDF for 35000 ft AWR.**

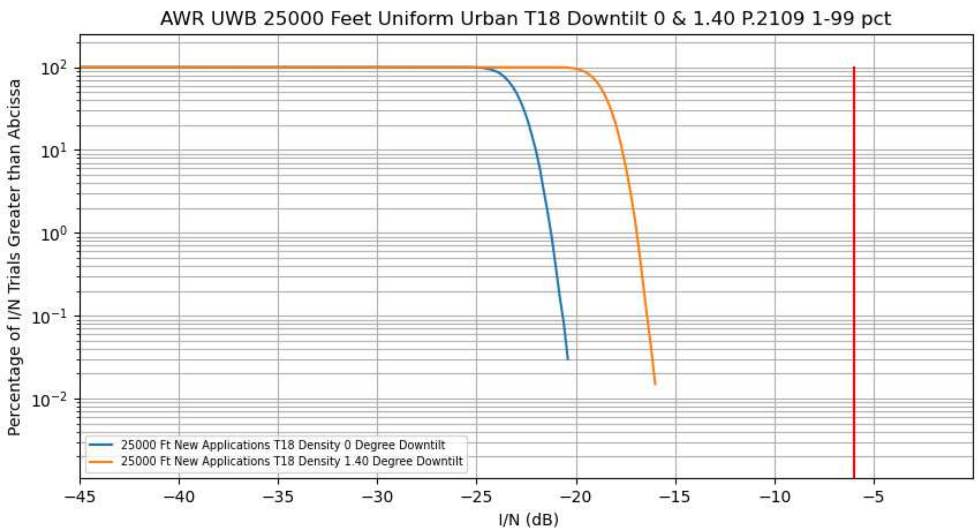



**Figure 9. Inverse I/N CDF for 25000 ft AWR.**

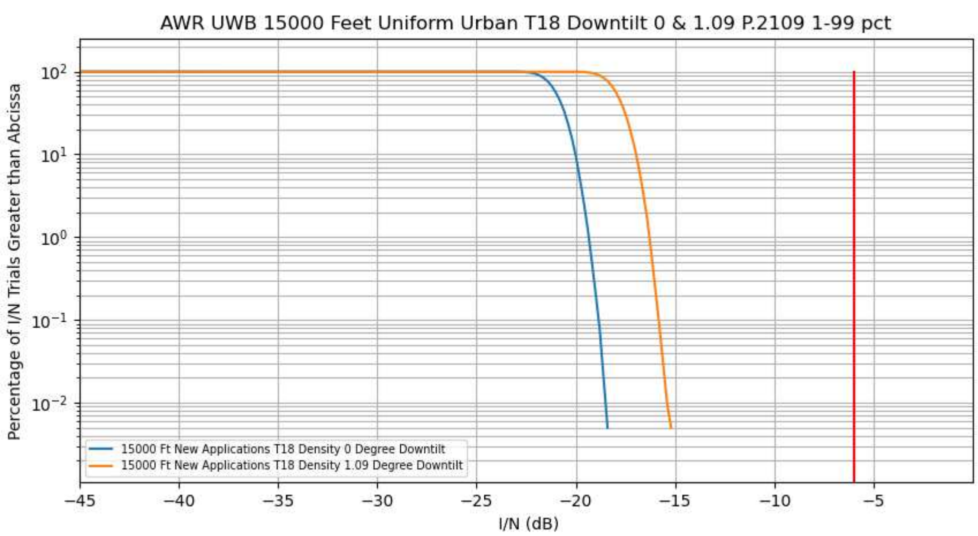



**Figure 10. Inverse I/N CDF for 15000 ft AWR.**

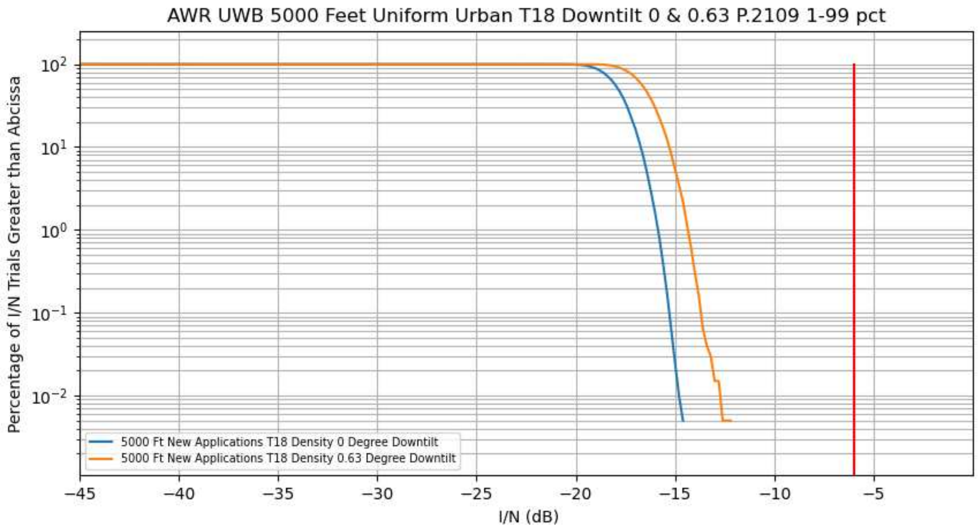



**Figure 11. Inverse I/N CDF for 5000 ft AWR.**

## *AWR MCL Calculations*

The MCL calculations for the Airborne Weather Radar are shown in the table below. The parameters were taken from the values used in the Monte Carlo simulations. The worst-case protection distance found was 0.727 km for a UWB device in the aircraft antenna boresight.

| | | Ptx (dBm/MHz) | Gx (dB) | Grx (dB) | Feeder Loss (dB) | I/N | NF (dB) | Tantenna (K) | MCL (dB) | Freq (MHz) | FSPL Protection Distance (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AWR | Fixed Outdoor | -41.3 | 0 | 34.4 | 0 | -6 | 4 | 290 | 109.07 | 9330 | 0.727 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 34.4 | 0 | -6 | 4 | 290 | 102.47 | 9330 | 0.340 |

**Table 10. MCL Calculations for Weather Radar**

# B. SURFACE MOVEMENT RADAR

Surface Movement Radars (SMR) are ground radars that operate at airports on frequencies between 9000 and 9200 MHz. These are also known as Airport Surface Detection Equipment (ASDE) radars. These radars use a narrow fan beam to search for unauthorized vehicles on the runways and taxiways at airports. The table below gives the parameters from ITU Rec M.1796-3 [5] for selected ASDE radars.

| Parameters from M.1796 System G18 (and G19) | |
|---|---|
| **Airport Surface Detection Equipment** | |
| Frequency | 9 – 9.2 GHz |
| Antenna Main Beam gain | 37.6 dBi |
| Elevation beamwidth | 9.91 degrees |
| Azimuth beamwidth | 0.37 degrees |
| **Elevation gain pattern: inverse cosecant-squared ($CSC^2$)** | |
| Horizontal scan type, sector | ± 30 degrees |
| Antenna (first) Sidelobe | 9.15 dBi |
| Receiver Noise Figure (5.0 G19) | 5.25 dB |

**Table 11. Parameters from ITU Rec M.1796 for Selected ASDE Radars**

## *Cosecant (CSC)-Squared SMR Antenna*

The SMR radar receiver antenna pattern is based on specifications found in Table 4 from ITU-R M.1796-3. The important parameters are reproduced below.

| | ITU-R M.1796-3 | M.1851-2 |
|---|---|---|
| Vertical Beamwidth | 9.91 Degrees | $CSC^2$ 9.91 degrees |
| Horizontal Beamwidth | 0.37 Degrees | $Cos^2$ 0.37 degrees |
| Pattern Type | Inverse CSC-Squared | |
| Gain | 37.96 dB | 37.96 dB |
| Front to Back (minimum gain) | | -60 dB |

**Table 12. SMR Radar Parameters**

The vertical pattern was designed using the procedure in section 2.2 of ITU.Rec-M.1851-2 [6]. The vertical beamwidth parameter was 9.91 degrees. The horizontal gain pattern used the $\cos^2$ design procedure in sections 2.1.2 and 2.1.3. The sidelobe envelope was used instead of the detailed sidelobe design. These patterns were sampled and applied to the SEAMCAT Horizontal-Vertical Gain antenna plugin. The azimuth and elevation patterns are shown below. The azimuth pattern is offset by 5 degrees for clarity. Note that the vertical pattern does not exhibit any nulls towards the ground surface. There is a mismatch between the minimum off-axis vertical and horizontal gains. The option for hybrid interpolation was selected to interpolate gains at angles between the vertical (azimuth=0) and azimuth (elevation =0).

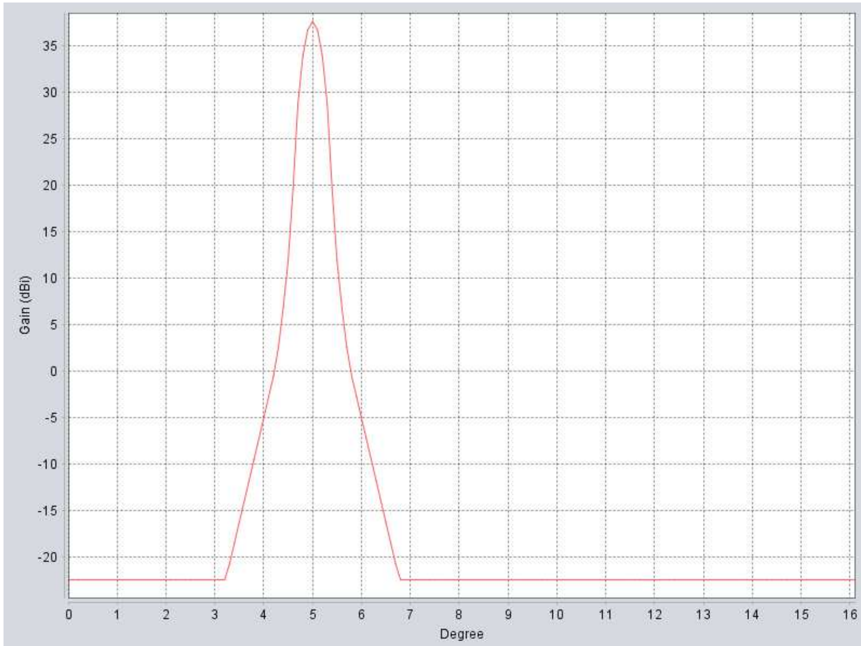



**Figure 12. SMR Antenna Azimuth Gain Pattern Offset 5 Degrees**

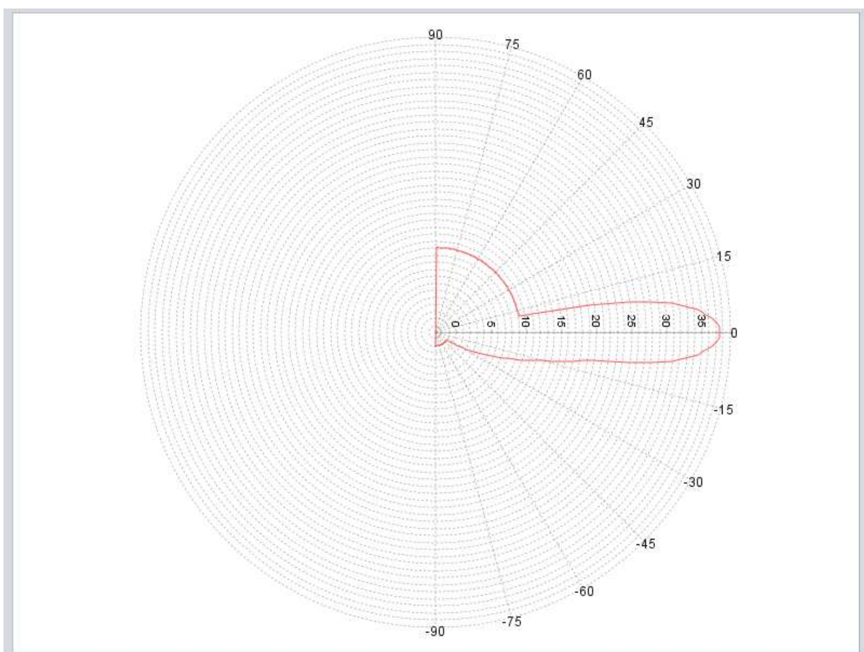



**Figure 13. SMR Elevation Gain Pattern Showing Preferential Gains Forwards Ground Surface.**

Figure 14 shows the calculated elevation gain pattern on the lower, towards-ground side of the pattern. The gain of the $CSC^2$ pattern within the $CSC^2$ region beyond the main lobe does not exhibit sidelobes.

