NTIA SPECIAL PUBLICATION 01-47

ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND (UWB) SYSTEMS AND GLOBAL POSITIONING SYSTEM (GPS) RECEIVERS (REPORT ADDENDUM)

SPECIAL PUBLICATION

U.S. DEPARTMENT OF COMMERCE ● National Telecommunications and Information Administration

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ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND (UWB) SYSTEMS AND GLOBAL POSITIONING SYSTEM (GPS) RECEIVERS (REPORT ADDENDUM)

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EXECUTIVE SUMMARY

BACKGROUND

The study described in this report was undertaken by the National Telecommunications and Information Administration (NTIA) in response to a Federal Communications Commission (FCC) Notice of Proposed Rule Making (NPRM) concerning the operation of a new class of spectrum-dependent devices, designated as ultrawideband (UWB) devices under the FCC's rules and regulations in Part 15 of Title 47 of the Code of Federal Regulations (CFR).[1] This NPRM raises a number of questions and concerns regarding the electromagnetic compatibility (EMC) of the proposed UWB transmitting devices with those spectrum-dependent systems currently in operation. The NTIA, as the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy affecting Federal Government spectrum users, is particularly interested in the potential for interference to telecommunications infrastructure utilizing Federal Government spectrum for critical and/or safety-of-life functions, many of which operate in spectrum designated as the restricted frequency bands for that reason. Before UWB devices can operate in restricted frequency bands used by critical Federal Government radiocommunication systems, NTIA must examine the potential interference introduced from their proposed operations. The Global Positioning System (GPS) is an example of a critical radionavigation system that operates in several of the restricted frequency bands.

In February of 2001, NTIA released Special Publication 01-45, *Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers*. This document reported on measurements and analysis results obtained for the C/A code tracking and semi-codeless GPS receiver architectures, and indicated ongoing efforts to measure and analyze the interference susceptibility for a C/A code tracking receiver employing multiple narrowly spaced correlators and a Technical Standard Order (TSO) C-129a compliant aviation receiver. This report serves as an addendum to NTIA Report 01-45, and details the results obtained for the remaining two receivers, and also provides a comparison to other data sets that are on the public record.

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[1] The UWB emissions considered in this report are limited to those using a burst of a series of impulse-like signals. However, there are several ways of defining UWB signals, one being an emission that has an instantaneous bandwidth of at least 25% of the center frequency of the device. There are also several ways of generating very wide signals, including the use of spread spectrum and frequency hopping techniques.

OBJECTIVE

The primary objective of this study is to define maximum allowable UWB equivalent isotropically radiated power (EIRP)[2] levels that can be tolerated by GPS receivers, when used within various operational applications, without causing degradation to GPS operations. NTIA then compared these EIRP levels to the emission levels derived from the limits specified for intentional radiators in C.F.R., Title 47, Part 15.209 to assess the applicability of the Part 15 limits to UWB devices.[3]

GPS SYSTEM DESCRIPTION

The GPS is a space-based radionavigation satellite system providing precise position, velocity, and time information on a continuous, worldwide basis. The GPS space segment consists of a 24-satellite constellation with the satellites distributed in six orbital planes at an approximate altitude of 20,000 km. With the current configuration of the GPS constellation, there are typically from 6 to 11 satellites simultaneously visible from any point on the surface of the Earth. However, within a metropolitan area, the number of visible satellites is often reduced due to blockage from buildings or other man-made structures. GPS satellites currently transmit a spread spectrum signal using a multiple access capability known as code division multiple access (CDMA) on two microwave frequencies: Link 1 (L1) on 1575.42 MHz, and Link 2 (L2) on 1227.60 MHz. A civil coarse/acquisition (C/A) code and a quadrature-phase precision (P) code are multiplexed on the GPS L1 frequency while only the P-code is modulated on the L2 carrier. The C/A signal supports the standard positioning service and the P signal supports the precise positioning service.

A modernization effort is currently ongoing that will add two new civil signals to the GPS system. A C/A-like signal has been proposed for addition on L2, and a new signal structure has been defined for broadcast in a recently allocated Radionavigation-Satellite Service frequency band (1164-1188 MHz) and will be designated Link 5 (L5).

GPS APPLICATIONS

GPS is becoming the cornerstone for air navigation for all phases of flight (en-route, precision and non-precision approach) and is the preferred navigation system for maritime operations. In order to meet the exacting standards required from a safety-of-life system, the U.S. Government has either developed, or is developing augmentations to the basic GPS system for aviation, maritime, and land use. The Wide Area Augmentation System (WAAS) and the Local Area

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[2] The computation of EIRP is in terms of the average power of the UWB signal for all cases considered in this report. This average power is based on root-mean-square (RMS) voltage.

[3] The existing Part 15 measurement procedure uses an average logarithm detector process and is not equivalent to measurements using an RMS detector process.

Augmentation System (LAAS) are under development to enhance aviation uses of GPS. Differential GPS (DGPS) has been fielded to augment GPS to meet maritime harbor and harbor approach requirements, and for use in intercoastal and inland waterways. GPS is also fast becoming an integral component of position determination applications such as Enhanced-911 (E-911) and personal location and medical tracking devices. The telecommunications, banking, and power distribution industries represent another sector that uses GPS for network synchronization timing. Moreover, GPS has proven to be a powerful enabling technology that has driven the creation of many new industries. GPS also provides the U.S. military and its allies with positioning, navigation, and timing capabilities that are critical to peacetime and wartime national and global security operations.

APPROACH

NTIA adopted a two-part approach consisting of a measurement and an analysis component for this assessment. NTIA's Institute for Telecommunication Sciences (ITS) measured the interference susceptibility of various GPS receiver architectures to a set of UWB waveforms. Utilizing the measured GPS receiver interference susceptibility levels, analyses were performed by NTIA's Office of Spectrum Management (OSM) for various operational scenarios to determine the maximum allowable UWB EIRP level that can be tolerated by GPS receivers before performance degradation is realized.

Measurement Component

NTIA developed a measurement plan to guide the measurement component of this study. In this plan, the performance criteria used to assess a performance degradation to the GPS receivers under measurement were established, a list of candidate GPS receivers to be measured was defined, and the UWB signal structures to be considered were identified. A set of procedures used in performing the measurements was also developed. The plan was published in the Federal Register and public comment was solicited. Comments were received from seven parties. Each set of comments was considered, detailed responses provided, and the information contained in the received comments was incorporated into the plan, as appropriate.

GPS Receivers Selected for Testing. Since GPS receivers are used in many applications, NTIA decided this study would attempt to measure across the space of GPS receiver architectures rather than attempt to measure across the space of GPS applications. One receiver from each of three basic GPS receiver architectures was identified for inclusion in the measurements. The receiver architectures considered in NTIA Report 01-45 were the C/A-code tracking receivers (which make up a significant share of the civil GPS receivers in use today) and the semi-codeless receivers (used in low-dynamic applications requiring high precision). This addendum report considers the C/A-code tracking receivers employing multiple, narrowly-spaced correlators to enhance accuracy and mitigate the effects of multipath. These three GPS receiver architectures encompass most, if not all, of the existing GPS applications.[4] To address particular concerns related to the aviation use of GPS, a TSO-C129a compliant aviation receiver (currently used in en-route and non-precision approach applications) was also included as a part of this measurement effort.

UWB Signals Examined. NTIA identified 32 UWB signal permutations for examination with respect to their interference potential to GPS receivers. NTIA decided that these signal permutations were representative of those expected to be used in UWB applications. For each of four pulse repetition frequencies (PRFs);100 kHz, 1 MHz, 5 MHz, and 20 MHz, eight distinct UWB waveforms were generated by combining four modulation types (constant PRF, On-Off Keying (OOK), 2% relative dither, and 50% absolute dither) and two states of gating (100% and 20%). The PRF defines the number of pulses transmitted per unit time (one second). The PRF governs both the magnitude and spacing of the spectral lines, and the percentage of time that pulses are present. Gating refers to the process of distributing pulses in bursts by employing a programmed set of periods where the UWB transmitter is turned on or off for a period of pulses. For the measurements performed in this study, the gated UWB signal utilized a scheme where a burst of pulses lasting 4 milliseconds (ms) was followed by a 16 ms period when no pulses were transmitted. This is referred to as 20% gating, because the UWB pulses are transmitted 20% of the time. The signal permutations depicted within this report as 100% gating, define a signal where pulses are transmitted 100% of the time. OOK refers to the process of selectively turning off or eliminating individual pulses to represent data bits. Dithering refers to the random or pseudo-random spacing of the pulses. Two forms of dithered UWB signals were considered in this effort. These are an absolute referenced dither, where the pulse period is varied in relation to the absolute clock, and a relative referenced dither, where the pulse spacing is varied relative to the previous pulse. The data collected from these measurements are applicable only to the UWB signal permutations that were considered in this assessment.

Performance Criteria Used. After researching available technical standards and other open literature, NTIA adopted a set of criteria that was not application specific for assessing the performance of the GPS receivers in this measurement effort. NTIA examined two performance criteria - “break-lock” and “reacquisition.” Break-lock refers to the loss of signal lock between the GPS receiver and a GPS satellite. This condition occurs when an interfering signal reduces the carrier-to-noise density (C/N_0) ratio (i.e., an increase in the undesired signal level, N_0, relative to the desired signal level, C) to such an extent that the GPS receiver can no longer adequately determine the pseudorange (the initial/uncorrected measure of distance from a single GPS satellite to a receiver) for the given satellite signal.

The reacquisition threshold is defined as the UWB power level that results in an abrupt increase in reacquisition time. To determine the impact on reacquisition time, the signal from the GPS satellite of interest was interrupted and a 50-meter step in pseudorange was introduced over a 10-second period. This was done to simulate a GPS-equipped vehicle passing behind a building

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[4] This effort did not consider the potential impact of UWB operations to military GPS receivers.

or other obstacle in the satellite-to-receiver path, causing a temporary loss-of-lock between the GPS receiver and the satellite of interest. As the vehicle clears the obstacle and again becomes visible, the GPS receiver must be able to reacquire the lost satellite signal in the presence of UWB energy in a time consistent with that associated with no UWB energy present.

Measurements Performed. ITS performed closed system (conducted) measurements to assess the potential impact to each of the GPS receivers from a single UWB transmitter (one-on-one) interaction. The complete measurement data sets for the narrowly-spaced correlator and TSO-C129a compliant receivers are presented in a separate report published by ITS.

Analysis Component

The data collected from the measurements were used in a subsequent analysis effort performed by NTIA's OSM to calculate the maximum allowable EIRP that can be emitted from a UWB transmitter without exceeding the measured interference susceptibility level. A source-path-receiver analysis was performed to calculate these maximum allowable EIRP levels for both a single UWB transmitter-to-GPS receiver interaction and for the case of an aggregate of UWB transmitters-to-GPS receiver interaction. In performing these analyses, related parameters were determined from operational scenarios, which define the conditions under which proposed UWB devices may be in proximity to GPS receivers in operational applications. These operational scenarios were developed in open, public meetings with participation from UWB and GPS manufacturers and users. The specific proposals for operational scenarios to be considered in the NTIA study included GPS receivers used in the following applications: terrestrial[5] (e.g., public safety applications such as cellular phone embedded E-911 and emergency response vehicle navigation, geographic information systems, precision machine control, and general operations), maritime navigation (in constricted waterways, harbors, docking, and lock operations); railway operations (positive train control), surveying, and aviation (en-route navigation and non-precision approach). These scenarios do not represent all possible applications of GPS, however, they do represent a reasonable bound on the parameters necessary to perform the broadly based analyses. For example, the separation distances represented in these scenarios range from a minimum of 2 meters for the embedded E-911 scenario, to a maximum of approximately 300 meters (1000 feet) for the en-route aviation scenario.[6]

An analysis was also performed to determine the distance separations that are required to preclude interference to the different GPS receiver architectures, if the UWB device is operating at the current Part 15 level of -71.3 dBW/MHz. The measured UWB interference thresholds for both single-entry and multiple-entry UWB device interactions were considered.

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[5] Within the context of this report, terrestrial refers to land-based operations.

[6] Enhanced sensitivity GPS receivers using base station augmentation/aiding for E911 applications are not represented in this report.

RESULTS

This report documents the results of the measurement and analysis program conducted by NTIA. Policy recommendations and/or guidance with respect to proposed UWB operations are not included within the scope of this effort. The following paragraphs discuss the findings of this program.

Analysis of Susceptibility Data

In the analysis of measurement results reported in this addendum report and in NTIA Report 01-45, it was found that the interference effects on GPS C/A-code receivers from each of the UWB signals considered could be classified as either continuous wave (CW)-like, noise-like, or pulse-like interference. In each case where the interference effect was classified as CW- or noise-like, a specific interference threshold value could be determined from the measured data. The susceptibility threshold values that were analyzed for CW-like interference effects were the UWB power in a single spectrum line (in dBW) that caused the GPS receiver to break-lock. For noise-like interference effects, a set of susceptibility threshold values were analyzed where the GPS receiver was caused to break-lock and a separate set of values where the GPS receiver reacquisition time was increased due to interference. For both data sets, the susceptibility values were the power spectral density (in dBW/MHz) of the UWB signal that resulted in the interference effect.

The data presented in this addendum report were for a GPS receiver employing narrowly-spaced correlators and a TSO-C129a (aviation) compliant GPS receiver. The GPS receiver employing the C/A code receiver architecture that was included in NTIA Report 01-45 is referred in this report as the C/A code receiver.

The susceptibility values for each of the three receivers and for each interference effect/criterion (i.e., CW-like/break-lock, noise-like/break-lock, and noise-like/reacquisition) were examined to gain insight into the variability, reliability and accuracy of the measured data. The susceptibility data analyzed herein was referenced to a desired signal level of -130 dBm and for the noise-like interference effects the power of the UWB signal was added to the -93 dBm/20 MHz noise signal that was also input to the GPS receiver as required in the test plan. These data conversions were used to facilitate the comparison of measured data resulting from this program and from other GPS interference measurement efforts.

The susceptibility data collected in the NTIA measurement effort was analyzed by determining the median along with the range of data for each receiver. The median for the CW-like interference effects might indicate that performance of the TSO-C129a compliant receiver is more robust (can withstand a higher interference level before a break-lock condition is realized) than the other receivers. However, examination of the range of data for CW-like effects would indicate the data is consistent. The noise-like susceptibility values are within the bounds of measurement accuracy including variations associated with slightly differing test set-ups.

The overall median and range of data for the combined data for the three receivers shows the range of the data varies over a fairly small range relative to the median values. This again is an indication of data consistency across all receivers. This data was used in the comparison with GPS/UWB measurements performed by the Stanford University (SU) and the Applied Research Laboratories University of Texas (ARL:UT).

In order to make a comparison between the NTIA and SU susceptibility data, data sets had to be identified where similar measurement procedures, interference criteria, and UWB signal characteristics are used. Because of the differences in measurement procedures, interference criteria, and UWB signal characteristics, not all the SU and NTIA data can be compared, only a subset of the data supports a comparison. In addition to break-lock and pseudo-range error measurements, SU carried out reacquisition tests, however, the procedures and criteria were different than those used in the NTIA tests. The SU data was found to be comparable to the NTIA receiver input threshold data. The high-grade aviation receiver is slightly more robust than the receivers tested by NTIA under break-lock conditions; the SU break-lock thresholds are within 2 dB of the range of the NTIA data. For the aviation receiver pseudo-range measurement and both the Original Equipment Manufacturer receiver measurements, the SU data is within the range of the NTIA data.

The interference threshold data reported in the ARL:UT report as analyzed by the Joint Spectrum Center (JSC) was also compared to the NTIA receiver susceptibility data. Again, because of differences in the UWB signal characteristics, the measurement approach, and the interference threshold criteria, only a subset of the ARL:UT data could be used in this comparison. The interference threshold for the ARL:UT results are the values shown in the JSC Report with an appropriate correction (-43 dB) to convert from dBm/20 MHz to dBW/MHz for comparison purposes. Most of the ARL:UT data examined are comparable to the NTIA data particularly if one compares the ARL:UT data to the range associated with the NTIA median value. The possible exception to this comparability is for Receiver 1 with UWB interference and a performance metric of a loss of one satellite (-142.3 dBW/MHz for UWB Mode 7 and -142.7 dBW/MHz for UWB Mode 13). For these conditions, the receiver seems to be more susceptible to UWB interference. As discussed in the JSC Report, there is evidence for possible CW-like interference effects having occurred during the ARL:UT tests for these conditions. As shown in many of the GPS interference tests, GPS receivers are more susceptible to CW-like interference than noise-like interference. The NTIA data shows a median value of -144.5 dBW for CW-like interference for a break-lock condition. This is comparable to the ARL:UT test results for these two cases.

The NTIA susceptibility data was also compared to the existing RTCA and International Telecommunication Union GPS interference limits. The corrected median value for CW-like interference would be -149.5 dBW and for noise-like interference for reacquisition would be -139.5 dBW/MHz. These values can be compared to the existing protection limits for GPS receivers of -150.5 dBW for CW-like interference and -140.5 dBW/MHz for noise-like interference.