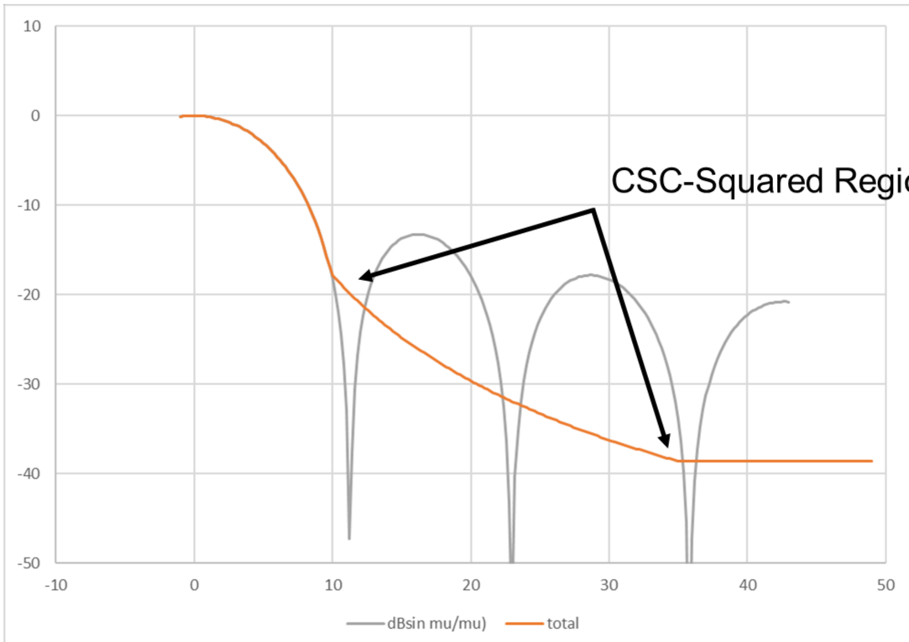



**Figure 14. Close-up View of $CSC^2$ Gain Pattern.**

The SMR radar reflections are modeled as isotropic sources. The transmit power level is not critical again since only the spectral density I/N ratios are used in the compatibility analysis.

## *Downtilt and Antenna Heights*

Detailed information about specific SMR deployments was not available. Certain assumptions were made to develop the simulation scenarios. The location of the SMR radar was assumed to be on the roof of a control tower located at the center of an airport. The heights of the control towers for a small number of airports and two values, 50 and 70 meters, were selected as being representative.

No downtilt was applied to the SMR receiver antenna. Two different antenna heights were used with the SMR receiver antennas. These were 50 and 70 meters representing smaller or larger airport scenarios respectively.

The height is set as a constant receiver (VLR) and transmitter (VLT) antenna height in the configuration of the victim system. This parameter is found within the *Local Environments* definition for the receiver and transmitter tabs.

## Propagation Model

The NTIA-ITS Longley Rice model was used for the SMR interference simulations. Point to point terrain models were not used. Instead, the terrain variation parameter was used to model different types of surrounding topography. Two values for terrain variation were selected, 30 and 90 meters.

The NTIA-ITS Time/Location/Situation parameters were set to the following ranges.

- Time Variation: 0.001% to 50%
- Location Variation: 0.001% to 99%
- Situation Variation: 0.1% to 99.9%

Variations were enabled in the scenario's propagation tab.

## UWB Device Placement

Two UWB device classes were used based on the indoor and outdoor devices described in Table 18 of the ECC Report 327. Devices are randomly drawn from distributions that include multiple power levels and antenna heights to simplify the simulations. The UWB devices classes follow those in the Fixed Service Appendix below.

The UWB devices were placed uniformly within a radius determined by the SMR receiver antenna height. Unlike the AWR simulations, the maximum radius was found by scaling the distance used in the Fixed Service simulations described below by the SMR antenna height. For the Fixed Service antenna height of 25 meters a simulation radius of 5 km was used. For the 50- and 70-meter SMR antenna heights used here the simulation radiuses were 10 and 14 km respectively. The number of active devices was found as before by multiplying the dense urban UWB device densities in UWB device per $km^2$ found in the ECC Report 327 Table 18 by the activity factor and then again by the total area in $km^2$. The dense urban UWB device densities represent a very worst-case scenario when modeled as adjacent to and encircling an airport. Suburban values were found by scaling the dense urban values down by a factor of 10.

Protection distances were applied in the interference scenarios to model the exclusion of unwanted UWB devices from inside airport boundaries. Two values were chosen by reviewing satellite images of a small number of airports. The protection distances (radiuses) were 2.6 km and 1.7 km for large and small airports respectively.

The UWB devices were modeled as before with Recommendation ITU-R P.2108 Ref 3.3 clutter for both indoor and outdoor scenarios and Recommendation ITU-R P.2109 building entry loss for indoor scenarios.

For this use case, both dense urban and suburban environments were simulated. The same device classes are included in suburban simulations, but device densities for suburban scenarios are assumed to be one-tenth that of urban densities. Dense urban densities are a worst-case scenario that is unlikely to be present directly adjacent to airports.

The power levels were also taken from the Fixed Service simulations described in the ECC Report 327. For the baseline case the power levels included a 4 dB body loss for 5.7% of the devices both indoor and outdoor. For the New Applications case the indoor power levels were split between -31.3 dBm and -41.3 dBm and then half again were reduced by a 4 dB body loss.

The antenna heights for the outdoor devices were 1.5 meters for the legacy vehicle case and the range from 1.5 to 10 meters for the outdoor case as described in Table 27 of the ECC Report 327.

The antenna heights for the indoor devices used the values from Table 28(c) from the ECC Report 327 as implemented in the Fixed Service simulations. See the H1 data in Figure 24 in the Fixed Service appendix below.

The number and power levels of actively transmitting UWB devices after scaling are shown in the tables below for the baseline and overall legacy combined with new application classes. Table 13 and Table 14 provide the simulation parameters for the urban and suburban baseline scenarios respectively. Table 15 lists the simulation parameters for the new UWB applications scenario in the urban environment. Table 16 provides the simulation parameters for the new UWB applications scenario in the suburban environment.

| | | Legacy Vehicle | | | Legacy Indoor | | |
|---|---|---|---|---|---|---|---|
| **SMR Antenna Height (meters)** | **Radius (km)** | **Number Active TX** | **TX Power** | **Antenna Heights** | **Number Active TX** | **TX Power** | **Antenna Heights** |
| 70 | 14 | 475 | -41.3 dBm (94.3%) -45.3 (5.7%) | 1.5m | 2966 | -41.3 dBm (94.3%) -45.3 (5.7%) | H1 Heights ranging from 1.5 to 28.5 meters |
| 50 | 10 | 244 | -41.3 dBm (94.3%) -45.3 (5.7%) | 1.5 | 1522 | -41.3 dBm (94.3%) -45.3 (5.7%) | H1 Heights ranging from 1.5 to 28.5 meters |

**Table 13. SMR Baseline UWB Device Classes, Dense Urban Environment**

| | | Legacy Vehicle | | | Legacy Indoor | | |
|---|---|---|---|---|---|---|---|
| **SMR Antenna Height (meters)** | **Radius (km)** | **Number Active TX** | **TX Power** | **Antenna Heights** | **Number Active TX** | **TX Power** | **Antenna Heights** |
| 70 | 14 | 47 | -41.3 dBm (94.3%) -45.3 (5.7%) | 1.5m | 297 | -41.3 dBm (94.3%) -45.3 (5.7%) | H1 Heights ranging from 1.5 to 28.5 meters |
| 50 | 10 | 24 | -41.3 dBm (94.3%) -45.3 (5.7%) | 1.5 | 152 | -41.3 dBm (94.3%) -45.3 (5.7%) | H1 Heights ranging from 1.5 to 28.5 meters |

**Table 14. SMR Baseline UWB Device Classes, Suburban Environment**

| | | Outdoor Vehicle and Fixed | | | Indoor | | |
|---|---|---|---|---|---|---|---|
| **SMR Antenna Height (meters)** | **Radius (km)** | **Number Active TX** | **TX Power** | **Antenna Heights** | **Number Active TX** | **TX Power** | **Antenna Heights** |
| 70 | 14 | 4153 | -41.3 dBm (94.3%)<br>-45.3 (5.7%) | 1.5m | 5932 | -31.3 dBm (25%)<br>-35.3 (25%)<br>-41.3 (25%)<br>-45.3 (25%) | H1 Heights ranging from 1.5 to 28.5 meters |
| 50 | 10 | 2131 | -41.3 dBm (94.3%)<br>-45.3 (5.7%) | 1.5 | 3044 | -31.3 dBm (25%)<br>-35.3 (25%)<br>-41.3 (25%)<br>-45.3 (25%) | H1 Heights ranging from 1.5 to 28.5 meters |

**Table 15. SMR New UWB Application Device Classes, Dense Urban Environment**

| | | Outdoor Vehicle and Fixed | | | Indoor | | |
|---|---|---|---|---|---|---|---|
| SMR Antenna Height (meters) | Radius (km) | Number Active TX | TX Power | Antenna Heights | Number Active TX | TX Power | Antenna Heights |
| 70 | 14 | 415 | -41.3 dBm (94.3%)<br>-45.3 (5.7%) | 1.5m | 593 | -31.3 dBm (25%)<br>-35.3 (25%)<br>-41.3 (25%)<br>-45.3 (25%) | H1 Heights ranging from 1.5 to 28.5 meters |
| 50 | 10 | 213 | -41.3 dBm (94.3%)<br>-45.3 (5.7%) | 1.5 | 304 | -31.3 dBm (25%)<br>-35.3 (25%)<br>-41.3 (25%)<br>-45.3 (25%) | H1 Heights ranging from 1.5 to 28.5 meters |

**Table 16. SMR New UWB Application Device Classes, Suburban Environment**

## Protection Ratios

The protection ratio used in this report is -6 dB I/N. A noise figure of 5.25 dB was used which leads to a -108.75 dBm noise floor.

## *Surface Movement Radar Results*

Simulations were conducted for the baseline case (legacy devices only) and for combined legacy and new application cases. For all the simulations discussed here, the number of trials was 20000.

### *Large Airport Results*

Figure 15 and Figure 16 show the results of the simulations for the large airport scenario for urban and suburban environments respectively. In general, the legacy plus new applications scenario presents higher interference than the baseline scenario. Similarly, 30m terrain height variability leads to higher interference estimates. However, in all cases, the interference is always below the target -6 dB I/N protection ratio.

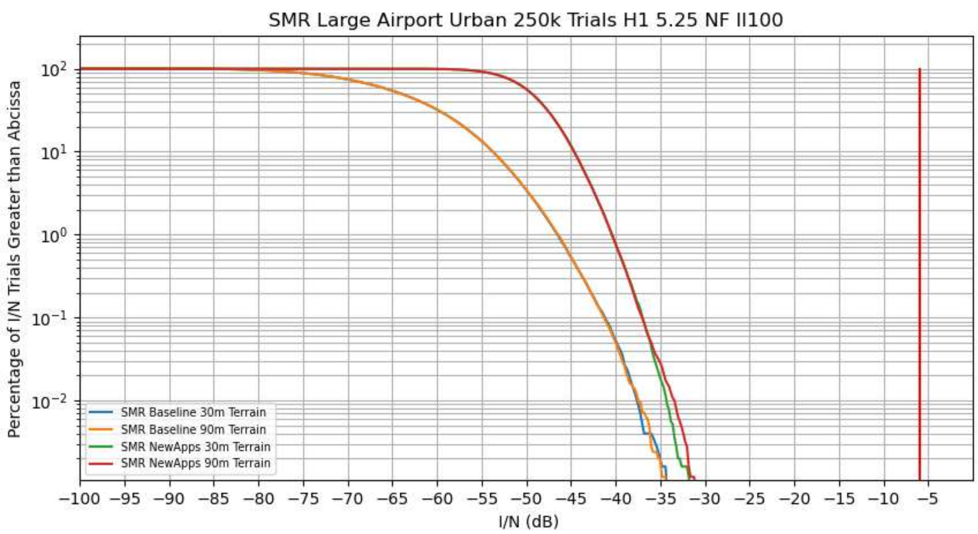



**Figure 15. SMR Large Airport Results – Urban Environment**

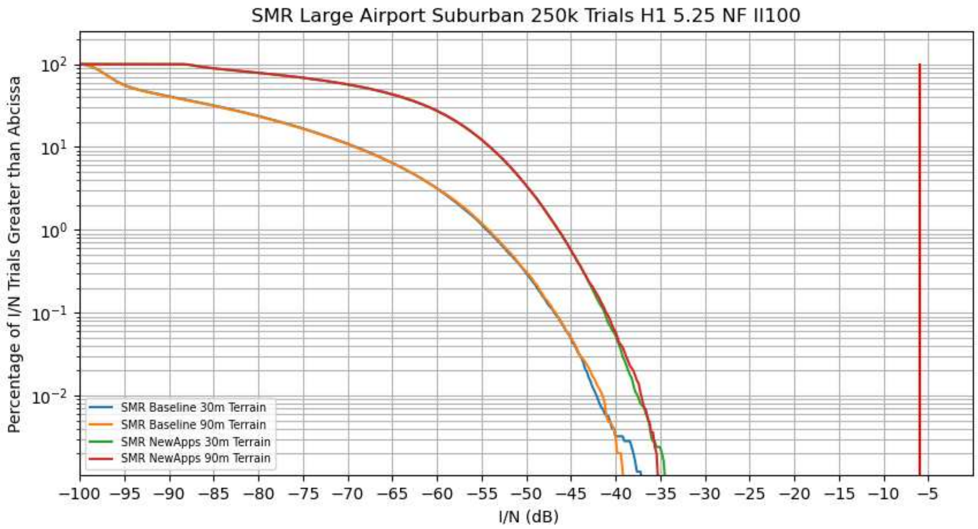



**Figure 16. SMR Large Airport Results – Suburban Environment**

### *Small Airport Results*

Figure 17 and Figure 18 show the results of the simulations for the small airport scenario for urban and suburban environments respectively. In general, the combined legacy plus new applications scenario presents higher interference than the baseline scenario. Similarly, 30m terrain height variability leads to higher interference estimates.

In the urban scenario, the interference prediction exceeds the target -6 dB I/N protection ratio for a fraction of the simulation trials for both baseline legacy and legacy plus new applications configurations. For the baseline conditions, the target I/N is exceeded in approximately 0.065% of the trials. For the combined legacy plus new application conditions, the target I/N is exceeded in approximately 0.2% of the trials.

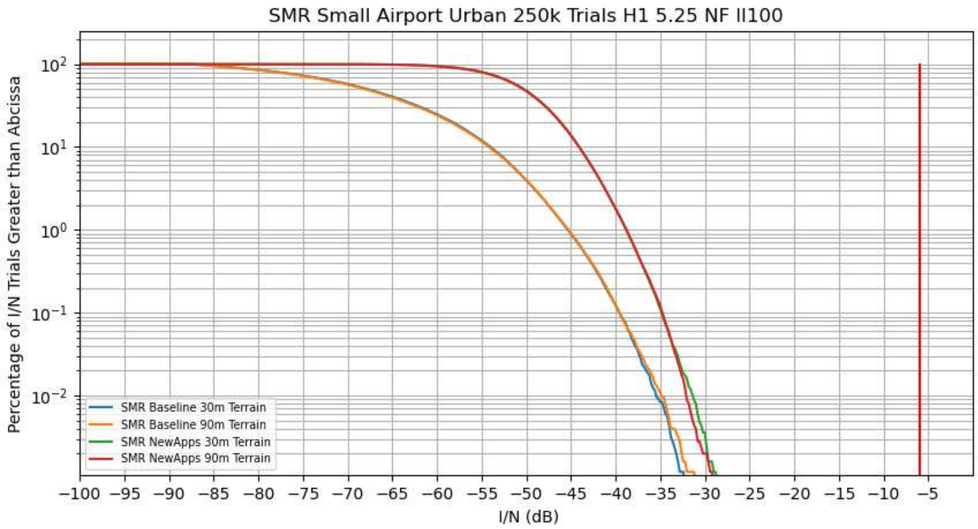



**Figure 17. SMR Small Airport Results - Urban Environment**

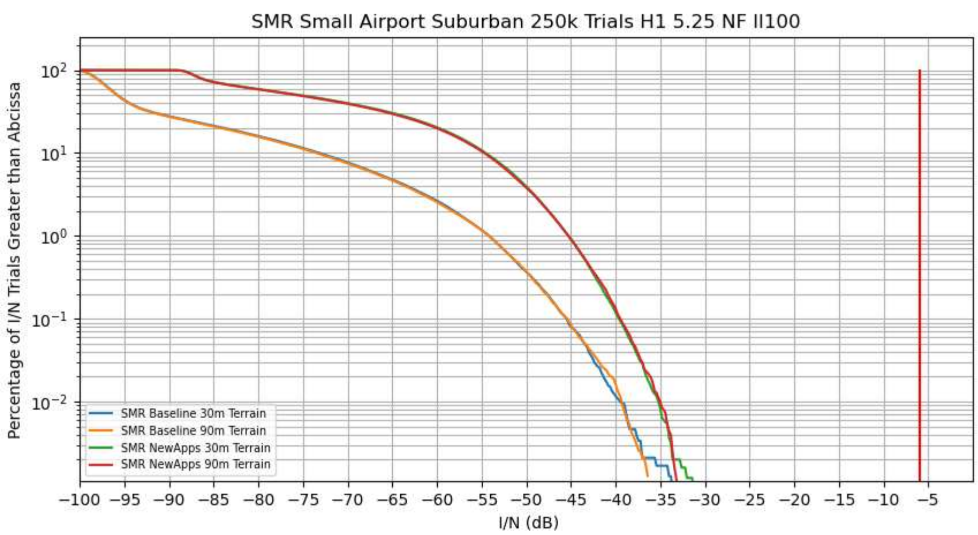



**Figure 18. SMR Small Airport Results - Suburban Environment**

## *SMR MCL Calculations*

The MCL calculations for the Surface Movement Radar are shown in the table below. The parameters were taken from the ECC Report 327 tables 37 and 38. The worst-case protection distance found was 0.642 km for a UWB device in the antenna boresight.

| | | Ptx (dBm/MHz) | Gtx (dB) | Grx (dB) | Feeder Loss (dB) | I/N | NF (dB) | Tantenna (K) | MCL (dB) | Freq (MHz) | FSPL Protection Distance (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SMR | Fixed Outdoor | -41.3 | 0 | 37.6 | 2 | -6 | 5.25 | 290 | 109.02 | 9100 | 0.741 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 37.6 | 2 | -6 | 5.25 | 290 | 102.42 | 9100 | 0.347 |

**Table 17. MCL Calculations for Surface Movement Radar**

# C. Fixed Satellite Service Space-to-Earth

Fixed Satellite Service (FSS) systems use high-gain directional antennas to connect terrestrial earth stations to orbiting satellites. Simulation results of the impact of UWB devices on Fixed Satellite Service earth station receivers were presented in ECC Report 327. The work presented here extends these results to use the NTIA-ITS propagation model.

## Simulation Scenarios

The set of simulation scenarios follows the structure of FSS simulations reported on in ECC Report 327. The simulation set focused exclusively on urban scenarios and the simulations assume the interfering RF link (iRSS) operate at 7.0 GHz. The simulation scenarios are detailed in Table 18 below.

Each simulation scenario varied in one or more of the following key parameters: FSS Receive Antenna Uptilt, FSS Receive Antenna Diameter and Exclusion Zone. The FSS Receive Antenna Diameter values represent antenna sizes used in actual FSS earth stations.

The variation in FSS Receive Antenna Uptilt values represent real-world scenarios of connections to geosynchronous satellites from earth stations located at different latitudes or of an earth station antenna tracking a low-earth orbit (LEO) as it moves across the sky.

| Scenario Identifier | Environment | FSS Receive Antenna Uptilt | FSS Receive Antenna Diameter | FSS Receive Antenna Height | Exclusion Zone |
|---|---|---|---|---|---|
| M-u1a | Urban | 10° | 3 m | 25 m | 30 m |
| M-u1e | Urban | 10° | 3 m | 25 m | 50 m |
| M-u2 | Urban | Uniform distribution 5° - 85° | 3 m | 25 m | 30 m |
| M-u3 | Urban | 27° | 3 m | 25 m | 30 m |
| M-u4 | Urban | 34.5° | 3 m | 25 m | 30 m |
| M-u5a | Urban | 10° | 1.4 m | 25 m | 30 m |
| M-u5e | Urban | 10° | 1.4 m | 25 m | 50 m |
| M-u6 | Urban | Uniform distribution 5° - 85° | 1.4 m | 25 m | 30 m |
| M-u7 | Urban | 27° | 1.4 m | 25 m | 30 m |
| M-u8 | Urban | 34.5° | 1.4 m | 25 m | 30 m |

**Table 18. FSS Scenarios**

## Victim Receiver

The victim Fixed Satellite Service antenna uses the Recommendation ITU-R S.465-6 model. Per the description in SEAMCAT:

> "Reference radiation pattern for earth station antenna in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz. It considers section 2.1.4 of the report ITU-R S.2196-2010 regarding the main beam calculation."

Two different antenna diameters are included in the simulation scenarios: 1.4m and 3m. The antenna aperture efficiency is set at 75%. The key parameters for the FSS receive systems are shown in Table 19.

| FSS Receive Antenna Diameter | FSS Receive Antenna Peak Gain | Receive Noise Floor |
|---|---|---|
| 1.4 m | 37.585 dBi | -111.89 dBm |
| 3 m | 44.205 dBi | -111.26 dBm |

**Table 19. FSS Victim Receiver Parameters**

The victim receiver bandwidth is 1 MHz. In all cases, the receive antenna height was 25 meters, and no clutter was included at the FSS receiver location.

## UWB Transmitters

Following the simulation design in ECC Report 327, the population of UWB devices is broken down into 2 classes: UWB outdoor and UWB indoor. The ECC Report used a simulation bandwidth of 1.2 MHz increasing the UWB power level from -41.3 dBm in 1 MHz to -40.5 dBm. This value was used to simplify comparison with the ECC Report results.

UWB outdoor devices use the default SEAMCAT transmit antenna configured with -2 dBi antenna gain. The various types of UWB devices and their characteristics are combined (as described in ECC Report 327) to create distributions of UWB transmitter power and antenna height. The overall UWB outdoor transmit power used in the simulations follows the distribution shown in Table 20. The overall UWB outdoor transmitter antenna height used in the simulations follows the distribution shown in Table 21.

| UWB Transmit Power | Probability |
|---|---|
| -40.5 dBm | 94.3% |
| -44.5 dBm | 5.7% |

**Table 20. UWB Outdoor Transmit Power Distribution**

| UWB Transmit Antenna Height | Probability |
|---|---|
| 1.5 m | 39.82% |
| 2 m | 0.03% |
| 5 m | 56.9% |
| 10 m | 3.25% |

**Table 21. UWB Outdoor Transmitter Antenna Height Distribution**

For UWB outdoor devices, clutter effects are applied according to Recommendation ITU-R P.2108. Details are included in the discussion of the propagation model below.