The GPS receiver interference susceptibility data resulting from the NTIA measurement program was examined and found to be consistent across the three receivers that process the C/A code L1 signal. The NTIA susceptibility data was shown to be comparable to the SU and ARL:UT test results. These comparisons can only be made for a subset of the SU and ARL:UT data because of differences in the UWB characteristics, the measurement procedures, and the interference criteria. Finally, the NTIA data was compared favorably to existing interference protection limits for GPS. For the parameter sets tested, this data defines the limit of the power level of the UWB signal that can be tolerated at the GPS receiver input to protect the desired performance. This body of susceptibility data can be used in source-path-receiver analyses to determine the interference impact of GPS/UWB operations in various operational scenarios.

Analysis Results

In this analysis, NTIA determined the maximum allowable EIRP for the different UWB signal permutations, using the operational scenarios proposed in the public meetings. The results of the analysis are summarized in Tables 1 through 4. Each table corresponds to a UWB PRF examined in the analysis. The tables provide a description of the: operational scenario; UWB signal characteristics; GPS receiver architecture; interfering signal characterization; interference threshold; and the computed values of maximum allowable EIRP. The values of maximum allowable EIRP shown in Tables 1 through 4 are for a single UWB device, and represent the highest EIRP at which UWB devices can operate and still provide protection to the GPS receiver architecture under consideration for the conditions specified in the operational scenarios. In a multiple UWB device interaction, the maximum allowable EIRP level of a single-entry UWB device as shown in the tables was determined by partitioning the total interference allotment in accordance with the multiple (aggregate) UWB device factor as discussed in Section 3.1.4.

Tables 1 through 4 also include a comparison of the computed values of maximum allowable EIRP with the current Part 15 level of -71.3 dBW/MHz. When the interference effects are classified as being pulse-like or noise-like, the values of maximum allowable EIRP can be directly compared to the current Part 15 level. When the interference effect is classified as being CW-like, the maximum allowable EIRP can be compared to the Part 15 level, if it is assumed that there is only a single spectral line in the measurement bandwidth. If the difference between the current Part 15 level and the computed maximum allowable EIRP is negative, no additional attenuation below the current Part 15 level is necessary to protect the GPS receiver architecture under consideration. If the difference is positive, this value specifies the additional attenuation below the current Part 15 level that is necessary to protect the GPS receiver architecture under consideration.

Table 1. Summary of Analysis Results (PRF = 100 kHz)

Operational Scenario Description					**UWB Signal Characteristics**		**GPS Receiver**	**Characterization of Interfering Signal**	**Maximum Interference Threshold (dBW/MHz)**	**Maximum Allowable EIRP (dBW/MHz)**	**Comparison with the Current Part 15 Level (dB)**
Application	**UWB Single**	**UWB Multiple**	**UWB Indoor**	**UWB Outdoor**	**Gating %**	**Mod.**					
Terrestrial	X			X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-70.8	-0.5
Terrestrial		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-55.2	-16.1
Terrestrial		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-59.9	-11.4
Maritime		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-39.3	-32
Maritime		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-45.7	-25.6
Railway		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.9	-17.4
Railway		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-55.4	-15.9
Surveying	X			X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.3	-18
Surveying		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.4	-17.9
Aviation-NPA		X		X	100	None	TSO C-129a	Pulse-Like	-117.9	-58.2	-13.1
Aviation-ER		X	X		Note 1	Note 1	TSO C-129a	Noise-Like	-136	-75.9[2]	4.6
Aviation-ER		X		X	Note 1	Note 1	TSO C-129a	Noise-Like	-136	-84.9[2]	13.6

Notes:
1. In this operational scenario, it is assumed that there is a large enough number of UWB devices such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.
2. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

Table 2. Summary of Analysis Results (PRF = 1 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	Gating %	Mod.					
Terrestrial	X			X	100	None	Narrow Correlator	CW-Like	-144.1	–104.7	33.4
Terrestrial	X			X	100	50% Abs.	Narrow Correlator	Pulse-Like	-105.9	-66.5	-4.8
Terrestrial		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-89.1	17.8
Terrestrial		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-83.2	11.9
Terrestrial		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-93.8	22.5
Terrestrial		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-87.9	16.6
Maritime		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-73.2	1.9
Maritime		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-67.3	-4
Maritime		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-79.6	8.3
Maritime		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-73.7	2.4
Railway		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-87.8	16.5
Railway		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-80.7	9.4
Railway		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-89.3	18
Railway		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-82.2	10.9
Surveying	X			X	100	None	Narrow Correlator	CW-Like	-144.1	-87.2	15.9
Surveying	X			X	100	50% Abs.	Narrow Correlator	Pulse-Like	-105.9	-49	-22.3
Surveying		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-87.3	16
Surveying		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-75.4	4.1
Aviation-NPA		X		X	20	None	TSO C-129a	CW-Like	-146.7	-87	15.7
Aviation-NPA		X		X	100	50% Abs.	TSO C-129a	Noise-Like	-142	-88.3	17
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

Table 3. Summary of Analysis Results (PRF = 5 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	Gating %	Mod.					
Terrestrial	X			X	100	OOK	Narrow Correlator	CW-Like	-146.7	–107.3	36
Terrestrial	X			X	20	Multiple	Narrow Correlator	Pulse-Like	-88.5	-49.1	-22.2
Terrestrial	X			X	100	50% Abs.	Narrow Correlator	Noise-Like	-127.7	–88.3	17
Terrestrial		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-91.7	20.4
Terrestrial		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-83.2	11.9
Terrestrial		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-96.4	25.1
Terrestrial		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-87.9	16.6
Maritime		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-75.8	4.5
Maritime		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-67.3	-4
Maritime		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-82.2	10.9
Maritime		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-73.7	2.4
Railway		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-90.4	19.1
Railway		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-80.7	9.4
Railway		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-91.9	20.6
Railway		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-82.2	10.9
Surveying	X			X	100	OOK	Narrow Correlator	CW-Like	-146.7	-89.8	18.5
Surveying	X			X	20	Multiple	Narrow Correlator	Pulse-like	-88.5	-31.6	-39.7
Surveying	X			X	100	50% Abs.	Narrow Correlator	Noise-Like	-127.7	-70.8	-0.5
Surveying		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-89.9	18.6
Surveying		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-75.4	4.1
Aviation-NPA		X		X	20	OOK	TSO C-129a	CW-Like	-143.3	-83.6	12.3
Aviation-NPA		X		X	100	2% Rel.	TSO C-129a	Noise-Like	-143	-89.3	18
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

Table 4. Summary of Analysis Results (PRF = 20 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	Gating %	Mod.					
Terrestrial	X			X	20	None	Narrow Correlator	CW-Like	-146.9	–107.5	36.2
Terrestrial	X			X	20	2% Rel.	Narrow Correlator	Pulse-Like	-122.2	-82.8	11.5
Terrestrial	X			X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	–96.1	24.8
Terrestrial		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-91.9	20.6
Terrestrial		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-86.5	15.2
Terrestrial		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-96.6	25.3
Terrestrial		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-91.2	19.9
Maritime		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-76	4.7
Maritime		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-70.6	-0.7
Maritime		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-82.4	11.1
Maritime		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-77	5.7
Railway		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-90.6	19.3
Railway		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-84	12.7
Railway		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-92.1	20.8
Railway		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-85.5	14.2
Surveying	X			X	20	None	Narrow Correlator	CW-Like	-146.9	-90	18.7
Surveying	X			X	20	2% Rel.	Narrow Correlator	Pulse-Like	-122.2	-65.3	-6
Surveying	X			X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-78.6	7.3
Surveying		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-90.1	18.8
Surveying		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-78.7	7.4
Aviation-NPA		X		X	20	None	TSO C-129a	CW-Like	-147.8	-88.1	16.8
Aviation-NPA		X		X	100	Multiple	TSO C-129a	Noise-Like	-141	-87.3	18
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

Certain observations were made based on a review of the last column in Tables 1 through 4. This column lists the difference between the current Part 15 level of -71.3 dBW/MHz (considered as an average power limit) and the computed maximum allowable EIRP values. As stated earlier, a positive number in the last column indicates that the computed level of maximum allowable EIRP is less than the current Part 15 level.

An examination of Table 1 (PRF = 100 kHz) shows the effect of the C/A code signal process, used by both the narrowly-spaced correlator and the TSO-C129a compliant receivers, being fairly robust to low-duty cycle pulsed interference. The worse-case comparison to the current Part 15 level is the aviation en-route navigation operational scenario with UWB devices operating outdoors (13.6 dB below the Part 15 level). This is based on a density of active UWB devices of $200/km^2$. If one considers the use of 100 kHz PRF could be of interest in only UWB device applications such as ground penetrating radars and through-the-wall imaging radars, the projected density of UWB devices may not be as high as assumed. If, for example, the density of UWB devices operating at 100 kHz is $20/km^2$, the maximum allowable EIRP would increase by 10 dB.

Tables 2 through 4 (UWB waveforms with PRFs of 1, 5, and 20 MHz) show that the maximum allowable EIRP level necessary to satisfy the measured GPS performance criteria must be below the current Part 15 level for most of the operational scenarios considered. Those interactions that involve operational scenario/UWB signal parameter combinations that require an attenuation of 20 dB or more below the Part 15 level were selected for closer examination. This examination indicates that in most of these cases, the interactions involve: 1) UWB waveforms that were deemed CW-like in their interference effect to the GPS receivers, for which the measurements indicate a greater interference susceptibility or 2) operational scenarios in which the UWB transmitter is considered to be operating at a close distance (within several meters) to the GPS receivers. This data suggests that if the spectral line content of the UWB waveforms could be removed from consideration, perhaps through regulation, there still remains several interactions involving noise-like UWB waveforms at these PRFs for which the EIRP levels would still have a potential to cause interference at levels 18 to 20 dB below the current Part 15 level.

As shown in Tables 1 through 4, the results of the analysis indicate that the values of maximum allowable EIRP that are necessary to preclude interference to GPS receivers is highly dependent on the parameters of the UWB signal. This is consistent with the findings from the measurement effort where the performance of the GPS receiver in the presence of a UWB signal was also found to be highly dependent on the UWB signal structure.

Figures 1 through 4 display computed maximum allowable EIRP levels for those UWB signal permutations that were classified within this study as pulse-like, noise-like, and CW-like with respect to their interference effects on the GPS narrowly-spaced correlator receiver architecture. The values reported in these charts represent the range of maximum allowable UWB EIRP levels. The values were determined from an analysis of each UWB signal permutation in potential interactions with the narrowly-spaced correlator receiver architecture. The analysis included all of the operational scenarios considered in the study.

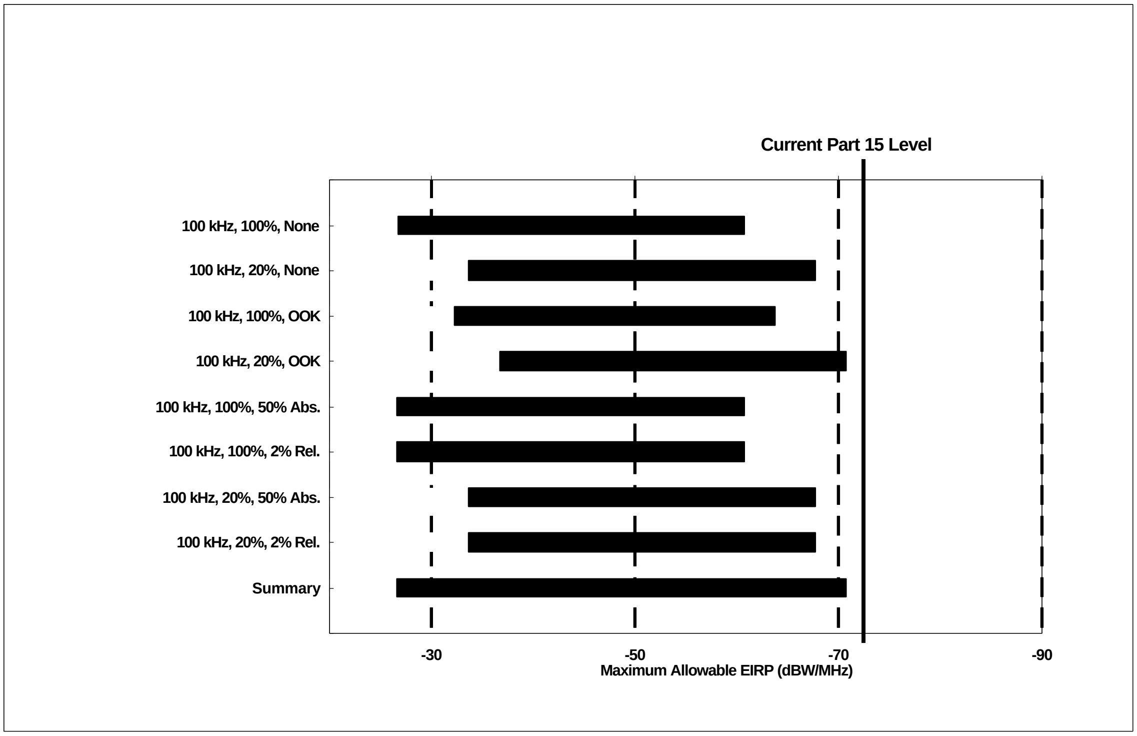

Figure 1. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal for the Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Operational Scenario)

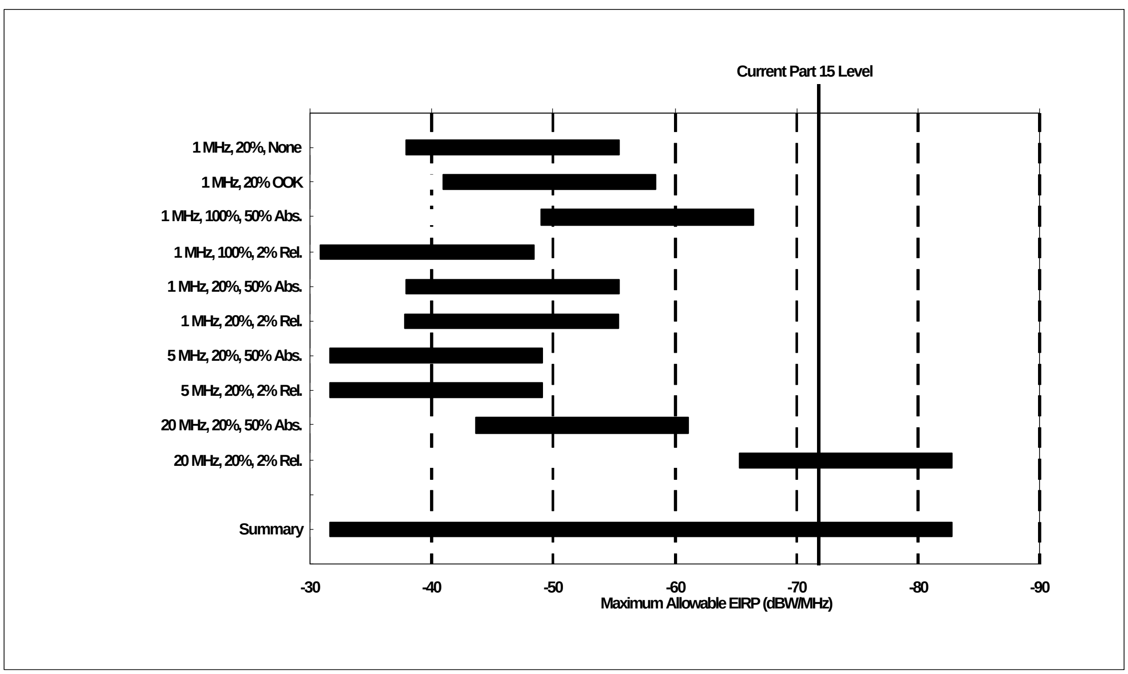

Figure 2. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal for the Narrowly-Spaced Correlator Receiver Architecture (Single UWB Device Operational Scenario)

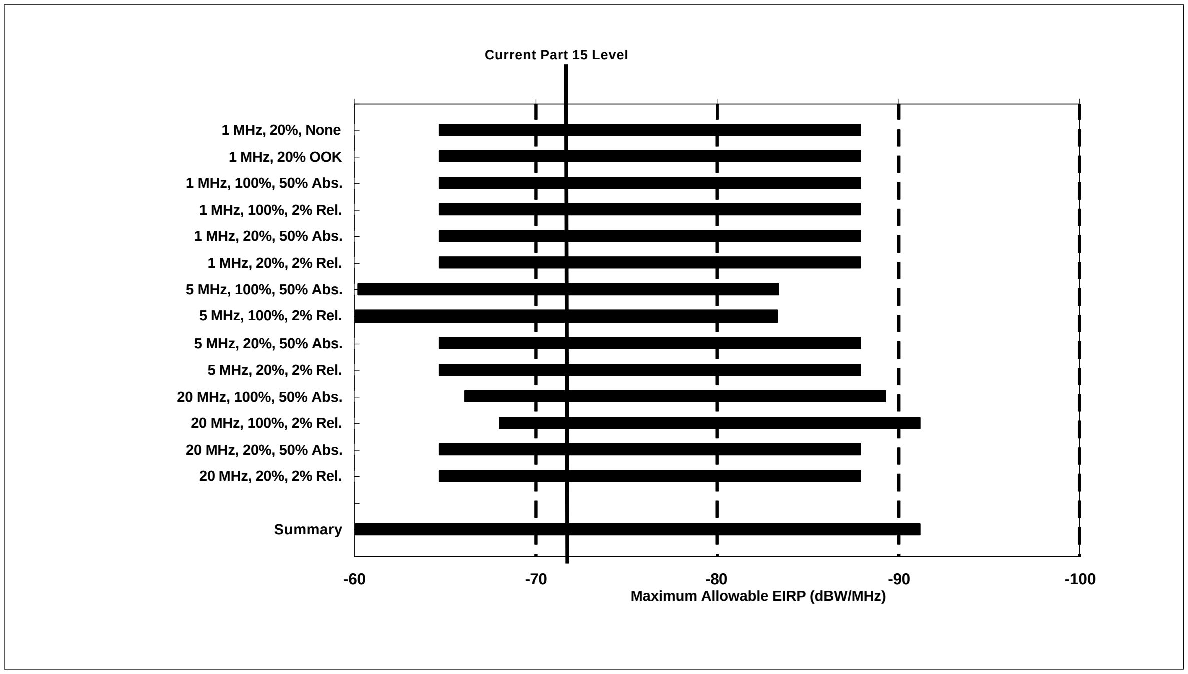

Figure 3. Range of Maximum Allowable EIRP for Noise-Like UWB Signals for Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Scenarios)

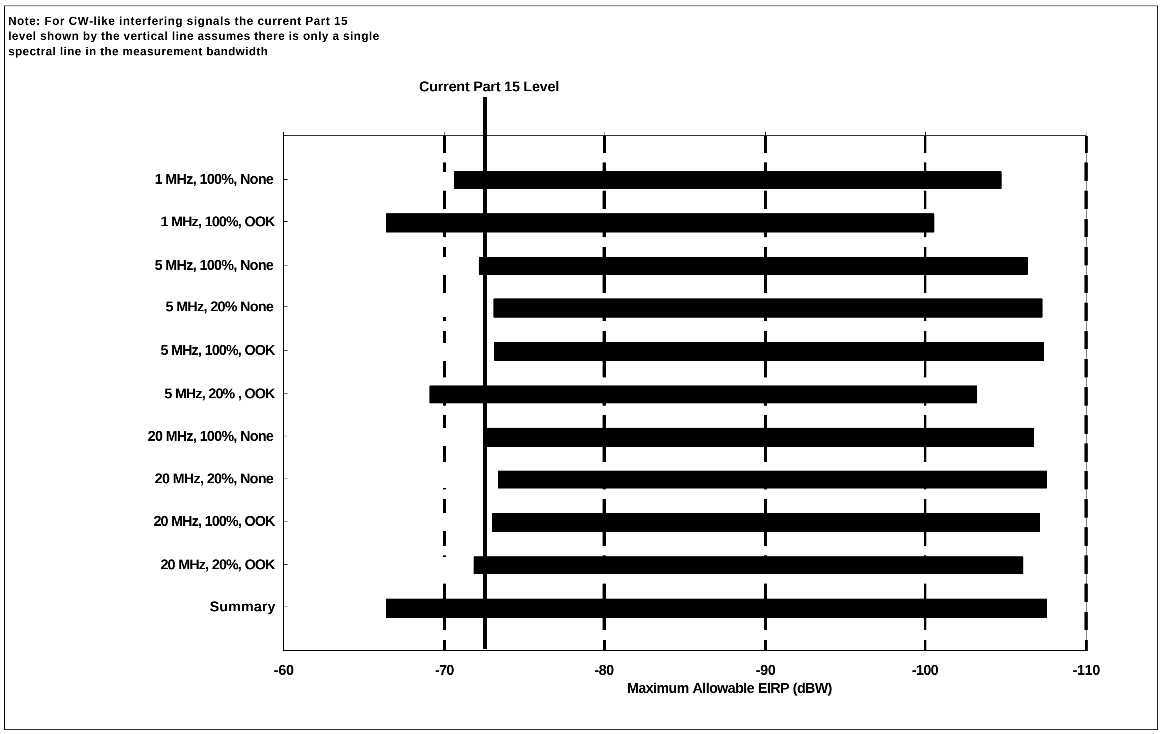

Figure 4. Range of Maximum Allowable EIRP for CW-Like UWB Signals for the Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Operational Scenarios)

For the operational scenarios considered for single and multiple UWB devices, Figures 1 and 2 display the range of maximum allowable EIRP for the UWB signals that were classified in this study as being pulse-like. Figure 3 displays the range of maximum allowable EIRP levels for those UWB signals that were classified in this study as being noise-like. Figure 4 displays the range of maximum allowable EIRP levels for those UWB signals that were classified in this study as being CW-like in their interference effects on the GPS narrowly-spaced correlator receiver. The labels on the y-axis in Figures 1 through 4 identify the various UWB signal structures in terms of PRF, percent gating, and the type of modulation. For example, a UWB signal structure with a PRF of 100 kHz, 100% gating, and no modulation will have a y-axis label of: 100 kHz, 100%, None.

An examination of Figures 1 through 4 clearly indicates that the maximum allowable EIRP required to satisfy the measured performance threshold of the narrowly-spaced correlator GPS receiver, across all of the operational scenarios is a function of the UWB signal structure. Figure 1 shows that the maximum allowable EIRP corresponding to those UWB signal permutations with a PRF of 100 kHz. For the UWB signal permutations represented in Figure 1, neither a break-lock nor a reacquisition could be measured for UWB power levels up to the maximum power available from the UWB signal generator. For these cases, the maximum UWB signal generator power level was used to compute the maximum allowable EIRP level. Thus the reported maximum allowable EIRP level represents a lower limit for these cases. That is, the actual maximum allowable EIRP level may be higher than the level shown in Figure 1 for these 100 kHz PRF UWB waveforms. From Figure 1, it can be observed that the maximum allowable EIRP levels necessary to satisfy the measured performance threshold for the narrowly-spaced correlator GPS receiver over all of the operational scenarios considered in this study range from -70.8 to -26.6 dBW/MHz.

In the operational scenarios where single UWB device interactions are considered, several UWB signal permutations employing PRFs of 1 MHz, 5 MHz, and 20 MHz, caused an effect similar to that of low-duty cycle pulsed interference to the narrowly-spaced correlator receiver. Figure 2 shows that for these UWB signal permutations, the maximum allowable EIRP levels necessary to satisfy the GPS receiver performance thresholds for the operational scenarios considered within this study range from -82.8 to -31.6 dBW/MHz.

Figure 3 shows that the maximum allowable EIRP levels necessary to satisfy the measured performance thresholds over all of the operational scenarios considered in this study range from -91.2 to -60.1 dBW/MHz for those UWB signals employing PRFs of 1 MHz, 5 MHz, and 20 MHz, that are classified as noise-like in their interference effects on the GPS narrowly-spaced correlator receiver.

The data presented in Figure 4 shows that the maximum allowable EIRP levels range from -107.5 to -66.4 dBW over all of the operational scenarios considered for those UWB signals that are classified as CW-like in their interference effects on the GPS narrowly-spaced correlator receiver. These maximum allowable EIRP levels are based on the power in a single spectral line and in order to make a comparison to the Part 15 level, it must be assumed that only a single spectral line appears in the measurement bandwidth.

Figures 5 through 7 present summary plots showing the maximum allowable EIRP calculated for the aviation non-precision approach operational scenario using the TSO-C129a compliant GPS receiver measured as part of this effort. The analysis results are presented as a function of the different UWB signal permutations examined. For the TSO-C129a compliant receiver, the interference effects of the UWB signals examined are classified as pulse-like, noise-like, or CW-like.

Figure 5 shows that for those UWB signals examined with a PRF of 100 kHz, the calculated maximum allowable EIRP level is above the current Part 15 level. Therefore, based on the results of the analysis, no additional attenuation is necessary.

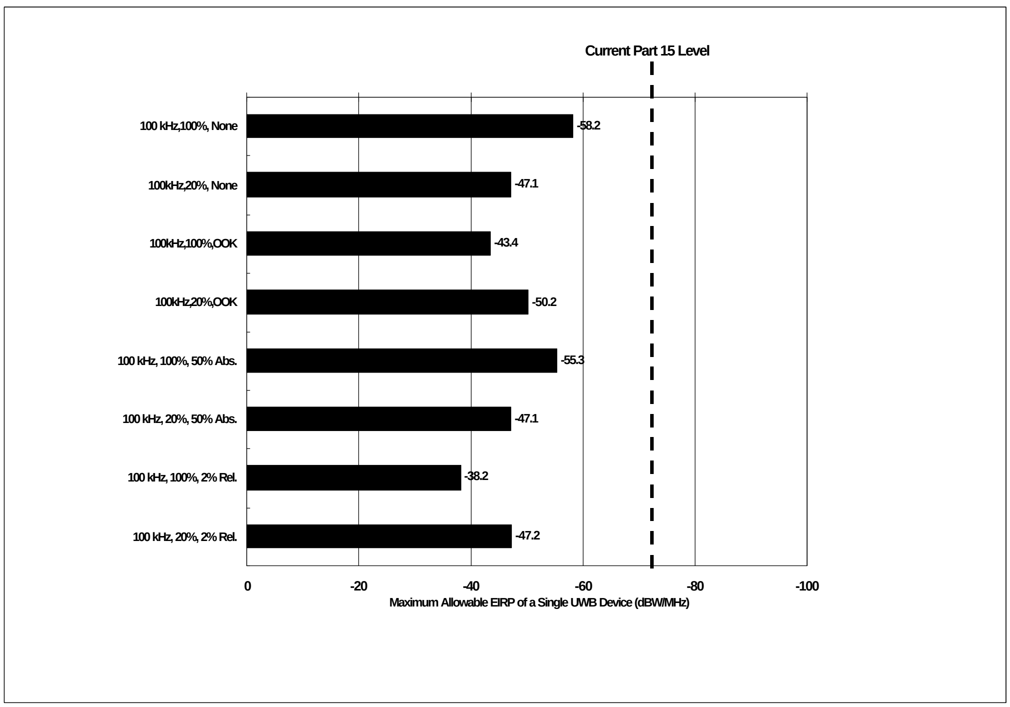

Figure 5. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (Pulse-Like UWB Signals)

Figure 6 shows the maximum allowable EIRP levels for PRFs of 1 MHz, 5 MHz, and 20 MHz, when the UWB signal permutations were classified as causing noise-like interference to the TSO-C129a compliant GPS receiver. As shown in Figure 6, the maximum allowable EIRP must be as much as 18 dB below the current Part 15 level to satisfy the measured performance threshold of the TSO-C129a compliant GPS receiver in the applicable operational scenario.

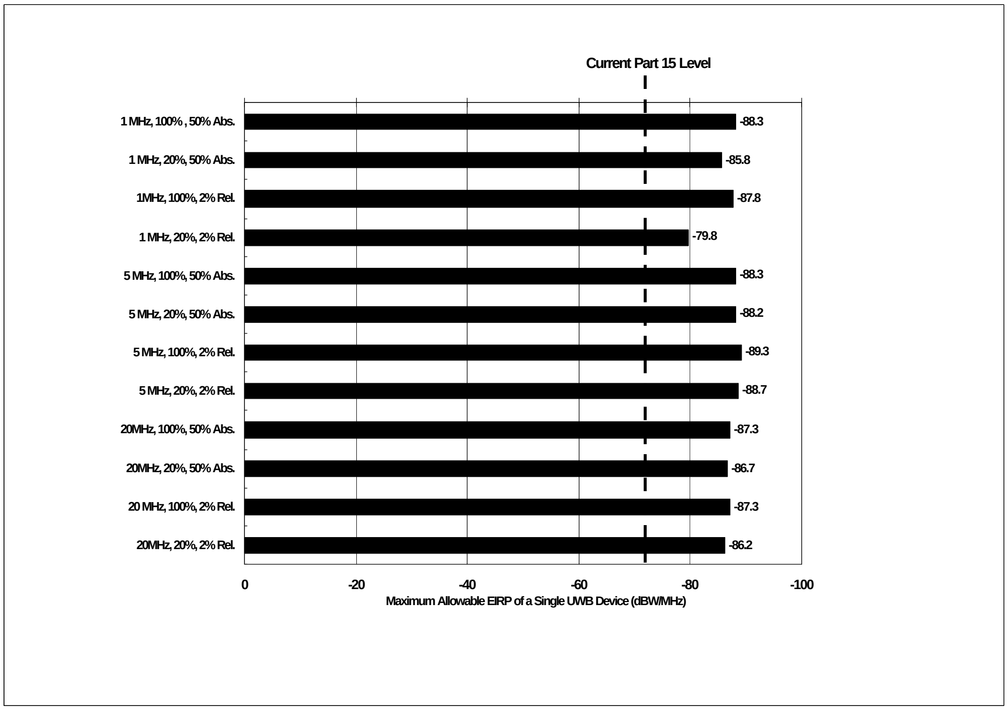

Figure 6. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (Noise-Like UWB Signals)

Figure 7 shows the maximum allowable EIRP levels for the PRFs of 1 MHz, 5 MHz, and 20 MHz, that have been classified as causing CW-like interference to the TSO-C129a compliant receiver. As shown in Figure 7, for those UWB signal permutations, the maximum allowable EIRP must be as much as 17 dB below the current Part 15 level to satisfy the measured performance threshold of the TSO-C129a compliant receiver.

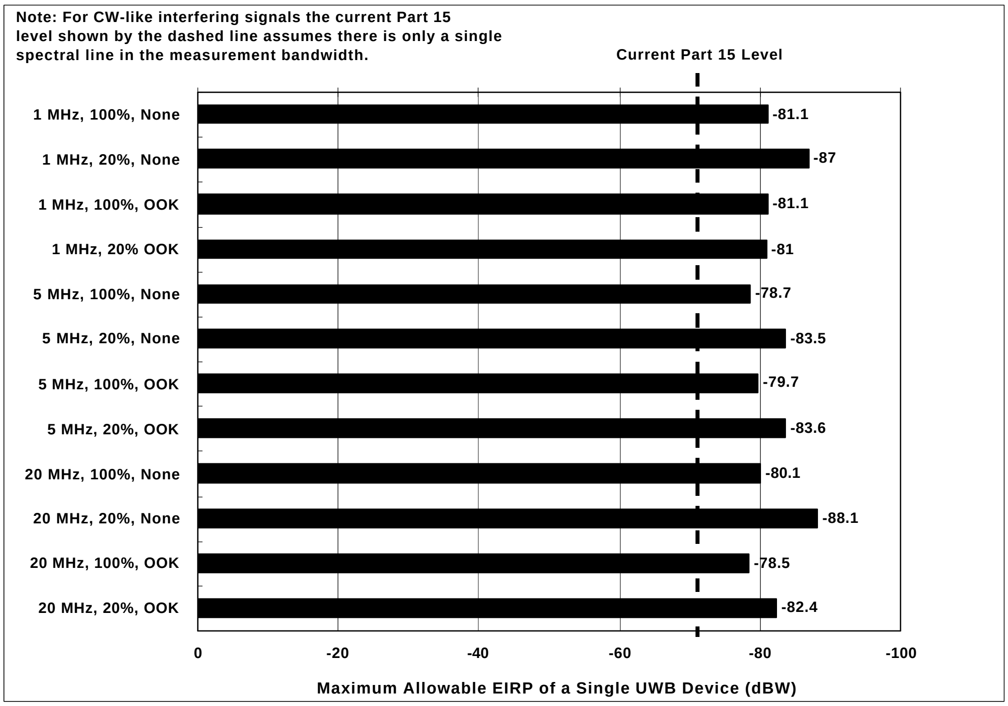

Figure 7. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (CW-Like UWB Signals)

Table 5 provides a comparison of the range of computed EIRP levels for the C/A code receiver architecture considered in NTIA Report 01-45 and the narrowly-spaced correlator receiver architecture considered in this addendum. Table 6 provides a comparison of the computed EIRP levels for the C/A code receiver architecture considered in NTIA Report 01-45 and the TSO-C129a compliant C/A code receiver architecture considered in this addendum. An examination of the computed EIRP levels shown in Tables 5 and 6 indicates that the ranges of computed EIRP levels are consistent among the different GPS receivers under the conditions of the operational scenarios that were analyzed.