UWB indoor devices also use the default SEAMCAT transmit antenna configured with -2 dBi antenna gain. The various types of UWB devices and their characteristics are combined (as described in ECC Report 327) to create distributions of UWB transmitter power and antenna height. The overall UWB indoor transmit power used in the simulations follows the distribution shown in Table 22. The overall UWB indoor transmitter antenna height used in the simulations follows the distribution shown in Table 23.

| UWB Transmit Power | Probability |
|---|---|
| -30.5 dBm | 25% |
| -34.5 dBm | 25% |
| -40.5 dBm | 25% |
| -44.5 dBm | 25% |

**Table 22. UWB Indoor Transmit Power Distribution**

| UWB Transmit Antenna Height | Probability |
|---|---|
| 1.5 m | 35.14% |
| 4.5 m | 24.74% |
| 7.5 m | 13.4% |
| 10.5 m | 9.31% |
| 13.5 m | 6.24% |
| 16.5 m | 3.78% |
| 19.5 m | 2.91% |
| 22.5 m | 2.16% |
| 25.5 m | 1.5% |
| 28.5 m | 0.82% |

**Table 23. UWB Indoor Transmitter Antenna Height Distribution**

For UWB indoor devices, building entry loss (BEL) effects are applied according to Recommendation ITU-R P.2109. Details are included in the discussion of the propagation model below.

## Propagation Model

The SEAMCAT supplied NTIA-ITS model was used for the FSS simulations. Point to point terrain models were not used. Instead, the terrain variation parameter was used to model different types of surrounding topography. Two terrain variation values were selected, 30 and 90 meters.

For outdoor propagation paths, clutter according to Recommendation ITU-R P.2108 was configured in SEAMCAT to match the parameters used for urban outdoor devices in the prior work (see Table 51 of ECC Report 327). The clutter model used a site-general clutter model for terrestrial paths (Recommendation ITU-R P.2108 Ref. 3.2) with a uniform distribution of locations between 0.001% and 99%.

For indoor propagation paths, Building Entry Loss (BEL) according to Recommendation ITU-R P.2109 was configured in SEAMCAT to match the parameters used for urban indoor devices in the prior work (see Table 51 of ECC Report 327). The probability of not exceeding the nominal BEL was set as a uniform distribution between 1% and 99%. The building mix was set to 70% traditional and 30% thermally efficient.

## UWB Device Placement Scenarios

UWB devices, both indoor and outdoor, were placed uniformly within a 5 km radius of the victim receiver with the exception that no devices were allowed within the defined exclusion zone. As noted in Table 18, exclusion zones of 30 m and 50 m were used in different simulation scenarios.

The device densities are shown in Table 24. These match that configured for the prior simulations in ECC Report 327. Note that the number of active transmitters is such that power scaling is not required in the simulations.

| UWB Device Class | Number of Active Transmitters |
|---|---|
| Indoor | 788 |
| Outdoor | 547 |

**Table 24. UWB Device Densities**

## Protection Ratios

The protection ratio used in this report is -6 dB I/N.

## FSS Simulation Results

SEAMCAT Monte Carlo methodology was used to generate I/N results using 250,000 events. For the graphs presented here, the results are grouped by victim receive antenna diameter and the terrain variation parameter configured for the NTIA-ITS propagation model.

Figure 19 and Figure 20 show the results for the 3 m victim receiver (simulation scenarios M-u1a through M-u4) and NTIA-ITS terrain variation of 30 m and 90 m respectively. These results can be compared to Figure 48 of ECC Report 327. In general, higher interference levels are predicted for lower victim receiver antenna uptilts. Also, as would be expected, a larger exclusion zone around the victim receiver leads to reduced levels of interference. Comparing Figure 19 and Figure 20, it is seen that 30 m terrain height variability within the propagation model leads to higher interference estimates as compare to 90 m terrain height variability. However, in all cases, the interference is always below the target -6 dB I/N protection ratio.

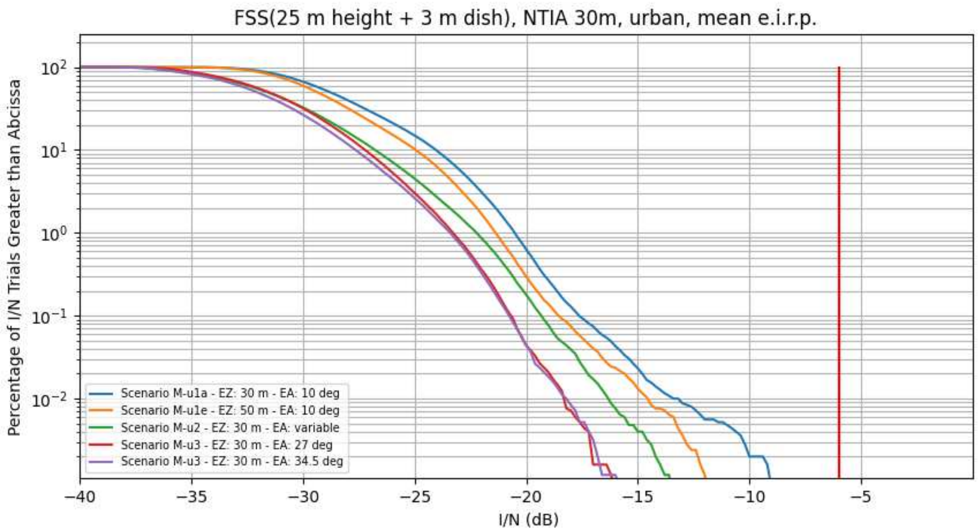



**Figure 19. FSS Results: 3 m Victim Antenna, 30 m Terrain Variation**

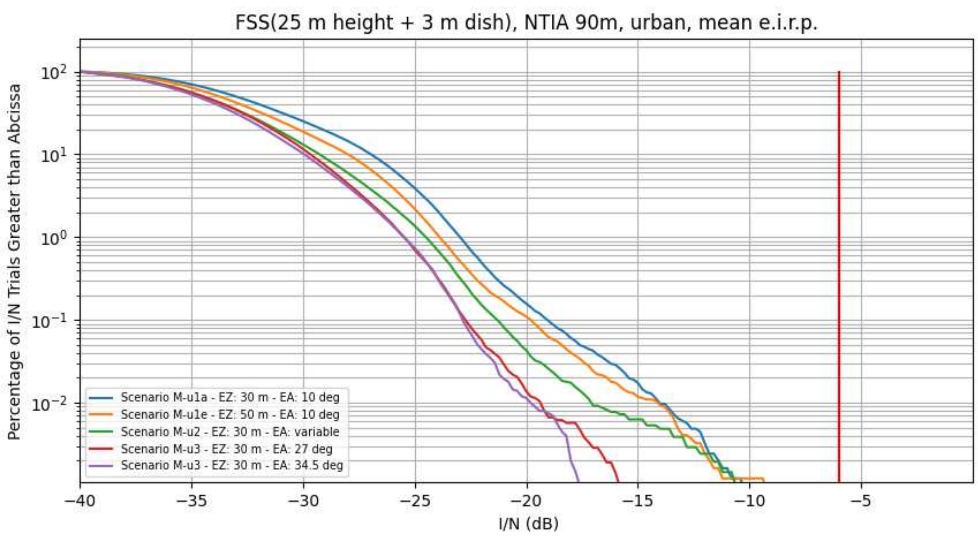



**Figure 20. FSS Results: 3 m Victim Antenna, 90 m Terrain Variation**

Figure 21 and Figure 22 show the results for the 1.4 m victim receiver (simulation scenarios M-u5a through M-u8) and NTIA-ITS terrain variation of 30 m and 90 m respectively. These curves can be compared to Figure 50 of ECC Report 327. In general, higher interference levels are predicted for lower victim receiver antenna uptilts. Also, as would be expected, a larger exclusion zone around the victim receiver leads to reduced levels of interference. Comparing Figure 21 and Figure 22, it is seen that 30 m terrain height variability within the propagation model leads to higher interference estimates as compare to 90 m terrain height variability. However, in all cases, the interference is always below the target -6 dB I/N protection ratio.

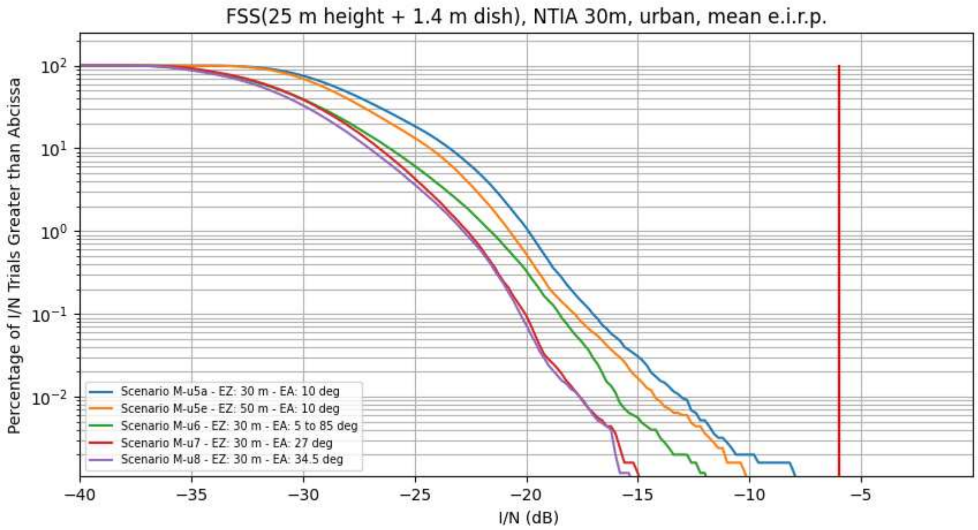



**Figure 21. FSS Results: 1.4 m Victim Antenna, 30 m Terrain Variation**

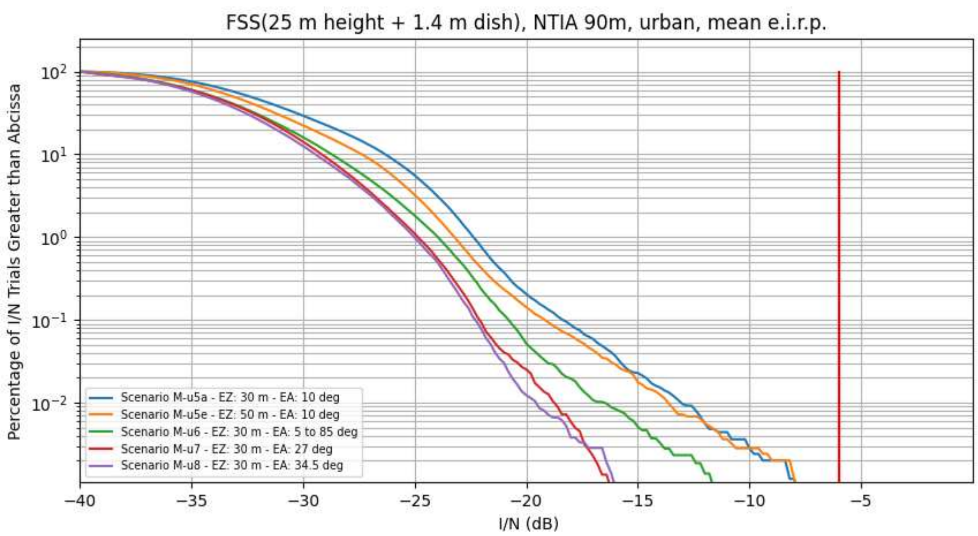



**Figure 22. FSS Results: 1.4 m Victim Antenna, 90 m Terrain Variation**

## *FSS MCL Calculations*

The MCL calculations for the Fixed Satellite Service are shown in the table below. The parameters were taken from the ECC Report 327 tables 37 and 38. The worst-case protection distance found was 2.664 km for a UWB device above the antenna and between the satellite above.

| | | Ptx (dBm/MHz) | Gtx (dB) | Grx (dB) | Feeder Loss (dB) | I/N | NF (dB) | Tantenna (K) | MCL (dB) | Freq (MHz) | FSPL Protection Distance (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FSS | Fixed Outdoor | -41.3 | 0 | 44.205 | 2 | -6 | 4 | 71 | 117.7885 | 7000 | 2.644 |
| | Fixed Outdoor | -41.3 | 0 | 37.585 | 2 | -6 | 4 | 150 | 110.8164 | 7000 | 1.185 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 44.205 | 2 | -6 | 4 | 71 | 111.1885 | 7000 | 1.237 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 37.585 | 2 | -6 | 4 | 150 | 104.2164 | 7000 | 0.554 |

**Table 25. MCL Calculations for Fixed Satellite Service**

# D. FIXED SERVICE

Fixed Service systems use high-gain directional antennas to connect terrestrial locations. Simulation results of the impact of UWB devices on Fixed Service receivers were presented in ECC Report 327 using a custom-coded blended Winner-II/ Recommendation ITU-R P.452 propagation model. The contribution presented here is the modification of the simulations to use the NTIA-ITS Longley Rice propagation model in place of the Recommendation ITU-R P.452 model in the blended propagation model.