Table 5. Comparison of EIRP Levels for C/A Code and Narrowly-Spaced Correlator Receiver Architectures

Operational Scenario	Interference Effects	C/A Code	Narrowly-Spaced Correlator
		EIRP Range	EIRP Range
Terrestrial - Single	Pulse-Like	-95.6 to -49.6 dBW/MHz	-82.8 to -48.4 dBW/MHz
Terrestrial - Multiple (Outdoor)	Pulse-Like	-62.3 to -49.7 dBW/MHz	-59.9 to -49.8 dBW/MHz
Terrestrial - Multiple (Indoor)	Pulse-Like	-57.6 to -45 dBW/MHz	-55.2 to -45.1 dBW/MHz
Terrestrial - Single	Noise-Like	-98.6 to -96.6 dBW/MHz	-96.1 to -88.2 dBW/MHz
Terrestrial - Multiple (Outdoor)	Noise-Like	-93.7 to -90.2 dBW/MHz	-91.2 to -83.3 dBW/MHz
Terrestrial - Multiple (Indoor)	Noise-Like	-89 to -85.5 dBW/MHz	-86.5 to -78.6 dBW/MHz
Terrestrial - Single	CW-Like	-106.9 to -104.3 dBW	-107.5 to -100.5 dBW
Terrestrial -Multiple (Outdoor)	CW-Like	-96 to -93.4 dBW	-96.6 to -89.6 dBW
Terrestrial - Multiple (Indoor)	CW-Like	-91.3 to -88.7 dBW	-91.9 to -84.9 dBW
Maritime (Outdoor)	Pulse-Like	-48.1 to -34.8 dBW/MHz	-45.7 to -34.9 dBW/MHz
Maritime (Indoor)	Pulse-Like	-41.7 to -26.5 dBW/MHz	-39.3 to -26.6 dBW/MHz
Maritime (Outdoor)	Noise-Like	-79.5 to -75.3 dBW/MHz	-77 to -68.4 dBW/MHz
Maritime (Indoor)	Noise-Like	-73.1 to -67 dBW/MHz	-70.6 to -60.1 dBW/MHz
Maritime (Outdoor)	CW-Like	-81.8 to -78.5 dBW	-82.4 to -74.7 dBW
Maritime (Indoor)	CW-Like	-75.4 to -70.2 dBW	-76 to -66.4 dBW
Railway (Outdoor)	Pulse-Like	-57.8 to -45.2 dBW/MHz	-55.4 to -45.3 dBW/MHz
Railway (Indoor)	Pulse-Like	-56.3 to -43.7 dBW/MHz	-53.9 to -43.8 dBW/MHz
Railway (Outdoor)	Noise-Like	-88 to -84.5 dBW/MHz	-85.5 to -77.6 dBW/MHz
Railway (Indoor)	Noise-Like	-86.5 to -83 dBW/MHz	-84 to -76.1 dBW/MHz
Railway (Outdoor)	CW-Like	-91.5 to -88.9 dBW	-92.1 to -85.1 dBW
Railway (Indoor)	CW-Like	-90 to -87.4 dBW	-90.6 to -83.6 dBW

Table 6. Comparison of EIRP Levels for C/A Code and TSO-C129a Complaint C/A Code Receiver Architectures

Operational Scenario	Interference Effects	C/A Code	TSO-C129a Compliant
		EIRP Range	EIRP Range
Aviation - Non-Precision Approach	Pulse-Like	-52.9 to -40.3 dBW/MHz	-58.2 to -38.2 dBW/MHz
Aviation - Non-Precision Approach	Noise-Like	-84.3 to -80.8 dBW/MHz	-89.3 to -79.8 dBW/MHz
Aviation - Non-Precision Approach	CW-Like	-86.6 to -84 dBW	-88.1 to -78.5 dBW
Aviation - En-route (Outdoor)	Noise-Like	-85.6 dBW/MHz	-84.9 dBW/MHz
Aviation - En-route (Indoor)	Noise-Like	-76.6 dBW/MHz	-75.9 dBW/MHz

An analysis was also performed to determine the distance separations that would preclude interference to the different GPS receiver architectures, if the UWB device is operating at the current Part 15 level of -71.3 dBW/MHz. The measured UWB interference thresholds for both single-entry and multiple-entry UWB device interactions were considered.

Table 7 presents an overview of the distance separation analysis results for the C/A code, semi-codeless, and narrowly-spaced correlator receiver architectures for single-entry UWB device interactions. Table 8 presents an overview of the analysis results for the TSO-C129a compliant receiver. Table 9 presents an overview of the distance separation analysis results for the C/A code receiver architecture for multiple-entry UWB device interactions.

Table 7. Overview of Single-Entry Distance Separation Analysis Results for the C/A Code, Semi-Codeless, and Narrowly-Space Correlator Receiver Architectures

UWB PRF (MHz)	Distance Separation (m)* To Preclude Interference								
	Gr = 3 dBi			Gr = 0 dBi			Gr = -4.5 dBi		
	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator
0.1	5	92	4	3.5	65	3	2	39	2
1	178	412	186	126	292	132	75	174	79
5	219	412	251	155	292	178	92	174	106
20	240	347	257	170	246	182	101	146	108

*Note: G_r is the GPS receive antenna gain.

Table 8. Overview of Distance Separation Analysis Results for TSO-C129a Compliant GPS Receiver

UWB PRF (MHz)	Distance Separation (m)
0.1	9
1	251
5	170
20	285

TABLE 9. Calculated Distance Separations to Preclude Interference from Multiple-Entry UWB Device Interactions Based on the Current Part 15 Emission Limit (C/A Code Receiver Architecture)

UWB Parameters				Distance Separation (meters)*		
PRF (MHz)	Gating Percent	Modulation	Number of UWB Signal Generators	Gr = 3 dBi	Gr = 0 dBi	Gr = -4.5 dBi
10	100	Dithering 2% Rel.	6	213	151	90
10	20	Dithering 2% Rel.	6	180	127	76
10 3 3	100 100 20	None None Dithering 2% Rel.	2 1 3	351	248	148
3 3	20 20	None Dithering 2% Rel.	4 2	174	123	73
1	100	Dithering 2% Rel.	1	41	29	17
1	100	Dithering 2% Rel.	2	104	73	44
1	100	Dithering 2% Rel.	3	127	90	54
1	100	Dithering 2% Rel.	4	147	104	62
1	100	Dithering 2% Rel.	5	184	130	78
1	100	Dithering 2% Rel.	6	180	127	76
Note: G_r is the GPS receive antenna gain						

CONCLUSIONS

This addendum was prepared to report on the results of the susceptibility measurements on the two GPS receivers that were not completed in time to be included in the initial NTIA report (NTIA Report 01-45). This addendum also provides the results of the analyses applying this measured data to determine maximum EIRP levels that would protect these GPS receivers within the applications represented by the operational scenarios examined. The measurements reported in this addendum are limited to single-entry interference cases. The aggregate and other ancillary measurements reported in NTIA Report 01-45 were not repeated as a part of this addendum. There were no noteworthy differences in either the receiver susceptibility measurements or the analysis results between the initial report and this addendum.

In addition to reporting the interference susceptibility data from the remaining two receivers tested in the overall NTIA measurement effort, this addendum presents a comparison among the data sets collected within the NTIA measurement program as well as a comparison of the NTIA data with comparable data sets measured in the other UWB-to-GPS measurement efforts conducted by SU and ARL:UT. In performing this comparison, a definite consistency in the total data set that has been made a part of the public record has been noted. This consistency within the measured data has also been noted by other parties to this proceeding.

The data sets acquired from three of the receivers tested in the NTIA measurement program were compared to one another and found to be consistent with respect to the interference susceptibility levels measured and the interference effects that were observed. In addition, the NTIA measured data was compared to similar data sets collected for the GPS receivers examined in the measurement efforts performed by SU and ARL:UT. This comparison also indicates a significant consistency between the measured susceptibility data and the observed interference effects among the GPS receivers considered in the various test programs. Finally, an NTIA comparison between the measured GPS susceptibility data and the existing interference protection criteria developed within RTCA and the ITU-R also indicates a consistency between the measured interference thresholds and the existing GPS interference criteria. This consistency across the data sets, coupled with emergence of consistent trends in the interference effects observed by all of the measurement parties, suggests that a meaningful record of GPS receiver susceptibility data has been compiled in this proceeding.

The previous NTIA report noted a relationship between the interference susceptibility of a GPS receiver, particularly the C/A-code receiver, and the characteristics of the interfering UWB signal (e.g., PRF, dithering, gating, etc). This same relationship is also noted in the results of the additional measurements reported in this addendum; however, another parameter effecting the interference potential to a GPS receiver from UWB emissions was noted - the pre-correlator bandwidth of the GPS receiver. In the supplemental measurement effort, the susceptibility to UWB emissions was examined for two additional GPS receivers. Both of these receivers process the GPS C/A-code signal transmitted on L1 (the narrowly-spaced correlator receiver also has an L2 capability, but it was disabled for these tests). The narrowly-spaced correlator GPS receiver utilizes an architecture that makes use of multiple correlators, spaced less than one chip apart, to mitigate multipath effects at the receiver. This GPS receiver architecture uses a precorrelator bandwidth of approximately 16 MHz. The second GPS receiver measured in the supplemental effort is an existing aviation-grade (TSO-C129a-compliant) receiver. This receiver is unique in that it provides a Receiver Autonomous Integrity Monitoring (RAIM) capability. The precorrelator bandwidth of this receiver is approximately 2 MHz. The C/A-code receiver for which the measured interference susceptibility data was reported in NTIA Report 01-45, employed a precorrelator bandwidth of approximately 10 MHz. When comparing the susceptibility data collected for each of these receivers, a relationship between the interference effect and the receiver bandwidth was observed. For example, some of the UWB signal permutations (particularly among the 1 MHz PRF signals) that produced pulse-like interference effects in the wider band GPS receivers (the 10 MHz C/A-code receiver and the 16 MHz narrowly-spaced correlator receiver), excited a response characteristic of the more disruptive noise-like or CW-like interference effects in the narrower bandwidth receiver (i.e., the 2 MHz aviation receiver).

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ADR	Accumulated Delta-Range
APD	Amplitude Probability Distribution
ARL:UT	Applied Research Laboratories University of Texas
ARNS	Aeronautical Radionavigation Service
BL	Break-Lock
C/A	Coarse/Acquisition
C/N_0	Carrier-to-Noise Power Density Ratio
CDMA	Code Division Multiple Access
CFR	Code of Federal Regulations
CMC	Code Minus Carrier
CW	Continuous Wave
dB	Decibels
dBi	Decibels relative to an isotropic antenna
dBic	Decibels relative to an isotropic circularly polarized antenna
dBm	Decibels relative to one milliwatt (equal to -30 dBW)
dBW	Decibels relative to one watt (equal to 30 dBm)
DGPS	Differential Global Positioning System
DNBL	Did Not Break lock
DoD	Department of Defense
E-911	Enhanced-911
EIRP	Equivalent Isotropically Radiated Power
EMC	Electromagnetic Compatibility
ER	En-Route Navigation
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FTE	Flight Technical Error
GEO	Geostationary Earth Orbiting
GHz	Gigahertz
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IF	Intermediate Frequency
IGEB	Interagency GPS Executive Board
IRAC	Interdepartment Radio Advisory Committee
ITS	Institute for Telecommunication Sciences
ITU-R	International Telecommunication Union - Radiocommunication Sector
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
JSC	Joint Spectrum Center
kHz	kilohertz
L1	GPS Link 1 (1575.42 MHz)
L2	GPS Link 2 (1227.60 MHz)
L5	GPS Link 5 (1176.45 MHz)

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

LAAS	Local Area Augmentation System
LNA	Low Noise Amplifier
LOS	Line-of-Sight
LR	Loss Ratio
MDH	Minimum Descent Height
MHz	Megahertz
ms	millisecond
MSS	Mobile Satellite Service
NASA	National Aeronautics and Space Administration
NBL	Noise Break-Lock
NOI	Notice Of Inquiry
NPA	Non-Precision Approach
NPRM	Notice of Proposed Rulemaking
NSE	Navigation System Error
NTIA	National Telecommunications and Information Administration
OEM	Original Equipment Manufacturer
OOK	On-Off Keying
OSM	Office of Spectrum Management
PDOP	Position Dilution Of Precision
PRF	Pulse Repetition Frequency
PROM	Programmable Read Only Memory
PTC	Positive Train Control
RAIM	Receiver Autonomous Integrity Monitoring
RMS	Root-Mean-Square
RNSS	Radionavigation Satellite Service
ROM	Read Only Memory
RTCA	RTCA, Inc.
RQT	Reacquisition Time
SPS	Standard Positioning Service
SU	Stanford University
SV	Space Vehicle
TSE	Total System Error
TSO	Technical Standard Order
USCG	United States Coast Guard
UWB	Ultrawideband
WAAS	Wide Area Augmentation System

SECTION 1.0
INTRODUCTION

1.1 BACKGROUND

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy. NTIA's responsibilities include establishing policies concerning spectrum assignments, allocation in use, and providing various departments and agencies with guidance to ensure that their conduct of telecommunication activities is consistent with these policies.[7] Accordingly, NTIA conducts technical studies and makes recommendations regarding telecommunication policies and presents Executive Branch views on telecommunications matters to the Congress, the Federal Communications Commission (FCC), and the public.

NTIA is responsible for managing the Federal Government's use of the radio frequency spectrum. The FCC is responsible for managing the spectrum used by the private sector, and state and local governments. In support of its responsibilities, the NTIA has undertaken numerous spectrum-related studies to assess spectrum utilization, examined the feasibility of reallocating spectrum used by the Federal Government or relocating Federal Government systems, identified existing or potential electromagnetic compatibility (EMC) problems between systems, provided recommendations for resolving any EMC conflicts, and recommended changes to promote efficient and effective use of the radio frequency spectrum and to improve Federal spectrum management procedures.

In February, 2001, NTIA released Special Publication 01-45, assessing the compatibility between ultrawideband (UWB) systems and Global Positioning System (GPS) receivers.[8] This publication was also submitted to the FCC for inclusion in the public record concerning revision of Part 15 of the FCC Rules.[9] This publication reported on measurement and analysis results obtained for two GPS receiver architectures (C/A code tracking and semi-codeless), and indicated ongoing efforts to measure and analyze the interference potential for two additional receivers (a C/A code tracking receiver employing multiple narrowly-spaced correlators, and a Technical Standard Order (TSO)-C129a compliant aviation receiver). This report serves as an addendum to NTIA Report 01-45, and presents the results obtained for the two remaining receivers, and also provides a comparison to other data sets that are on the public record.

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[7] NTIA, *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration (Jan. 2000 Edition with revisions).

[8] NTIA Special Publication 01-45, *Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers*, National Telecommunications and Information Administration, (Feb. 2001) (hereinafter "NTIA Report 01-45").

[9] *Revisions of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems,* Notice of Proposed Rulemaking, ET Docket No. 98-153, FCC 00-163 (rel. May 11, 2000) (hereinafter "UWB NPRM").

1.2 OBJECTIVE

The objective of this assessment was to define the maximum allowable UWB equivalent isotropically radiated power (EIRP)[10] levels that can be tolerated by GPS receivers used within various operational applications without causing degradation to their operations. These EIRP levels will then be compared to the existing Part 15 emission limits[11] to assess the applicability of these limits to UWB devices.

1.3 APPROACH

A two-part approach consisting of a measurement and an analysis component was adopted for this assessment. First, a measurement effort was undertaken to determine the interference threshold for different GPS receiver architectures for a set of UWB waveforms. Utilizing the measured GPS receiver interference thresholds, analyses were performed for various operational scenarios to determine the maximum allowable UWB EIRP level, in the radionavigation satellite service (RNSS) frequency bands, that can be tolerated by a GPS receiver before performance degradation is realized.

The measurement component of this assessment was conducted by NTIA's Institute for Telecommunication Sciences (ITS) and the analyses portion was performed by the NTIA Office of Spectrum Management (OSM). This document provides a description of the methods used and the results obtained from these measurements and analyses. A separate report, prepared by ITS, that presents the measured data in post-processed format and provides details of the measurement procedures and equipment used to acquire the data, is available and is referenced throughout this report.[12]

1.3.1 Measurement Approach

The first activity associated with this project was the development of a plan to guide the measurement of GPS receiver susceptibility to UWB signals. In the formulation of a measurement plan, NTIA considered a number of factors including which GPS receivers to

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[10] The computation of EIRP is in terms of the average power of the UWB signal for all cases considered in this report. This average power is based on root-mean-square (RMS) voltage.

[11] The existing Part 15 measurement procedure uses an average logarithm detector process and is not equivalent to measurements using an RMS detector process. *See* NTIA Special Publication 01-43, *Assessment of Compatibility Between Ultrawideband Devices and Selected Federal Systems* (Jan. 2001) (hereinafter "NTIA Report 01-43") at 2-1 for discussion of the differences in measuring average power versus log average power.

[12] NTIA Report 01-389, *Addendum to Report 01-384-Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems*, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (Oct. 2001) (hereinafter "ITS Report 01-389").

measure, what UWB signal parameters to examine, and what GPS receiver performance metrics and criteria to apply. Also as a part of the formulation of the measurement plan, a set of measurement procedures were developed with the intent that if followed, these procedures would lead to repeatable measurement results.

After the measurement plan was completed and made available to other Government agencies for review and comment, NTIA sought public comment in a notice published in the Federal Register.[13] The following seven parties submitted comments to the Federal Register notice:

- Air Transport Association
- ANRO Engineering, Inc.
- Multispectral Solutions, Inc.
- National Aeronautics and Space Administration (NASA) Glenn Research Center
- RAND Science and Technology Policy Institute
- Time Domain Corporation
- United States GPS Industry Council

NTIA considered the comments, made appropriate changes to the measurement plan, and provided a response for each commenter for the public record. The initial measurement plan, the Federal Register notice, the public comments received, and the NTIA responses to the comments can be obtained from the NTIA website or directly from NTIA/OSM upon request.

One of the immediate difficulties encountered in establishing a methodology for measuring the impact of UWB emissions to GPS receivers was the lack of documented performance criteria for GPS receivers intended for applications other than aviation. After researching available technical standards and other open literature, a set of criteria that was not application specific was adopted for assessing the performance of the GPS receivers in this measurement effort. The two performance criteria examined were "break-lock" and "reacquisition." Break-lock refers to the loss of signal lock between the GPS receiver and a GPS satellite. This condition occurs when an interfering signal reduces the carrier-to-noise density (C/N_0) ratio (i.e., an increase in the undesired signal level, N_0, relative to the desired signal level, C) to such an extent that the GPS receiver can no longer adequately determine the pseudorange (the initial/uncorrected measure of distance from a single GPS satellite to a receiver) for the given satellite signal. Within this measurement effort, the occurrence of a break-lock condition was as reported by the receiver. Depending on the receiver application, this condition could be a function of cycle slips, or a loss of carrier lock or phase lock. The reacquisition threshold refers to the UWB power level at which an abrupt increase from the nominal reacquisition time was observed.

To determine the impact on reacquisition time, the signal from the GPS satellite of interest

[13] National Telecommunications and Information Administration, Notice, Request for Comments on Global Positioning System/Ultrawideband Measurement Plan, Federal Register, Vol. 65, No. 157 (Aug. 14, 2000) at 49544.

was interrupted for 10 seconds and a 50-meter step in pseudorange was introduced. This was done to simulate a GPS-equipped vehicle passing behind a building or other obstacle in the satellite-to-receiver path, causing a temporary loss-of-lock between the GPS receiver and the satellite of interest. As the vehicle clears the obstacle and the satellite again becomes visible, the GPS receiver must be able to reacquire the lost satellite in the presence of UWB energy in a time consistent with that associated with no UWB energy present. In order to determine the maximum UWB level at which this can be accomplished, the UWB signal was reduced from the power level at which break-lock occurred until the receiver was able to reacquire the lost satellite in a time correspondent with the nominal receiver reacquisition time with no UWB signal present.

The UWB power level that results in receiver break-lock is not the preferred criterion for determining the interference threshold because it represents an extreme penalty to the performance of a GPS receiver. Thus, the interference threshold adopted for these measurements was the UWB signal level that resulted in an abrupt increase in the reacquisition time.[14] However, for some UWB signal permutations (e.g., those deemed to be CW-like signals), a statistical parameter such as reacquisition time could not be obtained due to limitations associated with the available test equipment (see discussion in Section 2.1.1 of this report). Initial reacquisition measurements for the narrowly-spaced correlator receiver architecture showed a two-level reacquisition effect. The receiver would either reacquire in a relatively short period of time (an actual reacquisition) or the receiver would not reacquire in the test time allotted for each reacquisition trial. This could indicate that the code acquisition search algorithm, as implemented in this receiver, was such that if code lock was not obtained within a very limited search window then the receiver was forced into a mode where a much broader acquisition strategy, requiring much more time, was used. Because of the uncertainty associated with this two level (bimodal) reacquisition effect, it was decided to not continue reacquisition measurements for the narrowly-spaced correlator receiver architecture. Thus, for the subsequent evaluation of the measured data, the break-lock interference threshold was used in those cases where a reacquisition threshold could not be determined.

The next challenge encountered was how to determine a representative sample of GPS receivers. Since GPS receivers are used in a myriad of applications, including navigation (aviation, space, maritime, rail, and vehicular), position determination (surveying, asset tracking, E-911), and timing (banking, power distribution, Internet synchronization), to name but a few, it is not feasible to attempt to measure a representative receiver from each possible application. Instead, NTIA decided to select candidate GPS receivers based upon the various available GPS receiver architectures. One receiver from each of three basic receiver architectures were identified for inclusion in the measurements: coarse acquisition (C/A)-code tracking receivers,

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[14] It should be noted that initial acquisition of a GPS satellite signal is an even more stringent performance criterion for GPS operations. However, this is an extremely difficult criteria to measure and is also highly dependent on manufacturer-specific receiver algorithms. Therefore, it was not considered feasible for use in this effort. A 6 dB factor is often used in GPS interference analyses to account for the greater sensitivity of initial satellite acquisition over the satellite tracking mode of operation.

which make up a significant share of the GPS receivers in use today, semi-codeless receivers used in low-dynamic applications requiring high precision (e.g., surveying and reference stations), and C/A-code tracking receivers employing multiple, narrowly-spaced correlators to enhance accuracy and mitigate the effects of multipath. These three GPS receiver architectures encompass most of the existing civil GPS applications.[15] In order to address particular concerns related to an aviation use of GPS, a TSO-C129a compliant aviation receiver (as currently used in en-route and non-precision approach) was also included. The assessment of potential UWB interference to aviation precision approach operations is addressed in a Department of Transportation sponsored study and therefore is not considered in the scope of this effort. Measurement and analysis results have already been presented for the C/A code tracking and the semi-codeless receivers in NTIA Report 01-45. This report focuses on the C/A code tracking receiver employing multiple narrowly-spaced correlators, and the TSO-C129a compliant aviation receiver.

A third question to be addressed concerned defining the UWB signal(s) to be generated. Since there was little information revealed in the public record with regard to the proposed signal structure of UWB devices, no single UWB signal structure could be identified that would be representative of a typical UWB transmission system. Therefore, NTIA identified 32 distinct UWB signal structures as being representative of those expected to be used in UWB applications. Those UWB signal permutations identified for examination considered various pulse repetition frequencies (PRFs), modulation schemes, and gating percentages. Each combination of the UWB signal parameters shown in Table 1-1 was used to represent a distinct UWB signal permutation.

TABLE 1-1. UWB Permutations Considered in Measurements

UWB Parameter	Parameter Value
PRF	0.1, 1, 5, and 20 MHz (nominal)
Modulation	None, OOK, 2% relative dither, 50% absolute dither
Gating	100% (always on), 20% (4 ms on, 16 ms off)

The PRF defines the number of pulses transmitted per unit time (one second). The PRF effects the spectral line magnitude and spacing, and the percentage of time that pulses are present.

Gating refers to the process of distributing pulses in bursts by employing a programmed set of periods where the UWB transmitter is turned on or off for a period of pulses. For the measurements performed in this assessment, the gated UWB signal utilized a scheme where a burst of pulses lasting 4 milliseconds (ms) was followed by a 16 ms period when no pulses were transmitted. This is referred to as 20% gating, because the UWB pulses are transmitted 20% of the time. The signal permutations depicted within this report as 100% gating, define a signal where pulses are transmitted 100% of the time.

[15] This effort did not consider the potential impact of UWB operations to military GPS receivers.

On-Off Keying (OOK) refers to the process of selectively turning off or eliminating individual pulses to represent data bits.

Dithering refers to the random or pseudo-random spacing of the pulses. Two forms of dithered UWB signals were considered in this effort. These are an absolute referenced dither, where the pulse period is varied in relation to the absolute clock, and a relative referenced dither, where the pulse spacing is varied relative to the previous pulse. The PRF of a relative dithered pulse train is equal to the reciprocal of the mean pulse period. Dithering of the pulses in the time domain spreads the spectral line content of a UWB signal in the frequency domain making the signal appear more noise-like.

A GPS satellite simulator was used to provide simulated GPS signals from a four satellite constellation (five satellites were used for the TSO-C129a compliant receiver in order to meet receiver autonomous integrity monitoring (RAIM) requirements) based on ephemeris data taken from an actual GPS constellation present on December 16, 1999. In the test constellation, one satellite was located at or near the zenith while the remaining three satellites were positioned near the horizon. The GPS receiver channel processing the signal from the near-zenith satellite was monitored for these measurements. This satellite was selected as the satellite to monitor because it has the least Doppler shift during the duration of the measurements. For the measurements performed on the C/A-code receiver, the simulator power representing the near-zenith satellite was set to the minimum specification level of -160 dBW at the GPS receiver input.[16] The simulator power representing the remaining three satellites was set 5 dB higher (-155 dBW at the GPS receiver input). The higher power level was used for the remaining satellites so that a break-lock condition would not occur for these signals prior to break-lock of the monitored signal. The value of 5 dB was selected so that UWB power increments of 3 dB could be used to induce break-lock only on the receiver channel being monitored. All of the conducted measurements in this effort were performed over a 55-minute evolution of the constellation.
The constellation was then reset for the subsequent test condition (e.g., another UWB signal permutation). More detailed information on this test constellation is presented in ITS Report 01-384.[17]

A broadband noise signal was generated using a noise diode to represent the noise contribution from the cross-correlation phenomenon associated with the use of the relatively short Gold Codes in the GPS C/A signal. This cross-correlation noise arises because within a GPS receiver channel, the signals generated from GPS satellites other than the one being monitored by

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[16] Global Positioning System Standard Positioning Service Signal Specification, 2nd Edition, GPS NAVSTAR (June 2, 1995) at 18.

[17] NTIA/ITS Report 01-384, *Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems*, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (Feb. 2001).

that channel, appear as undesired noise. This phenomenon is well documented in the open literature and the value used in this analysis is based upon work done within the International Telecommunication Union-Radiocommunications Sector (ITU-R).[18] This broadband noise was input to the GPS receiver at a level of -93 dBm/20 MHz (as derived for the minimum C/N_0 of 34 dB-Hz identified in the ITU-R work) in the measurements of the GPS receiver employing multiple narrowly-spaced correlators and the TSO-C129a compliant receiver.

Each UWB signal permutation was generated and combined with the simulated GPS satellite signals, and the broadband noise. The combined signal was injected into the GPS receiver at the antenna input. The UWB power level was increased until either the receiver broke lock with the satellite of interest or until the maximum available output power level from the UWB generator was reached. Plots of GPS receiver performance criteria (e.g., break-lock and reacquisition interference levels) were produced for each UWB signal permutation measured. From these plots, the UWB average power level wherein the performance criteria was realized was determined from these plots.

Both the measurement plan and ITS Report 01-384 contain more detail on these measurement procedures, including information on the measurement equipment used, test set-ups, and calibration procedures. These are available on the NTIA and ITS websites or directly from NTIA/OSM upon request.

1.3.2 Analysis Approach

In order to calculate the maximum allowable EIRP, a source-path-receiver analysis must be performed. The basic parameters that must be defined for this type of analysis are the receiver interference threshold, the source output power and antenna gain, the propagation path between the transmitter and the receiver, and the antenna gain of the receiver in the direction of the source transmitter. The data obtained from the ITS measurements defines the interference threshold level at the input of the GPS receiver as a function of UWB signal structure (e.g., power, PRF, modulation scheme) for each of the GPS receiver architectures examined. The UWB output power and antenna gain combined define the EIRP, which is the variable to be determined from the analysis. In order to make reasonable assumptions regarding the remaining values needed for the analysis, information regarding how the transmitter and receiver can interact within their operating environment is necessary. Collectively, this information defines an operational scenario, which establishes how close the two systems may come to one another under actual operating conditions, and the likely orientation of the antennas. This information is then used to compute the propagation loss and the GPS antenna gain in the direction of the UWB transmitting device. The operational scenario can also be used to determine the applicability of factors such as building attenuation, aggregate allowance, and safety margins.

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[18] Recommendation ITU-R M.1477, *Technical and Performance Characteristics of Current and Planned RNSS (Space-to-Earth) and ARNS Receivers to be Considered in Interference Studies in the Band 1559-1610 MHz*, at Section 3.2 (hereinafter "ITU-R M.1477").

NTIA hosted a series of public meetings to develop operational scenarios to be considered for GPS and envisioned UWB applications. The meetings were announced in the Federal Register on August 31, 2000.[19] Participation was encouraged within the UWB and GPS communities and among representatives of the interested Federal Agencies. Multispectral Solutions Inc., the National Oceanic and Atmospheric Administration/National Ocean Service/National Geodetic Survey, Time Domain Corporation, the United States Coast Guard (USCG), the U.S. GPS Industry Council, and NTIA submitted pertinent documents. Specific proposals for operational scenarios to be considered included GPS receivers used in the following applications: terrestrial[20] (e.g., public safety applications such as cellular phone embedded E-911 and emergency response vehicle navigation, geographic information systems, precision machine control, and general operations); maritime navigation (in constricted waterways, harbors, docking, and lock operations); railway operations (positive train control); surveying; and aviation (en-route navigation and non-precision approach). The input received at these meetings was used to develop the operational scenarios that were then used in the analyses documented in this report. These scenarios do not represent all possible applications of GPS, however, they do represent a reasonable bound on the parameters necessary to perform the broadly based analyses. For example, the separation distances represented in these scenarios range from a minimum of 2 meters for the embedded E-911 scenario, to a maximum of approximately 300 meters (1000 feet) for the en-route aviation scenario.

An analysis was also performed to determine the distance separations that are required to preclude interference to the different GPS receiver architectures, if the UWB device is operating at the current Part 15 level of -71.3 dBW/MHz. The measured UWB interference thresholds for both single-entry and multiple-entry UWB device interactions were considered.

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[19] National Telecommunications and Information Administration, Notice of Public Meeting to Develop Global Positioning System/Ultrawideband Operational Scenarios, Federal Register Vol. 65, No. 170 (Aug. 31, 2000) at 52989 (hereinafter "NTIA Notice").

[20] Within the context of this report, terrestrial refers to land-based operations.

1.4 COMPARISON TO OTHER MEASUREMENT EFFORTS

This report also compares the results of the NTIA measurements and analyses with those collected and performed by other parties with interests in the current FCC proceeding. Specifically, the NTIA measurement data were compared with data collected by Stanford University (SU) under contract to the Department of Transportation,[21] and with the data collected by the University of Texas Applied Research Laboratory (ARL:UT)[22] which has been analyzed by Johns Hopkins University/Applied Physics Laboratory (JHU/APL)[23] and the Department of Defense (DoD) Joint Spectrum Center (JSC).[24] These comparisons were conducted in order to assess consistency and agreement in the data sets available in the public record.

[21] Stanford University, *Potential Interference to GPS from UWB Transmitters Phase II Test Results* (March 16, 2001) (hereinafter "Stanford Report").

[22] University of Texas at Austin Applied Research Laboratories, *Final Report Data Collection Campaign for Measuring UWB/GPS Compatibility Effects* (Feb. 26, 2001).

[23] Johns Hopkins University/Applied Physics Laboratory, *Final Report UWB-GPS Compatibility Analysis Project* (March 8, 2001) (hereinafter "JHU/APL Report").

[24] JSC-CR-01-036, *Observations Regarding Test Data Collected at University of Texas Applied Research Laboratory On GPS Receivers Operating in the Presence of Ultrawideband Emissions*, Department of Defense Joint Spectrum Center (May 2001) (hereinafter "JSC Report").

SECTION 2.0
MEASUREMENT RESULTS

2.1 SUMMARY OF ANALYSIS OF MEASUREMENT RESULTS

As explained in NTIA Report 01-45, measured data and analysis results for the narrowly-spaced correlator and the TSO-C129a compliant GPS receivers are provided in this addendum to that report.[25] This section of the addendum report presents a summary and analysis of the data collected by ITS on the narrowly-spaced correlator and the TSO-C129a compliant GPS receivers. As appropriate, data from NTIA Report 01-45 on the C/A code receiver will also be considered in this analysis. The three GPS receivers considered use the GPS C/A code L1 signal to determine a navigation solution. This analysis includes a comparison of the measured data sets across the three C/A code receivers to gain insight into the variability, reliability, and accuracy of the measured data.

The NTIA data analyzed herein was extracted from the measurement plots documented in measurement reports published by ITS.[26] There are two methods for performing radio interference measurements; those where the desired and undesired signal are conducted into the test receiver via a cable connection, and those where the signals are radiated into the test receiver via the propagation medium and antenna assembly. In this effort, conducted measurements were used to evaluate the performance of the GPS receivers.

As part of this analysis, NTIA measured receiver susceptibility values are also compared to those from the GPS/UWB measurements carried out by SU and by ARL:UT. Because of some differences in test procedures, interference criteria and UWB signals tested, only a limited number of tests were similar. Measured susceptibility data are compared in those cases of similar test conditions.

2.2 SINGLE-ENTRY CONDUCTED MEASUREMENTS

The data in Tables 2-1 through 2-3 summarize the receiver susceptibility measurements, collected by ITS, used in this analysis. The data for the C/A code receiver in Table 2-1 is the same information that was presented in NTIA Report 01-45 and is included here for completeness.[27] The table entries correspond to the maximum tolerable UWB interference levels (referenced to the receiver input) associated with the GPS receiver performance criteria adopted for this program. These points are extracted from the data curves presented in the ITS Reports.