The ECC Report 327 SEAMCAT workspace files for simulating the mean interference to noise power ratio were utilized as a basis for the simulations. Due to backward incompatibility with the original workspaces (SEAMCAT 5.3.1), the workspace files were re-created in SEAMCAT 5.5.1-Alpha-3.

The I/N values from the simulations with the NTIA propagation model were calculated and graphed together for the two antenna height distributions and graphed together with the I/N results of the simulations using the blended propagation model.

## *Victim Receiver and Receive Antenna*

The victim Fixed Service antenna model is the ITU R F.1245-2 model. The peak gain used was 37.4 dB. The height of the receive antenna was 25 meters and no clutter was included at the Fixed Service receive location. The Fixed Service system is set to operate at 7500 MHz.

The bandwidth used for the Fixed Service simulations was 30 MHz. This differs from some of the other simulations, e.g., AWR and SMR.

Using this bandwidth the maximum UWB EIRP power spectral density is increased by $10\log_{10}(30)$ =14.8 dB. This changes the maximum EIRP level from -41.3 dBm/MHz to -26.5 dBm/30MHz.

The nominal height of the FS receive antenna is 25 meters. Note that the distribution of UWB device antenna heights has an upper limit of 28.5 meters. Fixed Service links are designed and deployed such that there are no obstacles or structures in the first Fresnel Zone. The 28.5 meter UWB device antenna height means that it is conceivable that a UWB device and supporting structure is in the Fixed Service first Fresnel Zone. This is a very unlikely scenario. Additional results for Fixed Service receivers with antenna heights of 45 and 70 meters are also included.

## *UWB System Antenna Heights*

Following the simulation design in the ECC Report 327, the population of UWB devices was broken down into 3 sub-classes (see Table 26). The first subclass are the outdoor UWB devices. These devices are limited to 10.5 meters antenna height. The next class is the indoor devices placed at distances greater than 180 meters from the FS receiver. These include enhanced power UWB devices and current UWB devices. The third class are UWB devices placed less than 180 meters from an FS receiver. The heights of these devices are also limited to 10.5 meters. The last column lists the number of UWB devices for the sensitivity analysis where the number is doubled compared to the expected density. These simulations include the characters “2_” in the simulation name legend.

| | Density per km2 | Min Radius | Max Radius | Max Antenna Height | Number of UWB Devices |
|---|---|---|---|---|---|
| UWB Outdoor | 7 | .02 km | 5 km | 10.5 m | 547 |
| UWB Indoor High | 10 | .18 km (Blended Winner) .25 (NTIA) | 5 km | 28.5 m | 787 |
| UWB Indoor Low | 10 | .02 | .18 | 10.5 m | 1 |

**Table 26. UWB Population Sub-Classes**

Two simulations were performed for the 30-meter NTIA terrain propagation models. The first difference is in the distribution of UWB device antenna heights. The simulations that include "H1" in their label placed UWB devices with antenna heights mostly below 5 meters for the Indoor Low class and below 10.5 meters for the Indoor High class. The simulations with "H8" in their label allowed for more devices above 5 meters in the Indoor Low class and more above 10.5 meters up to 28.5 meters for the Indoor High class.

Finally, from analysis of preliminary results it was found that the NTIA-ITS model uses free space propagation for distances below 180 meters. The antenna height for Fixed Service receivers was set to 25 meters as a conservative approach and Indoor High UWB transmitter antenna heights ranged from 1.5 to 28.5 meters. Fixed service point-to-point links are professionally installed and the presence of a building or interfering device antenna structure within 180 meters in the direction of the main beam is very unlikely. Therefore, for the Indoor High class of devices the minimum distance was set to 180 meters for.

| Simulation Name | Density Class | Antenna Height |
|---|---|---|
| 1_H1 | Nominal Density | Lower Indoor Heights |
| 1_H8 | Nominal Density | Higher Indoor Heights |

**Table 27. Simulation Summaries**

The distribution of antenna heights is described in Section 5.2.2.5 of ECC Report 327. The data for the antenna heights was taken from ECC Report 302 in Tables 9 and 10. The final distributions were derived from this data with some modifications. The distributions are graphed below.

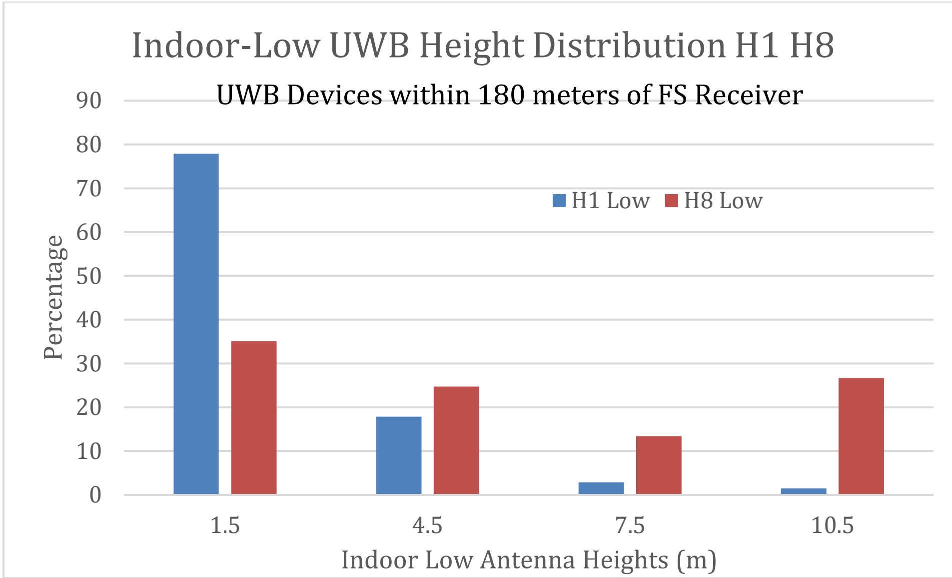



**Figure 23. Antenna Height Distribution: Near**

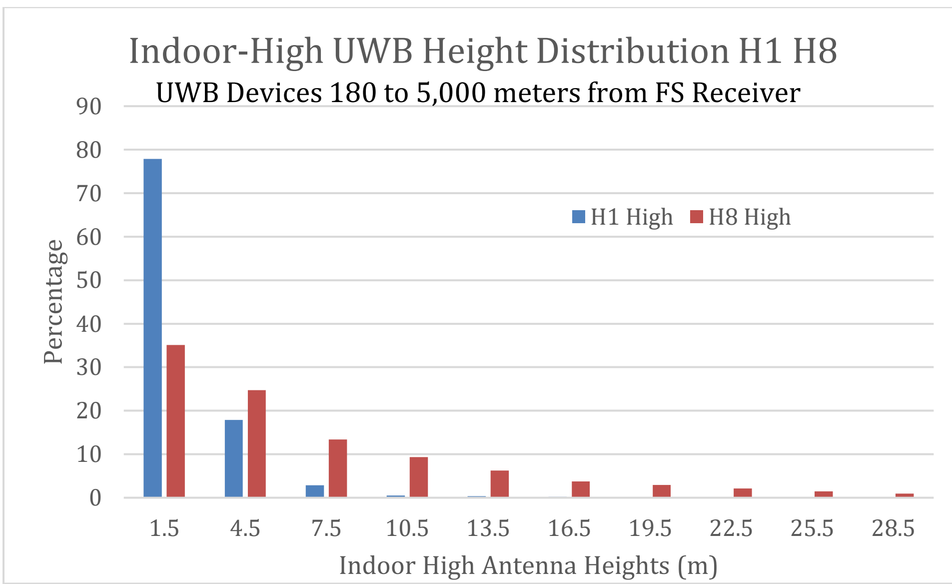



**Figure 24. Antenna Height Distribution: Far**

The transmit power levels of the Indoor UWB devices include both nominal and enhanced levels. In addition, a 4 dB body loss in included in the distribution of power levels. Details can be found in Section 5.2.2.4 of the ECC Report 327.

## *Propagation Models*

For the Fixed Service simulations, a blended model composed of Free space, Winner II model and the NTIA-ITS Longley Rice model was used to apply different propagation models for different

ILT to VLR distance subranges. The sub-models are entered left to right in the Scenario Propagation Model panel as

- Free Space for distance ranging from 0 to 40 meters
- Winner II for distance ranging from 40 meters to 1 km
- NTIA-ITS Longley Rice for distance ranging from 1 km to 100 km

The NTIA-ITS Time/Location/Situation parameters were set to the following ranges

- Time Variation: 0.001% to 50%
- Location Variation: 0.001% to 99%
- Situation Variation: 0.1% to 99.9%

Variations were enabled for the Winner II and NTAI-ITS Longley Rice models. The Winner II model used “LOS Probabilities” for the Line-of-Sight parameter.

## *UWB Device Placement Scenarios*

The UWB devices are distributed uniformly in a circle where the FS victim receiver is at the center as in ECC report 327. The maximum simulation radius is 5 km, and the minimum radius or protection distance is 20 meters. Two concentric rings are used to define the UWB device placements.

In the innermost ring the radius ranges from 20 meters to 180 meters. One Indoor Low device is placed randomly with an antenna height not greater than 10.5 meters.

In the second ring both Indoor High and Outdoor UWB devices are randomly placed between an inner radius of 180 meters and 20 meters respectively while the outer radius was set to 5 km. Depending on the simulation, the antenna heights were drawn from the H1 or the H8 distributions. For more details see table 31 in the ECC Report 327.

## *Protection Ratios*

The ratio of interference power in 30 MHz bandwidth compared to the noise floor in 30 MHz bandwidth, or I/N ratio, is plotted for comparison with the simulated I/N results. The noise figure used was 6.5 dB which results in a value of -92.7 dBm for the FS receiver noise floor.

## *FS Simulation Results*

The simulations of the I/N caused by UWB transmitters on Fixed Service receivers were performed with 250,000 events. The vertical red line highlights the -6 dB I/N ratio. These results were generated using the NTIA propagation model with 30 meter terrain height variation selected for the ITM propagation models. The FS antenna height is 25 m.

Both distributions, H1 and H8, of UWB device antenna heights were simulated in the results shown in each figure. The H8 distributions are more heavily weighted to higher elevations compared to the H1 distributions.


**Figure 25. Fixed Service I/N with 30 m Terrain Height with FS antenna height of 25 m. H1 and H8 UWB antenna heights**

## *Comparison of Different FS Antenna Heights and Inner Radiuses for Outdoor UWB Devices*

The graphs below show a comparison between Fixed Service systems with antenna heights of 25, 45, and 70 meters. The scenario was Dense-Urban with 30 meters terrain variation in the ITM propagation model were used in the simulations. The H8 height distributions was selected for UWB devices as a conservative approach. The H8 distributions are more heavily weighted to higher elevations compared to the H1 distributions. The minimum distance or inner radius for the placement of UWB devices was also varied including the original value of 20 meters and also 50 and 75 meters.

The three figures below show the results for the case when the FS antenna height was 25, 45 and 70 meters. Each figure also includes results for outdoor UWB inner radius values of 20, 50, and 75 meters.