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[25] NTIA Report 01-45 at v.

[26] ITS Report 01-384 at Appendix F; ITS Report 01-389 at Appendix B.

[27] NTIA Report 01-45 at 2-3.

Although each individual data plot is not reproduced within this report, a representative plot is provided in Figure 2-1 to illustrate how the data points associated with the GPS receiver performance criteria are obtained.

The break-lock and reacquisition threshold data points are taken from the ITS plots as illustrated in Figure 2-1. The break-lock level is represented by the heavy vertical line in Figure 2-1. This value is read directly from the scale on the horizontal axis, and has the units of dBm/20 MHz. There are two curves which represent reacquisition data. The lower curve is the mean reacquisition time for the successful reacquisition measurements over 10 trials. The upper curve is the maximum time for all successful reacquisition measurements within these 10 trials. The interference threshold level for the reacquisition performance criterion is determined by locating the point on the lower curve (mean reacquisition time) corresponding to a sharp increase in the reacquisition time. The threshold level is then read directly from the scale on the horizontal axis, and has the units dBm/20 MHz. The power levels are average values for all single-entry UWB measurements except for the 20% gated signal[28] where the level represents the average power for the time when the signal is gated on. In a limited number of cases, the reacquisition threshold level that is determined by these methods is at a higher interference signal level than the break-lock level. This is attributable to the break-lock measurement being carried out in conjunction with measurements such as pseudo-range error, accumulated delta-range (ADR) and code-minus-carrier (CMC) error. Certain of these, other than break-lock, measurements require a large sample size for each input UWB signal level to define statistically significant test data. If a break-lock condition occurs at any time during the longer sampling period, break-lock is declared. However, in a limited number of cases, the break-lock condition did not occur during the shorter time period used in the reacquisition measurements. In these instances (when the measured break-lock point was at a lower power than reacquisition), the reacquisition level threshold is set equal to the break-lock threshold.

The data collected by ITS is represented in Tables 2-1 through 2-3. These tables list the break-lock and reacquisition interference threshold levels for each UWB permutation measured. The tables are organized according to the GPS receiver architectures considered in the analysis.

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[28] 100% gating is a continuous uninterrupted PRF, 20% gating is a pulse train that is on for 4 ms in a 20 ms period.

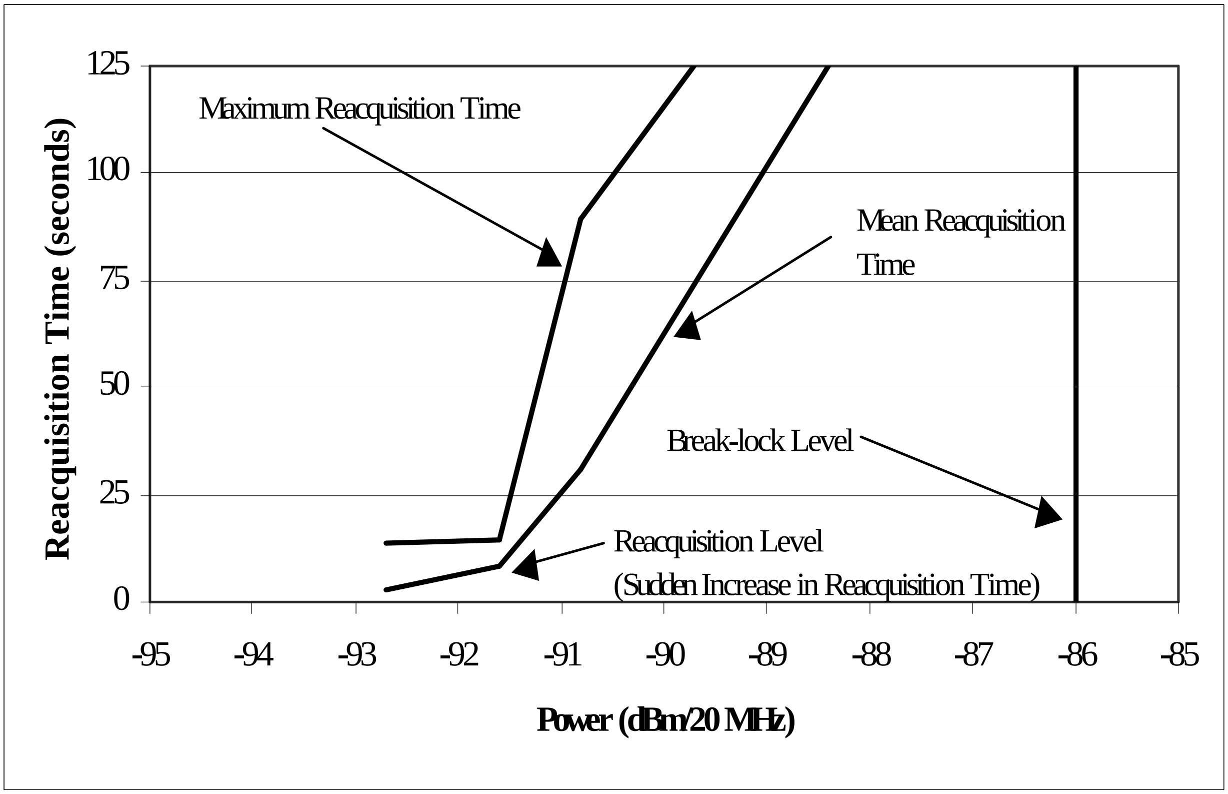

Figure 2-1. Illustration of Power Levels Resulting in Break-lock and Reacquisition

For those UWB signal permutations that produced spectral lines within the GPS receiver passband, the measurement of a statistical parameter such as reacquisition time, or pseudo-range error was not reliable or repeatable given the nature of the moving GPS constellation. To obtain 10 trials of reacquisition time can take as long as 20 minutes. During this time period, the statistics of GPS performance are non-stationary because the Doppler shift of the GPS C/A-Code lines causes them to, at some point, align with the UWB spectral lines. A GPS simulator with the capability of setting the Doppler shift to zero would facilitate collection of the reacquisition data for those UWB signal permutations containing spectral line components. The simulator used in this measurement effort did not have this capability. For this reason, entries in Tables 2-1 through 2-3 which contain an “x” indicate that the performance metric could not be measured with statistical reliability, and therefore is not reported.

Initial reacquisition measurements for the narrowly-spaced correlator receiver showed a two level reacquisition effect. The GPS receiver would either reacquire in a relatively short period of time (an actual reacquisition) or the receiver would not reacquire in the test time allotted (120 seconds) for each reacquisition trial. This could indicate the code acquisition search algorithm, as implemented in this receiver, was such that if code lock was not obtained within a very limited search window then the receiver was forced into a mode where a much broader acquisition strategy, requiring much more time, was used. Because of the uncertainty associated with reacquisition, it was decided to not continue reacquisition measurements for the narrowly-spaced correlator receiver. Thus, only break-lock levels are reported for this receiver in Table 2-2.

Other entries in these tables contain a power level in brackets. This indicates that for some of the UWB signal permutations, the total available power from the UWB simulator was used without resulting in a loss of lock or an impact on reacquisition time for the GPS receiver and the satellite of interest.

TABLE 2-1. Measurement Results for C/A-Code Receiver

Interfering Signal Structure	Interference Susceptibility Levels* (dBm/20 MHz)	
	Break-Lock	Reacquisition
Broadband Noise	-87	-91.5
0.1 MHz PRF, No Mod, 100% Gate	-70	x
0.1 MHz PRF, No Mod, 20% Gate	[-57]	x
0.1 MHz PRF, OOK, 100% Gate	[-60]	x
0.1 MHz PRF, OOK. 20% Gate	[-59.5]	x
0.1 MHz PRF, 50% abs, 100% Gate	[-57]	[-57]
0.1 MHz PRF, 50% abs, 20% Gate	[-56.5]	[-56.5]
0.1 MHz PRF, 2% rel, 100% Gate	[-57]	[-57]
0.1 MHz PRF, 2% rel, 20% Gate	[-57]	[-57]
1 MHz PRF, No Mod, 100% Gate	-100.5	x
1 MHz PRF, No Mod, 20% Gate	[-47.5]	x
1 MHz PRF, OOK, 100% Gate	-78	x
1 MHz PRF, OOK, 20% Gate	[-51]	x
1 MHz PRF, 50% abs, 100% Gate	[-47]	-70
1 MHz PRF, 50% abs, 20% Gate	[-47.5]	[-47.5]
1 MHz PRF, 2% rel, 100% Gate	[-47.5]	-88
1 MHz PRF, 2% rel, 20% Gate	[-47.5]	-47
5 MHz PRF, No Mod, 100% Gate	-108.5	x
5 MHz PRF, No Mod, 20% Gate	-94.5	x
5 MHz PRF, OOK, 100% Gate	-104.5	x
5 MHz PRF, OOK, 20% Gate	-90.5	x
5 MHz PRF, 50% abs, 100% Gate	-86.5	-94
5 MHz PRF, 50% abs, 20% Gate	[-40]	-55
5 MHz PRF, 2% rel, 100% Gate	-85.5	-93.5
5 MHz PRF, 2% rel, 20% Gate	[-39]	[-39]
20 MHz PRF, No Mod, 100% Gate	-115	x
20 MHz PRF, No Mod, 20% Gate	-102	x
20 MHz PRF, OOK, 100% Gate	-111.5	x
20 MHz PRF, OOK, 20% Gate	-99.5	x
20 MHz PRF, 50% abs, 100% Gate	-89.5	-95
20 MHz PRF, 50% abs, 20% Gate	[-34]	-85
20 MHz PRF, 2% rel, 100% Gate	-87	-93
20 MHz PRF, 2% rel, 20% Gate	[-33]	-83

* No measurable effect up to the power level shown in brackets.

TABLE 2-2. Measurement Results for the Narrowly-Spaced Correlator Receiver

Interfering Signal Structure	Interference Susceptibility Levels* (dBm/20 MHz)
	Break-Lock
Broadband Noise	-89.2
0.1 MHz PRF, No Mod, 100% Gate	[-57.2]
0.1 MHz PRF, No Mod, 20% Gate	[-57.2]
0.1 MHz PRF, OOK, 100% Gate	[-60.2]
0.1 MHz PRF, OOK. 20% Gate	[-60.3]
0.1 MHz PRF, 50% abs, 100% Gate	[-57.1]
0.1 MHz PRF, 50% abs, 20% Gate	[-57.2]
0.1 MHz PRF, 2% rel, 100% Gate	[-57.1]
0.1 MHz PRF, 2% rel, 20% Gate	[-57.2]
1 MHz PRF, No Mod, 100% Gate	-100.9
1 MHz PRF, No Mod, 20% Gate	[-44.9]
1 MHz PRF, OOK, 100% Gate	-93.9
1 MHz PRF, OOK, 20% Gate	[-47.9]
1 MHz PRF, 50% abs, 100% Gate	-62.9
1 MHz PRF, 50% abs, 20% Gate	[-44.9]
1 MHz PRF, 2% rel, 100% Gate	[-44.8]
1 MHz PRF, 2% rel, 20% Gate	[-44.8]
5 MHz, No Mod, 100% Gate	-108.7
5 MHz, No Mod, 20% Gate	-95.8
5 MHz, OOK, 100% Gate	-106.7
5 MHz, No OOK, 20% Gate	-88.8
5 MHz PRF, 50% abs, 100% Gate	-84.7
5 MHz PRF, 50% abs, 20% Gate	[-38.6]
5 MHz PRF, 2% rel, 100% Gate	-84.6
5 MHz PRF, 2% rel, 20% Gate	[-38.6]
20 MHz PRF, No Mod, 100% Gate	-116.1
20 MHz PRF, No Mod, 20% Gate	-103
20 MHz PRF, OOK, 100% Gate	-113.5
20 MHz PRF, OOK, 20% Gate	-98.5
20 MHz PRF, 50% abs, 100% Gate	-90.6
20 MHz PRF, 50% abs, 20% Gate	-50.6
20 MHz PRF, 2% rel, 100% Gate	-92.5
20 MHz PRF, 2% rel, 20% Gate	-72.3

* No measurable effect up to the power level shown in brackets.

TABLE 2-3. Measurement Results for the TSO-C129a Compliant Receiver

Interfering Signal Structure	Interference Susceptibility Levels* (dBm/20 MHz)	
	Break-Lock	Reacquisition
Broadband Noise	-92	-93
0.1 MHz PRF, No Mod, 100% Gate	-74.9	-74.9
0.1 MHz PRF, No Mod, 20% Gate	[-56.9]	[-56.9]
0.1 MHz PRF, OOK, 100% Gate	[-60.1]	[-60.1]
0.1 MHz PRF, OOK. 20% Gate	[-60]	[-60]
0.1 MHz PRF, 50% abs, 100% Gate	-72	-72
0.1 MHz PRF, 50% abs, 20% Gate	[-56.9]	[-56.9]
0.1 MHz PRF, 2% rel, 100% Gate	[-54.9]	[-54.9]
0.1 MHz PRF, 2% rel, 20% Gate	[-57]	[-57]
1 MHz PRF, No Mod, 100% Gate	-97.6	x
1 MHz PRF, No Mod, 20% Gate	-89.6	x
1 MHz PRF, OOK, 100% Gate	-94.6	x
1 MHz PRF, OOK, 20% Gate	-80.6	x
1 MHz PRF, 50% abs, 100% Gate	-96.6	-99
1 MHz PRF, 50% abs, 20% Gate	-89.6	-89.6
1 MHz PRF, 2% rel, 100% Gate	-97.6	-98.5
1 MHz PRF, 2% rel, 20% Gate	-83.6	-83.6
5 MHz PRF, No Mod, 100% Gate	-101.4	x
5 MHz PRF, No Mod, 20% Gate	-92.4	x
5 MHz PRF, OOK, 100% Gate	-99.4	x
5 MHz PRF, OOK, 20% Gate	-89.5	x
5 MHz PRF, 50% abs, 100% Gate	-98.3	-99
5 MHz PRF, 50% abs, 20% Gate	-88.4	-92
5 MHz PRF, 2% rel, 100% Gate	-98.2	-100
5 MHz PRF, 2% rel, 20% Gate	-89.3	-92.5
20 MHz PRF, No Mod, 100% Gate	-109.8	x
20 MHz PRF, No Mod, 20% Gate	-103.9	x
20 MHz PRF, OOK, 100% Gate	-105.2	x
20 MHz PRF, OOK, 20% Gate	-95.2	x
20 MHz PRF, 50% abs, 100% Gate	-97.4	-98
20 MHz PRF, 50% abs, 20% Gate	-86.4	-90.5
20 MHz PRF, 2% rel, 100% Gate	-95.2	-98
20 MHz PRF, 2% rel, 20% Gate	-87.2	-90

* No measurable effect up to the power level shown in brackets.

2.3 ANALYSIS OF NTIA RECEIVER SUSCEPTIBILITY MEASUREMENTS

The analysis of the measured results contained in Tables 2-1 through 2-3 initially involves classifying the UWB interference effect on the GPS receiver for each UWB signal permutation considered as either pulse-like, CW-like, or noise-like. The procedures for making these classifications are discussed in detail in Section 2.2.2 of NTIA Report 01-45 [29] and the results of this classification are shown in Tables 2-4 through 2-6 for each of the three GPS receivers. It should be noted that the bandwidth of the band limiting filters of the narrowly spaced correlator receiver is wider (approximately 16 MHz) than the C/A code receiver (approximately 10 MHz) and the bandwidth for the TSO-C129a receiver is narrower (approximately 2 MHz). The ramifications of this are that the cases judged to be pulse-like for the TSO-C129a receiver are somewhat different than those for the other two receivers. Specifically, most of the 1 MHz PRF UWB signal permutations that are classified as having a pulse-like interference effect, for the narrowly spaced correlator and C/A code receivers, show either a CW-like or noise-like interference effect for the TSO-C129a receiver. This is because the impulse response of the TSO-C129a receiver band limiting filter is lengthening the individual impulses of the 1 MHz PRF UWB signal permutations to the point where the output of the filter is approaching a continuum in the time domain as opposed to a series of individual pulses.

Tables 2-4 through 2-6 also contain adjusted interference threshold data to convert the noise-like interference levels to dBW/MHz and the CW-like interference levels to the power in a single spectral line expressed in dBW. The procedures followed to make these adjustments are also explained in Section 2.2.2 of NTIA Report 01-45.[30] The exception to the previous adjustments was that the interference levels in Tables 2-4 through 2-6 are relative to a GPS signal level of -130 dBm rather than -134.5 dBm as used in NTIA Report 01-45. Also, for the noise-like interference cases the power of the UWB signal is added to the -93 dBm/20 MHz noise signal that was also input to the GPS receiver. This is done to facilitate the data analysis and the comparison to data measured in the other measurement efforts.

It should be noted that the adjusted interference threshold values (Tables 2-4 through 2-6) used here in this analysis and the median values derived later in this section are not always numerically the same threshold values used in Section 3 of this report. However, the threshold values of Section 2 and Section 3 are all derived directly from the same measured data (Tables 2-2 through 2-4). These numerical differences are brought about by a need to use differing reference units to facilitate the analyses in each section.

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[29] NTIA Report 01-45 at 2-9.

[30] *Id.* at 2-12.

TABLE 2-4. Single-Entry UWB Interference Effects and Adjusted Interference Thresholds for the C/A Code Receiver

Interfering Signal Structure	Category Of Interfering Signal Effect	Adjusted Interference Threshold	
		Break-Lock	Reacquisition
Broadband Noise	Noise-Like	-130 dBW/MHz	-134.5 dBW/MHz
0.1 MHz PRF, No Mod, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, No Mod, 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, OOK, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, OOK. 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x	x
1 MHz PRF, No Mod, 100% Gate	CW-Like	-143.7 dBW	x
1 MHz PRF, No Mod, 20% Gate	Pulse-Like	x	x
1 MHz PRF, OOK, 100% Gate	Pulse-Like	x	x
1 MHz PRF, OOK, 20% Gate	Pulse-Like	x	x
1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	x	x
1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x	x
1 MHz PRF, 2% rel, 100% Gate	Pulse-Like*	x	-129.8 dBW/MHz
1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x	x
5 MHz PRF, No Mod, 100% Gate	CW-Like	-145.5 dBW	x
5 MHz PRF, No Mod, 20% Gate	CW-Like	-145.5 dBW	x
5 MHz PRF, OOK, 100% Gate	CW-Like	-144.5 dBW	x
5 MHz PRF, OOK, 20% Gate	CW-Like	-144.5 dBW	x
5 MHz PRF, 50% abs, 100% Gate	Noise-Like	-128.6 dBW/MHz	-133.5 dBW/MHz
5 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x	x
5 MHz PRF, 2% rel, 100% Gate	Noise-Like	-127.8 dBW/MHz	-133.2 dBW/MHz
5 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x	x
20 MHz PRF, No Mod, 100% Gate	CW-Like	-145 dBW	x
20 MHz PRF, No Mod, 20% Gate	CW-Like	-146 dBW	x
20 MHz PRF, OOK, 100% Gate	CW-Like	-144.5 dBW	x
20 MHz PRF, OOK, 20% Gate	CW-Like	-146.5 dBW	x
20 MHz PRF, 50% abs, 100% Gate	Noise-Like	-130.9 dBW/MHz	-133.9 dBW/MHz
20 MHz PRF, 50% abs, 20% Gate	Pulse-Like*	x	-132.5 dBW/MHz
20 MHz PRF, 2% rel, 100% Gate	Noise-Like	-129 dBW/MHz	-133 dBW/MHz
20 MHz PRF, 2% rel, 20% Gate	Pulse-Like*	x	-131.2 dBW/MHz

* These UWB parameter sets were judged to cause pulse-like interference for break-lock, which was in keeping with the measured data that showed the GPS receiver did not break-lock with maximum available UWB signal power. However, reacquisition data was obtained for these cases. These cases were categorized as noise-like to compute the adjusted thresholds as they involved dithered signals which showed noise-like spectra in the amplitude probability distribution and spectrum analyzer measurements of the UWB signals.

TABLE 2-5. Single-Entry UWB Interference Effects and Adjusted Interference Thresholds for the Narrowly-Spaced Correlator Receiver

Interfering Signal Structure	Category Of Interfering Signal Effect	Adjusted Interference Threshold
		Break-Lock
Broadband Noise	Noise-Like	-132.2 dBW/MHz
0.1 MHz PRF, No Mod, 100% Gate	Pulse-Like	x
0.1 MHz PRF, No Mod, 20% Gate	Pulse-Like	x
0.1 MHz PRF, OOK, 100% Gate	Pulse-Like	x
0.1 MHz PRF, OOK. 20% Gate	Pulse-Like	x
0.1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	x
0.1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x
0.1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	x
0.1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x
1 MHz PRF, No Mod, 100% Gate	CW-Like	-144.1 dBW
1 MHz PRF, No Mod, 20% Gate	Pulse-Like	x
1 MHz PRF, OOK, 100% Gate	CW-Like	-139.9 dBW
1 MHz PRF, OOK, 20% Gate	Pulse-Like	x
1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	x
1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x
1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	x
1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x
5 MHz PRF, No Mod, 100% Gate	CW-Like	-145.7 dBW
5 MHz PRF, No Mod, 20% Gate	CW-Like	-146.6 dBW
5 MHz PRF, OOK, 100% Gate	CW-Like	-146.7 dBW
5 MHz PRF, OOK, 20% Gate	CW-Like	-142.6 dBW
5 MHz PRF, 50% abs, 100% Gate	Noise-Like	-127.1 dBW/MHz
5 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x
5 MHz PRF, 2% rel, 100% Gate	Noise-Like	-127 dBW/MHz
5 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x
20 MHz PRF, No Mod, 100% Gate	CW-Like	-146.1 dBW
20 MHz PRF, No Mod, 20% Gate	CW-Like	-146.9 dBW
20 MHz PRF, OOK, 100% Gate	CW-Like	-146.5 dBW
20 MHz PRF, OOK, 20% Gate	CW-Like	-145.4 dBW
20 MHz PRF, 50% abs, 100% Gate	Noise-Like	-131.6 dBW/MHz
20 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x
20 MHz PRF, 2% rel, 100% Gate	Noise-Like	-132.7 dBW/MHz
20 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x

TABLE 2-6. Single-Entry UWB Interference Effects and Adjusted Interference Thresholds for the TSO-C129a Compliant Receiver

Interfering Signal Structure	Category Of Interfering Signal Effect	Adjusted Interference Threshold	
		Break-Lock	Reacquisition
Broadband Noise	Noise-Like	-135 dBW/MHz	-136 dBW/MHz
0.1 MHz PRF, No Mod, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, No Mod, 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, OOK, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, OOK. 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	x	x
0.1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	x	x
0.1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	x	x
1 MHz PRF, No Mod, 100% Gate	CW-Like	-140.8 dBW	x
1 MHz PRF, No Mod, 20% Gate	CW-Like	-146.7 dBW	x
1 MHz PRF, OOK, 100% Gate	CW-Like	-140.8 dBW	x
1 MHz PRF, OOK, 20% Gate	CW-Like	-140.7 dBW	x
1 MHz PRF, 50% abs, 100% Gate	Noise-Like	-134.4 dBW/MHz	-135 dBW/MHz
1 MHz PRF, 50% abs, 20% Gate	Noise-Like	-134.4 dBW/MHz	-134.4 dBW/MHz
1 MHz PRF, 2% rel, 100% Gate	Noise-Like	-134.7 dBW/MHz	-134.9 dBW/MHz
1 MHz PRF, 2% rel, 20% Gate	Noise-Like	-131.6 dBW/MHz	-131.6 dBW/MHz
5 MHz PRF, No Mod, 100% Gate	CW-Like	-138.4 dBW	x
5 MHz PRF, No Mod, 20% Gate	CW-Like	-143.2 dBW	x
5 MHz PRF, OOK, 100% Gate	CW-Like	-139.4 dBW	x
5 MHz PRF, OOK, 20% Gate	CW-Like	-143.3 dBW	x
5 MHz PRF, 50% abs, 100% Gate	Noise-Like	-134.9 dBW/MHz	-135 dBW/MHz
5 MHz PRF, 50% abs, 20% Gate	Noise-Like	-134 dBW/MHz	-135 dBW/MHz
5 MHz PRF, 2% rel, 100% Gate	Noise-Like	-134.9 dBW/MHz	-135.2 dBW/MHz
5 MHz PRF, 2% rel, 20% Gate	Noise-Like	-134.3 dBW/MHz	-135.1 dBW/MHz
20 MHz PRF, No Mod, 100% Gate	CW-Like	-139.8 dBW	x
20 MHz PRF, No Mod, 20% Gate	CW-Like	-147.8 dBW	x
20 MHz PRF, OOK, 100% Gate	CW-Like	-138.2 dBW	x
20 MHz PRF, OOK, 20% Gate	CW-Like	-142.1 dBW	x
20 MHz PRF, 50% abs, 100% Gate	Noise-Like	-134.7 dBW/MHz	-134.8 dBW/MHz
20 MHz PRF, 50% abs, 20% Gate	Noise-Like	-133.2 dBW/MHz	-134.7 dBW/MHz
20 MHz PRF, 2% rel, 100% Gate	Noise-Like	-134 dBW/MHz	-134.8 dBW/MHz
20 MHz PRF, 2% rel, 20% Gate	Noise-Like	-133.6 dBW/MHz	-134.5 dBW/MHz

The data shown in Tables 2-4 through 2-6 is analyzed for consistency by determining the median along with the range of the data for break-lock and reacquisition threshold levels for noise-like and CW-like interference effects for each GPS receiver.[31] The data analysis was not applied to the pulse-like interference effects because, in most cases, the measured UWB level was the maximum power available from the UWB signal generator not the level that degraded GPS receiver performance. For the noise-like data analysis the broad-band noise measurements are included as part of the data set. The results of this analysis are shown in Table 2-7. The overall median for the combined data for the three receivers is shown in Table 2-8. As shown in Tables 2-7 and 2-8, most of the median threshold values for the individual receivers are consistent with one another and the data ranges associated with each median shows that the individual interference threshold values vary over a small range relative to the median values. The median threshold levels for the TSO-C129a receiver show this receiver to be slightly more robust, for CW-like interference effects, than the C/A code and narrowly-spaced correlator receivers. However, the data ranges are consistent. The overall median information is used for comparison with other measured data and with existing interference protection limits as discussed in the following sections.

TABLE 2-7. Median and Range of Data Values for the Interference Thresholds

Data Set	**Interference Threshold Values**		
	C/A Code	**Narrowly-Spaced Correlator**	**TSO-C129a Compliant**
Median for CW-Like Interference (Break-Lock)	-145 dBW	-145.9 dBW	-140.8 dBW
Range of Data	-143.7 to -146.5 dBW	-139.9 to -147 dBW	-138.2 to -147.8 dBW
Median for Noise-Like Interference (Break-Lock)	-129 dBW/MHz	-131.6 dBW/MHz	-134.4 dBW/MHz
Range of Data	-127.8 to -130.9 dBW/MHz	-127 to -132.7 dBW/MHz	-131.6 to -135 dBW/MHz
Median for Noise-Like Interference (Reacquisition)	-133 dBW/MHz	No Measured Data	-134.9 dBW/MHz
Range of Data	-129.8 to -133.9 dBW/MHz		-131.6 to -136 dBW/MHz

31 The median is the value in an ordered set of values below and above which there is an equal number of values or which is the arithmetic average of the two middle values if there is no middle number.

TABLE 2-8. Overall Median and Range of Data Values for the Interference Thresholds

Data Set	Interference Threshold Values (Data Combined for the Three Receivers)
Median for CW-Like Interference (Break-Lock)	-144.5 dBW
Range of Data	-138.2 to -147.8 dBW
Median for Noise-Like Interference (Break-Lock)	-133.2 dBW/MHz
Range of Data	-127 to -135 dBW/MHz
Median for Noise-Like Interference (Reacquisition)	-134.6 dBW/MHz
Range of Data	-129.8 to -136 dBW/MHz

2.4 ANALYSIS OF SU RECEIVER SUSCEPTIBILITY MEASUREMENTS

The first comparison of the NTIA data is with certain data collected by SU. In order to make a comparison between the NTIA and SU data, data sets had to be identified where similar measurement procedures, interference criteria, and UWB signal characteristics are used. Where measurement procedures, interference criteria, and UWB signal characteristics were similar, appropriate comparisons are made. The comparison of the NTIA and SU data is presented in Table 2-9.

As indicated in Table 2-9, the SU GPS/UWB interference measurement program considered two types of GPS receivers. These are referred to as a high-grade GPS aviation receiver and a low-cost Original Equipment Manufacturer (OEM) receiver.[32] Several interference criteria were also used including break-lock and pseudo-range accuracy. The interference effects for the SU data examined in this analysis can be characterized as noise-like or CW-like. The SU measured interference threshold data is reported in units of dBm (average power) as measured in a 24 MHz bandwidth filter. For comparison purposes the SU data is adjusted to units of dBW/MHz for noise-like interference cases and referenced to a GPS signal level of -130 dBm using the methods described in Section 2.2.2 of NTIA Report 01-45.[33] The SU measurements were carried out using a GPS signal level of -131.3 dBm. Similarly, the CW-like cases are adjusted using the method described in Section 2.2.2 of NTIA Report 01-45, to determine power in a single

[32] Stanford Report at 1.

[33] NTIA Report 01-45 at 2-16.

TABLE 2-9. Comparison of SU and NTIA Interference Threshold Levels

SU Receiver Type	Interference Criteria	Category of Interfering Signal Effect	SU Report Threshold Level	SU Adjusted Threshold Level	Comparable NTIA Adjusted Threshold Overall Median Level	Range of Data Associated with NTIA Median Levels
Aviation	Break-Lock	Noise-like	-83.8 dBm/24 MHz[34]	-126.3 dBW/MHz	-133.2 dBW/MHz	-127 to -135 dBW/MHz
	Break-Lock	CW-like	-101.27 dBm/24 MHz[35]	-136.5 dBW	-144.5 dBW	-138.2 to -147.8 dBW
	15 cm Pseudo-Range Error	Noise-like	-89.7 dBm/24 MHz[36]	-132.2 dBW/MHz	-134.6 dBW/MHz	-129.8 to -136 dBW/MHz
OEM	Break-Lock	Noise-like	-87.8 dBm/24 MHz[37]	-130.3 dBW/MHz	-133.2 dBW/MHz	-127 to -135 dBW/MHz
	Break-Lock	CW-like	-104.27 dBm/24 MHz[38] (4 dB back off)	-139.5 dBW	-144.5 dBW	-138.2 to -147.8 dBW

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34 Stanford Report at 30.

35 *Id.*

36 *Id.* at 21.

37 *Id.* at 39.

38 *Id.* at 40.

spectral line in dBW and referenced to a GPS signal level of -130 dBm.[39] Both SU measured CW-like interference cases in Table 2-9 used a UWB signal that resulted in only one line within the 24 MHz measurement filter. In the case of the OEM receiver with the CW-like interference effect, the measured break-lock level for the 4 dB noise back off condition is used in Table 2-9. This back off condition is selected because the SU injected noise level (-93.5 dBm/24 MHz) is closer to the NTIA injected level (-93 dBm/20 MHz) than the 2 dB back off condition. The adjusted interference threshold levels are shown in Table 2-9. The NTIA data shown in Table 2-9 is primarily for the break-lock condition either for CW-like or noise-like interference effects and is compared to the SU data for CW-like and noise-like interference effects as appropriate. For the SU test that used pseudo-range accuracy as the interference criterion, the NTIA median interference threshold value for reacquisition was used for comparison. This is used because pseudo-range accuracy is more a performance based criterion (than break-lock) and reacquisition is somewhat a performance rather than a failure criterion. Table 2-9 also contains the range of data associated with each NTIA median threshold level.

A review of the Table 2-9 information indicates that the SU data is consistent (comparing the adjusted threshold level columns) with the NTIA receiver input threshold data. The high-grade aviation receiver is slightly more robust than the receivers tested by NTIA under break-lock conditions. However, the SU break-lock thresholds are within 2 dB of the range of the NTIA data. For the aviation receiver pseudo-range measurement and both the OEM receiver measurements, the SU data is within the range of the NTIA data.

2.5 ANALYSIS OF ARL:UT RECEIVER SUSCEPTIBILITY MEASUREMENTS

Certain interference threshold data reported in the ARL:UT report as analyzed by the JSC are also compared to the NTIA data.[40] Again, because of differences in the measurement approach and the interference threshold criteria, only a subset of the ARL:UT data can be used in this comparison. These differences in measurement approach are explained in the JSC Report.[41] The comparison of NTIA data with ARL:UT data is shown in Table 2-10. The interference thresholds in Table 2-10 for the ARL:UT results are the values shown in the JSC Report with an appropriate correction (-43 dB) to convert from dBm/20 MHz to dBW/MHz for comparison purposes. The referenced values in the JSC report were modified (by JSC) to adjust the ARL:UT UWB power levels, measured using a log average procedure, to an RMS power level and to adjust UWB power levels to a reference GPS signal level of -130 dBm. Most of the ARL:UT cases shown in Table 2-10 are consistent with the NTIA data particularly if one compares the ARL:UT data to the range associated with the NTIA median value. A possible exception to this consistency is for

[39] NTIA Report 01-45 at 2-13.

[40] JSC Report at 4-7.

[41] *Id* at 4-1.