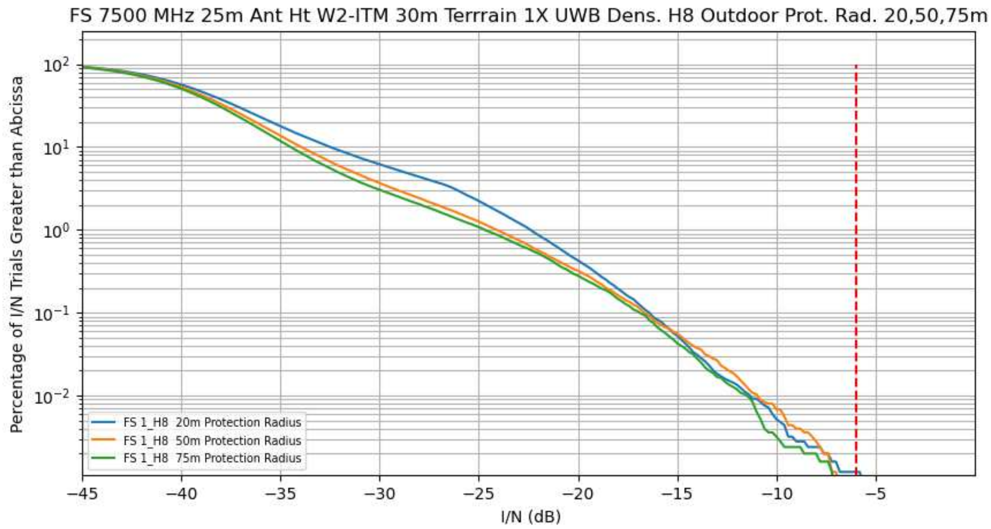



**Figure 26. Fixed Service with 25 meters antenna height I/N with Outdoor UWB inner radiuses of 20, 50, and 75 meters)**

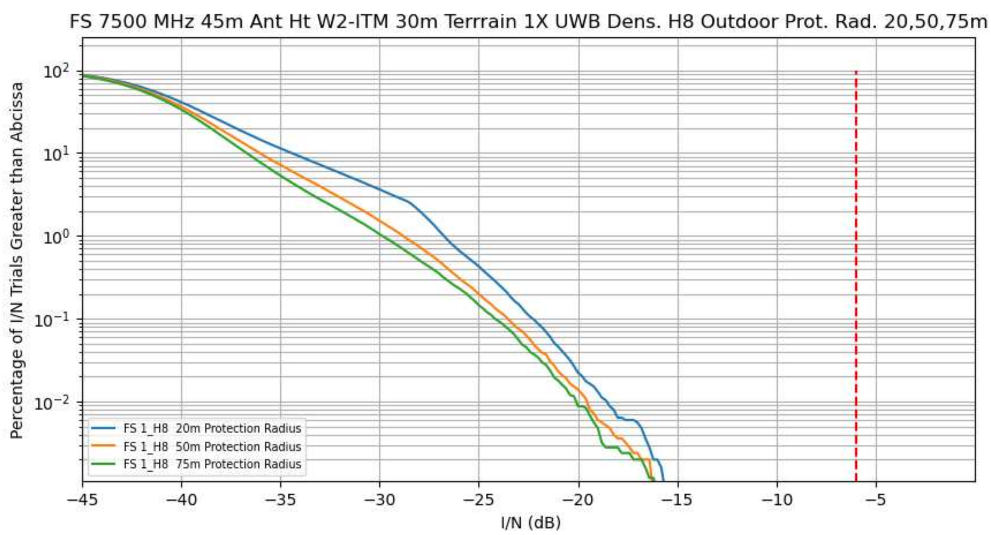



**Figure 27. Fixed Service with 45 meters antenna height I/N with Outdoor UWB inner radiuses of 20, 50, and 75 meters)**

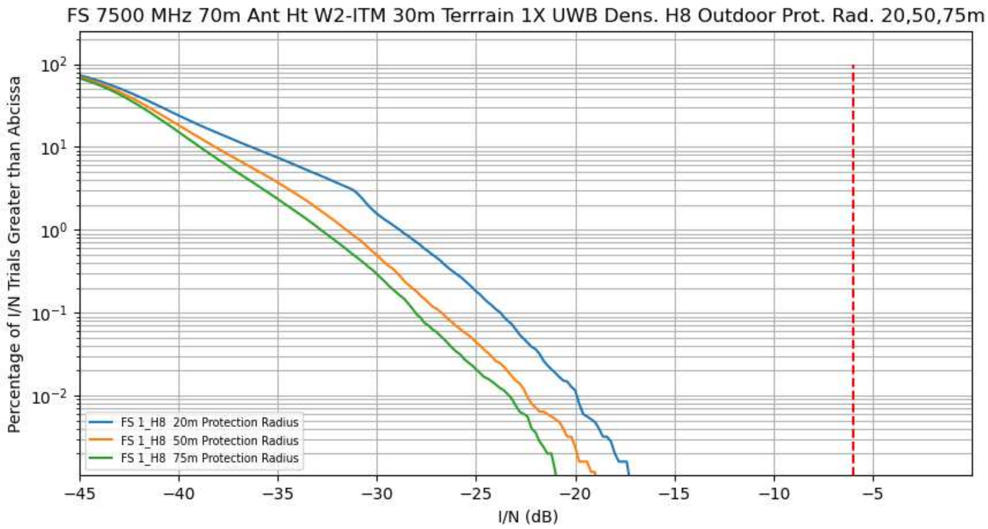



**Figure 28. Fixed Service with 70 meters antenna height I/N with Outdoor UWB inner radiuses of 20, 50, and 75 meters)**

## *FS MCL Calculations*

The MCL calculations for the Fixed Service are shown in the table below. The parameters were taken from table 82 in the ECC Report 327. The worst-case protection distance found was 3.173 km for a UWB device in the antenna boresight between the antenna and the horizon.

| | | Ptx (dBm/MHz) | Gtx (dB) | Grx (dB) | Feeder Loss (dB) | I/N | NF (dB) | Tantenna (K) | MCL (dB) | Freq (MHz) | FSPL Protection Distance (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FS | Fixed Outdoor | -41.3 | 0 | 38.7 | 1.3 | -6 | 4 | 290 | 112.07 | 7500 | 1.278 |
| | Fixed Outdoor | -41.3 | 0 | 46.6 | 1.3 | -6 | 4 | 290 | 119.97 | 7500 | 3.173 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 38.7 | 1.3 | -6 | 4 | 290 | 105.47 | 7500 | 0.598 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 46.6 | 1.3 | -6 | 4 | 290 | 113.37 | 7500 | 1.484 |

**Table 28. MCL Calculations for Fixed Service**

# E. SYSTEM A12 SURVEILLANCE/SAR RADAR

In addition to the Airborne Weather Radar (AWS) systems examined above and described in Appendix A, ITU Recommendation ITU-R M.1796 describes, in column A12 of Table 1, the characteristics for "Multipurpose surveillance, scanning, tracking, search, (imaging)" radar systems. These radars operate between 8500 and 10500 MHz. The characteristics cover a variety of radar systems including "pulse, FM, and linear FM pulse (chirp)". The antenna is described as using digital beamforming with gain between 35 and 42 dB and elevation and azimuth beamwidths of 1.6 degrees. The design equations for the digital beamforming antenna are provided by reference to ITU-R M.1851. The digital array antenna vertical beam can be steered (tilted) electronically ± 60 degrees and even to -90 degrees with additional mechanical tilt. The peak sidelobes are between 14 and 19 dB below the peak gain depending on the steering angle. The receiver noise-figure is 6 dB. The altitudes where these radar types are listed as ranging from 300 meters to 13700 meters.

Airborne surveillance radars are used to track moving objects on the ground. Doppler techniques are us to separate moving objects from fixed background reflections. Synthetic aperture radars (SAR) are used to create detailed two-dimensional synthetic images from the radar returns taken over a path flown by the aircraft radar.

A fixed communications link could experience continuous interference from nearby sources. Terrestrial interference sources will appear as transient interference to an airborne radar as the radar platform is flown over the ground.

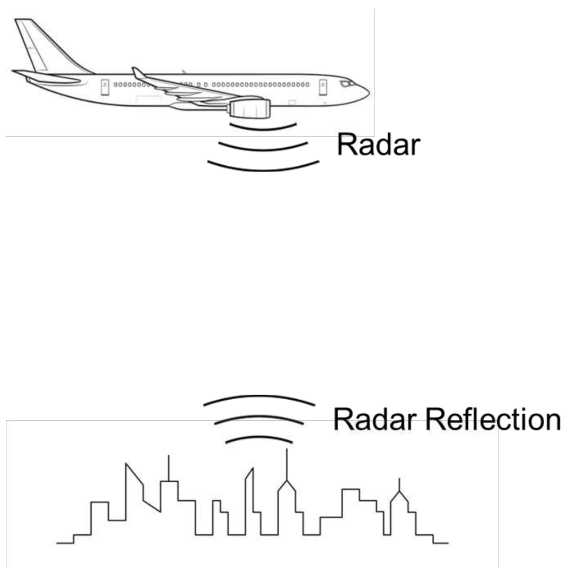



**Figure 29. Surveillance/SAR airborne radar shown over dense urban environment.**

[Dense-urban UWB deployment environments were simulated in this study for Surveillance/SAR radar operation.] Note that, at low altitudes, the power level of received radar reflections is much greater than that for radars operating at high altitudes. The use of the I/N metric in the previous appendices for interference assumes that the power levels of the desired signals are received with levels approaching the minimum useful level. That is not the case for radar targets well inside their maximum radar range such as when a radar is operated at very low altitudes. Dense urban scenarios have also been used in the previous appendices for worst-case interference Monte Carlo simulations. Flying an airborne radar at low altitudes over a dense urban area is not realistic for two reasons. First, aviation rules require vertical altitude separation between buildings and aircraft. Second, urban areas are served by airports and the controlled airspace for arrivals and departures around the airport extends over the urban area. Results for dense urban areas are presented below for altitudes 1200 meters and 600 meters for 90 degree and 30-degree downtilts respectively. The very short distances between the radar and ground targets that would be experienced by a radar operating at an altitude of 300 meters would result in very strong radar signal power levels. The I/N interference metric would be inappropriate in this situation since it is based on the assumption that the desired signals are very weak and a small increase in the noise plus interference level would make detection unreliable. Results of a sample, dense urban, Carrier-to-Interference-plus-Noise (CINR) calculation are presented for low altitude, 90 Degree downtilt scenario to illustrate that the expected strong received radar return signal strengths are far above the thermal noise level in this scenario.

### *Surveillance Radar Antenna Design*

The design of the airborne surveillance radar antenna model for the SEAMCAT interference simulations is based on the method described in section 7 of ITU-R M.1851 “Patterns for phased array antennas”. The method is based on a linear array of uniform antenna elements. The model that was developed for SEAMCAT modeling was based on matching both the peak gain of 42 dB and the beamwidth of 1.6 degrees. The design that was selected used 64 elements with half wavelength spacing. The individual antenna elements have a one-sided 90-degree beamwidth and are assumed to have a peak gain of about 6 dB.

The gain for a linear array is given in M.1851 equation (20) by

$$g(\theta) = f(\theta)\frac{1}{N}|AF(\theta)|^2$$

Where $\theta$ is the angle, $f(\theta)$ is the gain of each individual element as a function of the angle, N is the number of elements, and $AF(\theta)$ is the array gain as a function of the angle $\theta$. The array gain is given by.

$$|AF(\theta)| = \frac{\sin\left(\frac{N\Psi}{2}\right)}{sin\left(\frac{\Psi}{2}\right)}$$

And

$$\Psi = 2\pi\left(\frac{d}{\lambda}\right)(\sin(\theta) - \sin(\omega))$$

Where $\omega$ is the steering angle of the antenna main-beam and d is the distance between antenna elements.

The gain of the individual elements is a $\cos^2(\theta)$ function which has a 90-degree ($\pm$ 45 degrees) beamwidth. This mirrors the results shown in M.1851.

A 64x64 array will have an array gain of 4096 or 36 dB. The peak gain of each individual element is assumed to be about 6 dB given hemispherical operation and a 90-degree beamwidth. The resulting gain estimate of 36+6= 42 dB aligns well with the peak gain listed for M.1796 system A12.

### *30 Degree Downtilt Antenna Array*

A 64-element linear array antenna with a 30-degree downtilt was designed for use in SEAMCAT simulations. The gains off-axes were taken in a piece-wise manner from the gain mask and entered into a SEAMCAT XY antenna model for the vertical gain. For the horizontal gain a 0-degree, 64 element array design gain mask was used. The gain, gain mask, and individual element gain for the 30-degree design are shown below.

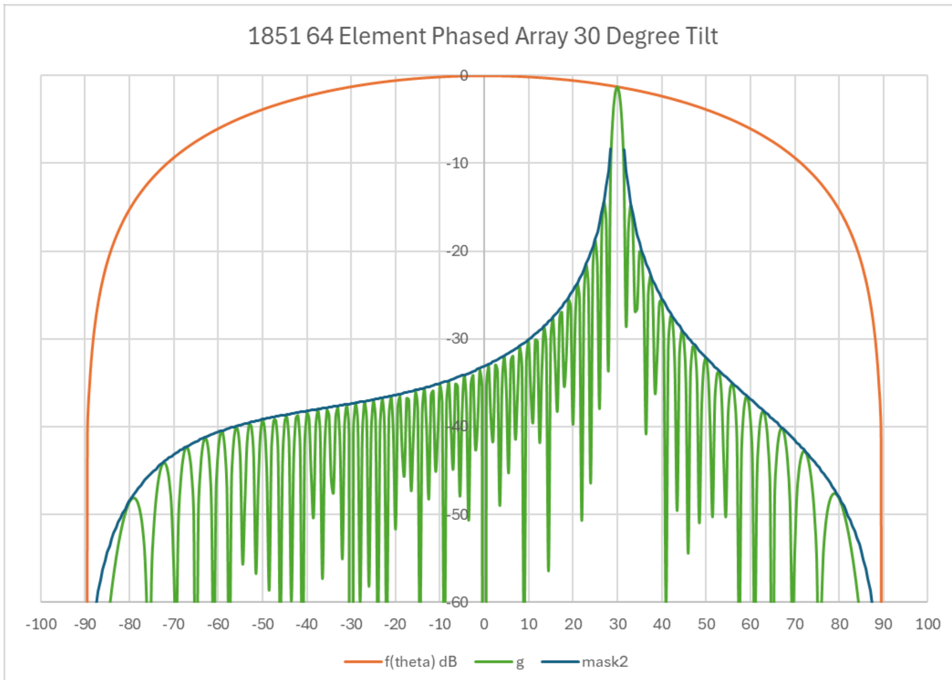
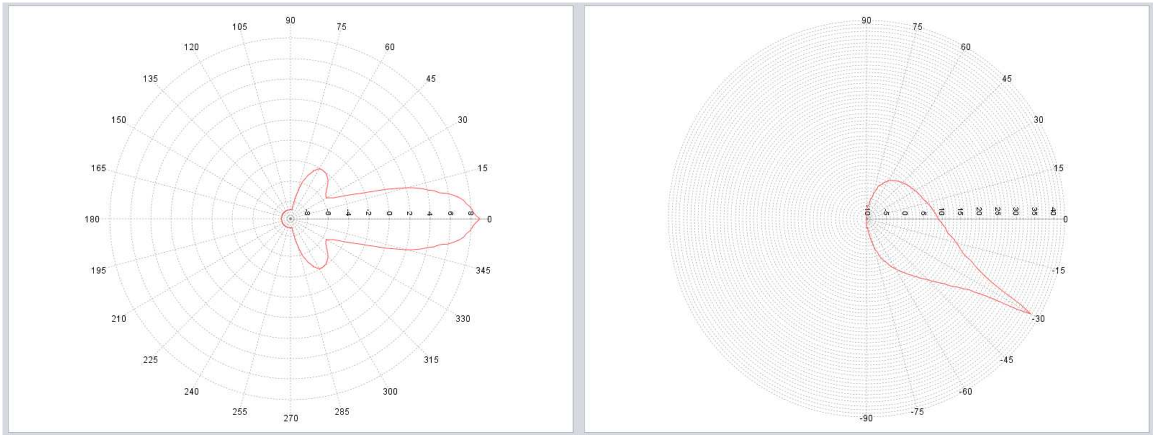



**Figure 30. Linear Array gain for 64 element array with $\lambda/2$ element spacing. Mask gain is shown in blue and individual element gain is shown in red.**

The elevation beamwidth for the 30-degree steered array is just under 2 degrees. The azimuth and elevation plots for the SEAMCAT antenna model are shown below.




(a) Azimuth (b) Elevation

**Figure 31. SEAMCAT azimuth (a) and elevation (b) plots for 30-degree downtilt, system A12, antenna model. Peak gain set to 42 dB.**

## *Antenna Model Scenarios*

Two downtilts were eventually used in SEAMCAT simulations. The first corresponded to the worst-case scenario when the antenna is pointed straight down towards the earth with an effective 90-degree downtilt. The basic antenna was the 30-degree downtilt design with an additional 60-degree mechanical downtilt added.

The second antenna scenario used the 30-degree electronic downtilt model with no additional mechanical downtilt.

## *Simulation Scenarios*

### *Ground Environment*

Dense-urban ground environments were considered in this study. Dense urban environments are considered the worst-case UWB deployment scenario because of the potentially large number of active UWB devices that may be present. The dense-urban environment was considered to extend over the entire simulation radius for both downtilts used.

### *90 Degree Downtilt*

Various simulation radius values were tested at different altitudes for the 90-degree downtilt case. It was found that because of the narrow beamwidth that a 5 km simulation radius was sufficient for all altitudes used in the simulations. The device densities used for the dense urban environment were as before. A minimum altitude of 1200 meters was used in 90-degree downtilt simulations.

### *30 Degree Downtilt*

When there is no mechanical downtilt and only 30 degrees of electronic downtilt then for altitudes up to 2400m the simulation radius was set to 10 km. For the other altitudes up to 13700m a simulation radius of 40km was used. A minimum altitude of 600 meters was used in 30-degree downtilt simulations.

# Propagation

The free-space Recommendation ITU-R P.525 propagation model was used for the links between the UWB transmitters and the Surveillance/SAR radar receiver. Clutter was enabled using the Recommendation ITU-R P.2108 clutter models for earth to space paths (type 3). The Percentage of Locations parameter was set to a uniform distribution ranging from .001% to 100%.

# Antenna Heights

The antenna heights for the UWB devices were the same as those used above for the Fixed Service simulation studies.

## Outdoor

The outdoor fixed and vehicle antenna heights are listed below.

| Type | Height (m) | Percentage | Cumulative Pct. |
|---|---|---|---|
| Fixed | 10 | .0325 | .0325 |
| Fixed | 5 | .569 | .6015 |
| Vehicle | 2 | .0003 | .6018 |
| Vehicle | 1.5 | .3982 | 1 |

**Table 29. Fixed and vehicle (portable) UWB device antenna height distribution.**

## Indoor

The indoor UWB device antenna height distribution is shown below.

| Height (m) | Percentage | Cumulative Pct. |
|---|---|---|
| 28 | .0003 | .0003 |
| 25.5 | .0005 | .0008 |
| 22.5 | .0009 | .0017 |
| 19.5 | .0016 | .0033 |
| 16.5 | .0024 | .0057 |
| 13.5 | .0036 | .0093 |
| 10.5 | .0052 | .0145 |
| 7.5 | .0285 | .043 |
| 4.5 | .1785 | .2215 |
| 1.5 | .7785 | 1 |

**Table 30. Indoor UWB antenna height distribution**

## UWB Power Levels

### Outdoor

The fixed and vehicle outdoor UWB transmitter power levels are shown in the next table.

| Outdoor Power Level | Percentage |
|---|---|
| -41.3 dBm | 94.3 |
| -45.3 dBm | 5.7 |

**Table 31. Outdoor UWB device power distribution**

### Indoor

The indoor UWB device power levels included the enhanced power setting and are shown below.

| Indoor Power Level | Percentage |
|---|---|
| -31.3 dBm | 25 |
| -35.3 | 25 |
| -41.3 | 25 |
| -45.3 | 25 |

**Table 32. Indoor UWB device transmit power level distribution.**

## Active UWB Device Populations

For low radar altitudes simulation radiuses of 5 and 10 km were used in the SEAMCAT simulations. The dense urban device populations were based as before on the ECC Report 327 values in Table 18 of 10 indoor devices per square kilometer and 7 outdoor UWB device per square kilometer. The dense urban active UWB device populations are shown below.

| Simulation Radius (km) | Outdoor | Indoor |
|---|---|---|
| 5 | 550 | 785 |
| 10 | 2199 | 3142 |

**Table 33. UWB dense-urban active device counts for 5 km (90-degree downtilt) and 10 km (30-degree downtilt) dense urban simulations**

When 30-degree radar downtilts were simulated with a larger 40 km simulation radius case the device population was broken into an inner 20km ring and an outer 40 km ring with a 20 km radius void similar to a donut. The outer ring device counts were used for radar altitudes above 2400 meters. Power scaling was needed in the outer ring to control the total number of devices. The

'Extend Simulation Radius' option was selected for the outer ring population and the simulation radius was adjusted so that the extended radius was 40 km.

| | Radius | Outdoor | Outdoor Max Power (dBm) | Indoor | Indoor Max Power (dBm |
|---|---|---|---|---|---|
| Inner | 20 km | 8796 | -41.3 | 12566 | -31.3 |
| Outer | 20 to 40 km | 13195 | -38.3 | 18850 | -21.3 |

**Table 34. UWB dense-urban device counts and Power levels for higher altitude Surveillance/SAR radar simulations.**

## *Fixed Outdoor UWB Device Antenna*

For some simulations the fixed outdoor UWB antenna was modeled in SEAMCAT based on information in figures 16 through 19 in the ECC Report 327. These antennas are meant for fixed mounting on a structure such as a light-pole and have maximum gain directed towards terrestrial UWB devices. The azimuth and elevation data were extracted from the figures in the report. Interpolation was used to create a horizontal/vertical gain table after rotating the z-axis around the y-axis until the z-axis was horizontal. This way the maximum gains were directed below the horizon. The table values were entered into the SEMACAT table antenna model. The azimuth gain pattern is shown below.

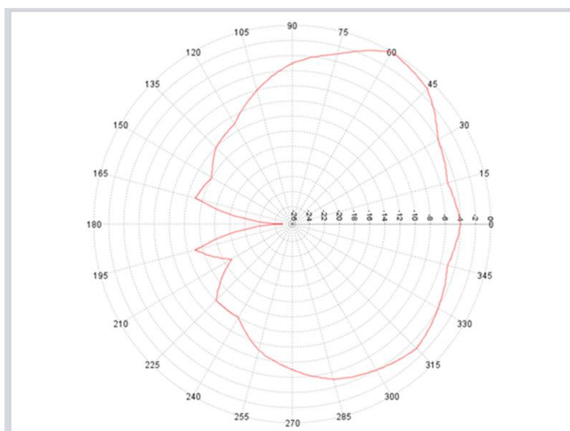



**Figure 32. Fixed Outdoor UWB Antenna azimuth gain pattern.**

The front and rear elevation patterns are shown next.

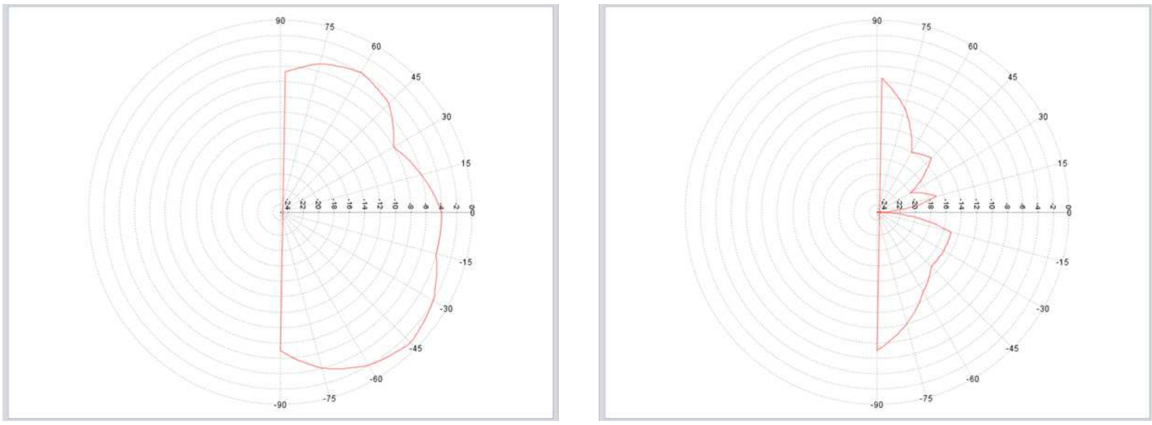



**Figure 33. Front (left) and rear (right) elevation patterns for fixed outdoor UWB antenna.**

# *Dense Urban Surveillance/SAR Radar I/N results*

## *No Mechanical Downtilt 30-degree Electronic Downtilt Dense Urban*

In these simulations the radar is tilted down by 30 degrees from horizontal. The minimum altitude is 1200 meters with a 30-degree downtilt and for a 90-degree downtilt in these simulations.

## *Mitigations*

Three mitigations were introduced in the results analysis to better reflect the real-world conditions for the Surveillance/SAR radar operating over dense urban areas. First, the 300- and 600-meter altitude results were removed. It is unlikely and not allowed for an aircraft to operate at such a low altitude over a dense urban area.

Second, all results shown so far in the preceding sections of this report do not include any reduction in interfering UWB power from polarization mismatch. A 3 dB reduction in interference power due to polarization mismatch is included in the results below.

Third, the 30 degree off-axis array gain is 1.25 dB below the assumed 42 dB peak gain as seen in Figure 30

Additionally, the antenna model described above for the UWB fixed outdoor sites was used.

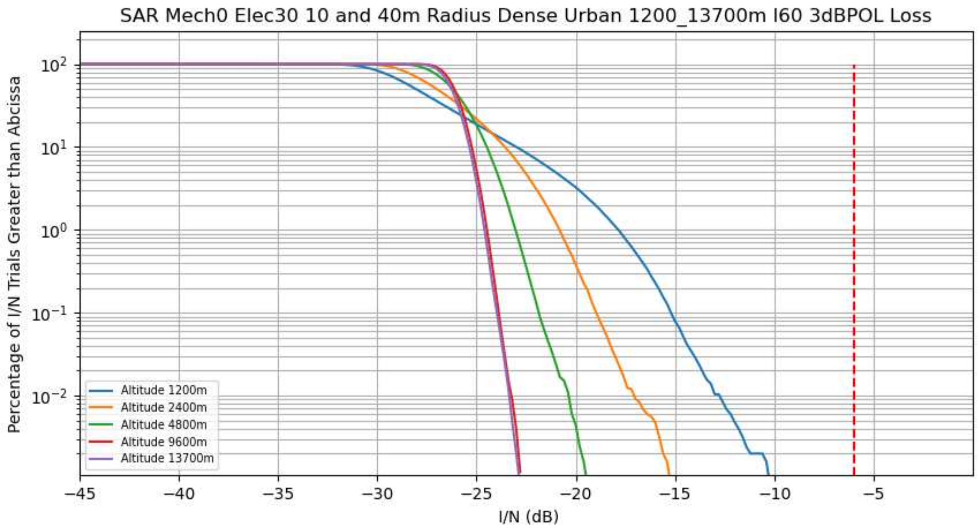



**Figure 34. I/N CDF curve for 30-degree electronic downtilt with mitigations included.**

### *Direct 90 Degree Downtilt Dense Urban*

In this set of simulations, the 30-degree electronic downtilt was supplemented with a 60-degree mechanical downtilt so that the radar signal points direction. The results for a range of altitudes from 1200m up to 13700m are presented.

Two mitigations were applied. First, a 3 dB polarization loss was added to the received UWB signal power.

Second, the max gain of the radar receiver was reduced from 42 dB by 1.25 dB because of the 30-degree off axis beam steering.

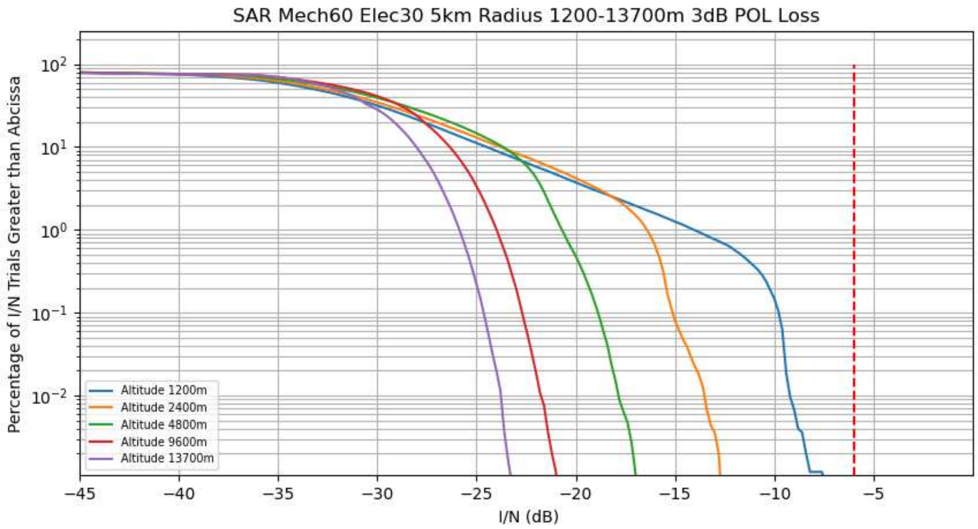



**Figure 35. I/N CDF curve for 90-degree downtilt Surveillance/SAR radar with mitigations included.**

These simulation results show that the I/N ratio even for 90-degree downtilt never exceeds the -6 dB level.

The I/N results show the I/N almost never exceeding the -6 dB value. Note that at 300 meters the radar return signal is expected to easily exceed the noise floor. In this case the UWB signal will impact the received radar return by much less than the 1 dB that a -6 dB I/N ratio would imply.

## *Results for C/I+N Calculations for Dense-Urban 90 Degree Downtilt*

### *Low Altitude Radar Signal Levels*

A radar operating at 300 meters altitude is likely to receive reflected signals at levels will above the receiver thermal noise floor. For example, using a radar cross section $\sigma$ for a bird of .01 meter-squared from Table 2.1 of [14] for a radar with 30 Watts of power into the 42 dB gain antenna then the received radar reflection power level is calculated to be -52 dBm.

### *Calculation*

In this section the C/I+N ratio is calculated for the 300 meter and 600-meter cases. The Radar transmitter power is assumed to be the lowest value, 30 Watts, listed in M.1796. The bandwidth is assumed to be 10 MHz. The radar target, a bird, is assumed to have a cross section of .01 square meters.

The receiver radar signal power is calculated using the Radar equation. The Radar equation is [ref]

$$C = \frac{P_{tx} G^2 \lambda^2}{(4\pi)^3 R^4} \sigma$$

Where G is the radar antenna gain (42 dB), $\lambda$ is the radar signal wavelength, R is the range from the radar to the object (300 or 600 meters), and $\sigma$ is the radar target cross section (.01) in meters squared. The radar bandwidth is assumed to be 10 MHz.

The Interference power values, I, were taken from the SEAMCAT iRSS simulation results. The 1 MHz SEAMCAT interference levels are scaled to the radar system bandwidth of 10 MHz. The noise level, N, is calculated from thermal noise, bandwidth, and radar receiver noise figure. No mitigations were applied in these calculations.

The graph below shows the calculated return for a bird near the ground for altitudes of 300 and 600 meters. In both scenarios the C/I+N is greater than zero even though there is a small probability that the interference to noise ration I/N might be greater than the -6 dB level. Other targets with larger cross sections will return signals with greater power levels.

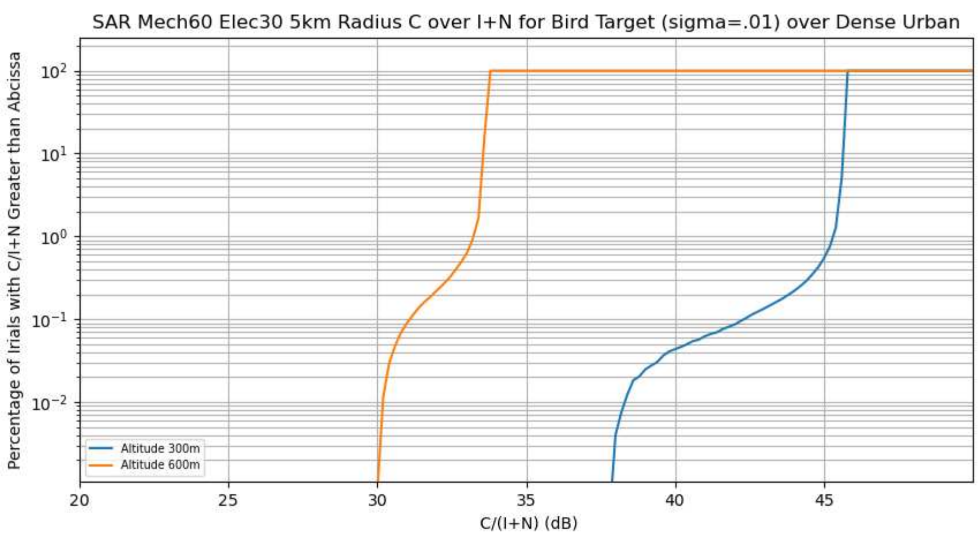



**Figure 36. Radar C/I+N for insect radar cross section at 300- and 600-meter altitudes.**

The figure shows that the simulated signal-to-noise ratio expressed as CINR is very high for the radar parameters in ITU M.1796 system A12. Note that no radar "pulse compression" or processing gain techniques such as FMCW or pulsed-CHIRP modulation were assumed to be present. These techniques would increase the CINR even further than the results shown in the figure.

## MCL Calculation

The table below shows the I/N based MCL calculations for the Surveillance/SAR radar scenario. The rows marked 'Mitigations' include 3 dB polarization losses and 1.25 dB of beam steering loss at the radar receiver. No radar "pulse compression" techniques were assumed. Note that I/N is not necessarily the best metric for high power radars operating at close ranges.

| | | Ptx (dBm/MHz) | Gtx (dB) | Grx (dB) | Feeder Loss (dB) | I/N | NF (dB) | Tantenna (K) | MCL (dB) | Freq (MHz) | FSPL Protection Distance (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAR | Fixed Outdoor | -41.3 | 0 | 42 | 0 | -6 | 6 | 290 | 114.7 | 8500 | 1.521 |
| | Fixed Outdoor (Mitigations) | -41.3 | 0 | 37.75 | 0 | -6 | 6 | 290 | 110.4 | 8500 | 0.932 |
| | Enhanced Power Indoor | -31.3 | -16.6 | 42 | 0 | -6 | 6 | 290 | 108.1 | 8500 | 0.711 |
| | Enhanced Power Indoor (Mitigations) | -31.3 | -16.6 | 37.75 | 0 | -6 | 6 | 290 | 103.8 | 8500 | 0.436 |

**Table 35. MCL table for Surveillance/SAR radar**

## Summary

Interference from UWB devices is not likely to cause interference with the Surveillance/SAR airborne radars described in Recommendation ITU M.1796 system A12. Even if the surveillance radar is directed at targets on the ground directly below the radar equipped aircraft flying at very low altitudes, the radar receives a UWB signal that signal is only present during the transient instants when the SAR/Surveillance radar aircraft is above the UWB device. If there is also a radar return signal it is very likely at low altitudes to have a very good signal to noise ratio and the small levels of the UWB signal will not affect the radar detection.

For Surveillance/SAR radars on radar equipped aircraft flying at higher altitudes then the UWB signals are attenuated by the greater loss due to the greater path lengths and the I/N ratios found in simulations show there would be no impact on radar operation.