Receiver Number One with UWB interference and a performance metric of a loss of one space vehicle (SV) (-142.3 dBW/MHz for UWB Mode 7 and -142.7 dBW/MHz for UWB Mode 13). For these conditions, the receiver seems to be more susceptible to UWB interference. As discussed in Section 5 the JSC Report, there is evidence for possible CW-like interference effects having occurred with Receiver Number One during the ARL:UT tests for these conditions.[42] As shown in many of the GPS interference tests, these receivers are more susceptible to CW-like interference than noise-like interference. The NTIA data shows a median value of -144.5 dBW for CW-like interference for a break-lock condition. This is consistent with the ARL:UT test results for these two cases.

Table 2-10. Comparison of ARL:UT and NTIA Interference Threshold Levels

ARL:UT Receiver	Interference Effects[a]	ARL:UT Interference Signals and Threshold Interference Levels			Comparable NTIA Median Threshold Levels with Associated Range of Data
		White Noise (dBW/MHz)	UWB Mode 7 (dBW/MHz)	UWB Mode 13 (dBW/MHz)	
1	Loss of 1 SV	-126.8	-142.3[b]	-142.7[b]	-133.2 dBW/MHz Median Break-Lock Level for Noise-Like Interference
	Loss of Multiple SVs	-124.8	-131.3	-133.7	
2	Loss of 1 SV	-126.2	-129.7	-131.1	-127 to -135 dBW/MHz Range of Data Associated with Median
	Loss of Multiple SVs	-126.2	-127.7	-129.1	
3	Loss of 1/Multiple SVs	-127.9	-127.4	-128.8	
4	Loss of 1 SV	-129.9	-129.4	-133.8	
	Loss of Multiple SVs	-127.9	-129.4	-133.8	

a. The ARL:UT data shows, among many other performance measures, the interference power level at the input of the GPS at which the signal from one and/or more than one GPS SV cannot be tracked. This performance metric measure compares with the break-lock metric used by NTIA.
b. In reviewing the data there is evidence of possible CW-like interference effects in this receiver for these UWB modes.

[42] JSC Report at 5-1

2.6 COMPARISON OF MEASURED RESULTS WITH EXISTING GPS C/A CODE INTERFERENCE LIMITS

Finally, if one subtracts 4.5 dB from the median values of Table 2-8 to correct the GPS reference signal from -130 dBm to -134.5 dBm, the NTIA data can be compared to the existing RTCA and ITU-R GPS interference limits.[43] The adjusted median value for CW-like interference would be -149 dBW and for noise-like interference for reacquisition would be -139.1 dBW/MHz. These values are consistent with the existing protection limits for GPS receivers of -150.5 dBW for CW-like interference and -140.5 dBW/MHz for noise-like interference.

2.7 SUMMARY

In summary, the GPS receiver interference threshold data is consistent across the three receivers tested in the NTIA measurement program. These receivers are those that process the C/A code L1 signal. The NTIA data was also shown to be consistent with the SU and ARL:UT test results. These comparisons can only be made for a subset of the SU and ARL:UT data because of differences in the UWB characteristics considered and the measurement procedures used. Finally, the NTIA data was shown to be consistent with existing interference protection limits for GPS. For the parameter sets tested, this data defines the power level of the UWB signal that can be tolerated at the GPS receiver input without causing break-lock or increasing reacquisition time. This body of susceptibility data can be used in source-path-receiver analysis (such as that in Section 3) to determine the interference impact to GPS receivers from UWB emissions in various operational scenarios.

[43]NTIA Report 01-45 at 2-8.

SECTION 3.0
ANALYSIS OVERVIEW

3.1 ANALYSIS DESCRIPTION

The measurements performed by the ITS define the GPS receiver interference threshold for a UWB waveform as a function of the UWB signal parameters (e.g., power, PRF, gating, modulation). The interference threshold is measured at the input of the GPS receiver and is used in the analysis for each specific GPS/UWB operational scenario to calculate the maximum allowable emission level at the output of the UWB device antenna. This section of the addendum report describes the analysis method used.

The maximum allowable emission level from the UWB device is based on an EIRP limit. The EIRP is the power supplied to the antenna of the UWB device multiplied by the relative antenna gain of the UWB device in the direction of the GPS receiver. The maximum allowable EIRP is computed using the following equation:

$$EIRP_{max} = I_T - G_r + L_p - L_{mult} - L_{allot} - L_{man} + L_{AF} + L_{BA} + L_{align} - L_{safety} \quad (1)$$

where:

$EIRP_{max}$ is the maximum allowable EIRP of the UWB device (dBW or dBW/MHz);
I_T is the interference threshold of the UWB signal at the input of the GPS receiver (dBW or dBW/MHz);
G_r is the gain of the GPS antenna in the direction of the UWB device (dBi);
L_p is the radiowave propagation loss (dB);
L_{mult} is the factor to account for multiple UWB devices (dB);
L_{allot} is the factor for interference allotment (dB);
L_{man} is the factor to account for manufacturer variations in GPS receivers (dB);
L_{AF} is the activity factor of the UWB device (dB);
L_{BA} is the building attenuation loss (dB);
L_{align} is the factor for UWB device antenna alignment (dB);
L_{safety} is the aviation safety margin (dB).

The following paragraphs explain each of the technical factors used in the analysis.

3.1.1 UWB Interference Threshold (I_T)

The UWB interference threshold referenced to the input of the GPS receiver is obtained from the single source interference susceptibility measurements performed by ITS as discussed in Section 2.1.1 (Tables 2-2 and 2-3). Adjustments are made to the measured interference susceptibility levels to compute the UWB interference threshold. As discussed in Section 3.3 (Tables 3-13 and 3-14), the adjustments made to the measured interference susceptibility levels are based on the individual UWB signal structure.

3.1.2 GPS Receive Antenna Gain (G_r)

3.1.2 GPS Receive Antenna Gain (G_r)

The GPS receive antenna gain model used in this analysis is provided in Table 3-1. The antenna gain used is based on the position of the UWB device with respect to the GPS antenna and is determined from the GPS/UWB operational scenario under consideration.

TABLE 3-1. GPS Antenna Gain Based on UWB Device Position With Respect to GPS Antenna

Off-axis Angle (Measured with Respect to the Horizon)	GPS Antenna Gain (dBi)
-90 degrees to -10 degrees	-4.5
-10 degrees to 10 degrees	0
10 degrees to 90 degrees	3

The off-axis angle measured with respect to the horizon is computed by:

$$\text{Theta} = \tan^{-1} [(h_{UWB} - h_{GPS})/D] \quad (2)$$

where:

Theta is the off-axis angle measured with respect to the horizon (degrees);
h_{UWB} is the UWB device antenna height (m);
h_{GPS} is the GPS receiver antenna height (m);
D is the horizontal separation between the GPS receiver and UWB device (m).

3.1.3 Radiowave Propagation Loss (L_p)

The radiowave propagation loss is computed using the minimum distance separation between the GPS receiver and the UWB device as defined by the GPS/UWB operational scenario. The radiowave propagation model used also depends on the GPS/UWB operational scenario. By definition, "free-space" assumes that there is a line-of-sight (LOS) path between the UWB device and the GPS receiver. The radiowave propagation model described by the free-space loss equation is :

$$L_p = 20 \text{ Log } F + 20 \text{ Log } D_{min} - 27.55 \quad (3)$$

where:

L_p is the free-space propagation loss (dB);
F is the frequency (MHz);
D_{min} is the minimum distance separation between the GPS receiver and UWB device (m).

As a result of antenna heights and terrain conditions, free-space conditions may not exist. There is a phenomenon referred to as the propagation loss breakpoint, which consists of a change in the slope of the propagation loss versus distance curve at a radial distance from the transmitter. It is caused by the reflection of the transmitted signal by the ground. This multipath signal can combine constructively or destructively with the direct path signal and usually occurs only in areas with clear LOS and ground reflection paths.

For the frequency range of interest, the propagation loss changes by 20 dB/decade (i.e., free-space loss) at distances close to the transmitter, and by 40 dB/decade after the propagation loss breakpoint occurs. The propagation loss breakpoint radius from the transmitter, R_b, is calculated using the formula:[44]

$$R_b = 2.3x10^{-6}\ F\ (h_t h_r) \qquad (4)$$

where:

R_b is the propagation loss breakpoint radius (mi);
F is the frequency (MHz);
h_t is the UWB device antenna height (ft);
h_r is the GPS receiver antenna height (ft).

When the minimum distance separation between the UWB device and the GPS receiver is less than R_b, the free-space propagation model should be used. When the minimum distance separation between the UWB device and the GPS receiver is greater than R_b, a propagation model that takes into account non-LOS conditions should be used.

3.1.4 Multiple UWB Devices (L_{mult})

The GPS/UWB operational scenario determines whether single or multiple UWB devices should be considered. The factor for multiple UWB devices was obtained from the multiple source (aggregate) measurements performed by ITS. Section 2.1.2 of NTIA Report 01-45, discusses the multiple UWB devices measurement results.[45] Based on the multiple source measurements, the factor to be included in the analysis for multiple UWB devices will depend on whether the interference effect has been characterized as being pulse-like, CW-like, or noise-like. The exception is the en-route navigation operational scenario, where it is assumed that there are a large enough number of UWB devices, such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.

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[44] E. N. Singer, *Land Mobile Radio Systems* (Second Edition) at 194.

[45] NTIA Report 01-45 at 2-5.

As discussed in Section 2.2.3 of NTIA Report 01-45, signals that were characterized as being pulse-like for single UWB device interactions were characterized as being noise-like when multiple UWB devices are considered.[46] The occurrence of the transition from pulse-like to noise-like interference was verified in Measurement Case V.[47] The number of UWB devices required for this transition to occur depends on the PRF. For the 1 MHz PRF signals, the measurements show that three UWB signals are required for the transition to occur. In the case of the 100 kHz PRF signals, the number of UWB devices necessary for the transition to occur will be much larger than the number of UWB devices under consideration in the operational scenarios. Based on the measurement results, a factor for multiple UWB devices is not included in this analysis for signal permutations that have been characterized as causing pulse-like interference with a PRF of 100 kHz.

The interference effect for UWB signals that have been characterized as being CW-like is attributed to the single interfering CW line that is coincident with a dominant C/A-code line. This was discussed in Section 2.2.3 of NTIA Report 01-45, and confirmed in Measurement Cases III and IV.[48] Multiple UWB signals that are characterized as causing CW-like interference, do not add to determine the effective interfering signal power. A large number of UWB devices producing spectral lines would be necessary before there is a transition to a noise-like interference effect. This transition from CW-like to noise-like will not occur with the number of UWB devices under consideration in the operational scenarios. Based on the measurement results, a factor for multiple UWB devices is not included in this analysis for UWB signal permutations that have been characterized as causing CW-like interference.

UWB signals permutations with PRFs of 1 MHz, 5 MHz, and 20 MHz that have been characterized as being pulse-like, will transition to noise-like interference as the number of UWB devices is increased. This is discussed in Section 2.2.3 of NTIA Report 01-45 and verified in Measurement Case V.[49] For these UWB signal permutations, a factor of 10 Log (number of UWB devices) is included in the analysis.

As discussed in Section 2.2.3 of NTIA Report 01-45, and verified in Measurement Case I and II, if the individual signals cause an interference effect that is noise-like, the interference effect of the multiple noise-like signals is noise-like.[50] Based on the measurement results, for UWB signal permutations that have been characterized as causing noise-like interference, a factor of 10 Log (number of UWB devices) is included in the analysis.

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[46] *Id.* at 2-15.

[47] *Id* at 2-17.

[48] *Id.*

[49] *Id.*

[50] *Id.*

3.1.5 Interference Allotment (L_{allot})

In addition to the potential interference from UWB devices, several other potential sources of interference to GPS receivers have been identified. These potential sources of interference include but are not limited to: 1) adjacent band interference from mobile satellite service (MSS) handsets; 2) harmonics from television transmitters; 3) adjacent band interference from super geostationary earth-orbiting (super GEO) satellite transmitters[51]; 4) spurious emissions from 700 MHz public safety base, mobile, and portable transmitters; and 5) spurious emissions including harmonics from 700 MHz commercial base, mobile, and portable transmitters. Multiple sources of interference, which might individually be tolerated by a GPS receiver, may combine to create an aggregate interference level (e.g., noise and emissions) that could prevent the reliable reception of the GPS signal. In the GPS/UWB operational scenarios, a percentage of the total allotment for all interfering sources is attributed specifically to UWB devices.

In this analysis the percentage of the total interference allotment that is attributed to UWB devices is dependent on the minimum distance separation between the GPS receiver and the UWB device. The minimum distance separation is established by each operational scenario. For operational scenarios where the minimum distance separation is small (e.g., on the order of several meters), the UWB device is expected to be the dominant source of interference, and 100% of the total interference budget is allotted to the UWB device. For operational scenarios where a larger distance separation exists, there is a greater likelihood that other interfering sources will contribute to the total interference level at the GPS receiver. In these operational scenarios, 50% of the total interference budget is allotted to UWB devices. That is, one half of the total allowable interference is allotted to UWB and the other half is allotted to all other interfering sources combined. For the aviation operational scenarios, larger geographic areas are visible to a GPS receiver onboard an aircraft at altitude. This larger field of view will increase the number of interfering sources that can contribute to the total interference level at the receiver. In the aviation operational scenarios, 10% of the total interference budget is allotted to UWB devices. The factor for UWB device interference allotment is computed from 10 Log (UWB interference allotment ratio). For example, if the UWB device interference allotment is 50% (a ratio of 0.5), a 3 dB factor is included in the analysis.

3.1.6 GPS Receiver Variation (L_{man})

A 2001 GPS Receiver Survey lists 64 different manufacturers of GPS receivers.[52] The survey lists approximately 500 different models of GPS receivers representing the C/A code, semi-codeless, and narrowly-spaced correlator receiver architectures. The results in NTIA Report 01-45 and this addendum consider four different GPS receivers. Based on the measured data that

[51] Super GEOs are geostationary earth orbiting satellites that are designed to employ a high transmit power to communicate with mobile handsets.

[52] *GPS World Receiver Survey*, GPS World Magazine (Jan. 2001) at 32.

is part of the public record in this proceeding and that are presented in this addendum, a trend has emerged regarding the interference effects of UWB signals on the different GPS receiver architectures. However, the number of different models of GPS receivers and manufacturers considered in the current measurement efforts may not completely represent the performance of all of the GPS receivers currently being manufactured. Ignoring the hardware differences in the GPS receivers, differences also exist in firmware[53] and software (e.g., tracking and acquisition algorithms) employed in the receivers which were not considered in the three measurements efforts.

There will be differences between receivers produced by different manufacturers as well as differences in the models produced by the same manufacturer. Therefore, the inclusion of a factor in the analysis to account for these possible differences is reasonable. Moreover, one of the main conclusions in the JHU/APL report states[54]:

> *Variations in the measures of performance due to different GPS receivers are greater than those due to the operating modes of the UWB tested devices. The impact of UWB devices on all GPS receivers cannot be assessed using a single GPS receiver.*

As shown in Table 2-8, the range of data indicates that the more susceptible interference thresholds (e.g., lower values) are within 3 dB of the median. Therefore, the value of 3 dB used in this analysis for GPS receiver variation is appropriate.

3.1.7 UWB Device Activity Factor (L_{AF})

The activity factor represents the percentage of time that the UWB device is actually transmitting. For example, a UWB device that is transmitting continuously will have an activity factor of 100%, no matter what PRF, modulation, or gating percentage is employed. The activity factor is only applicable when a large number of UWB devices are considered in the GPS/UWB operational scenario. Some UWB devices are expected to have inherently low activity factors such as those that are manually activated with a trigger or “deadman” switch. Others will likely have high activity factors such as a UWB local area network. Since it is not possible to estimate practical values of activity factors for each potential UWB application, an activity factor of 100% (a ratio of 1) is used in all of the operational scenarios considered in this analysis. Thus, the activity factor used is set equal to 0 dB (i.e., 10 Log (1)).

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[53] Firmware is software installed in a device that is typically stored in a read only memory (ROM) or programmable read only memory (PROM).

[54] JHU/APL Report at ES-2.

3.1.8 Building Attenuation (L_{BA})

For GPS/UWB operational scenarios that consider the use of UWB devices operating indoors, a building attenuation factor is included in the analysis. ITS has conducted building attenuation loss measurements at 912, 1920, and 5990 MHz.[55] The measurements were performed for different buildings representing typical residential and high rise office construction. Based on the results of these measurements, whenever the UWB device is considered to be operating indoors an average building attenuation of 9 dB is used in the analysis.

3.1.9 UWB Device Antenna Alignment (L_{align})

The mainbeam of the UWB device antennas considered in the analysis are assumed to be pointing at the GPS antenna. This means that there is no reduction in the UWB device antenna gain to address the alignment of the UWB device antenna. In general this is a valid analysis assumption because of the unknown antenna characteristics and locations of the UWB devices. This analysis assumption is further supported if the UWB devices employ omnidirectional antennas. Omnidirectional antennas provide essentially uniform coverage in the horizontal direction and the vertical direction for low elevation angles. This means that for the land-based (terrestrial, maritime, railway, surveying) operational scenarios the antenna gain of the UWB device in the direction of the GPS antenna is essentially constant. Moreover, these operational scenarios only consider a small number of UWB devices. A similar situation exists for a low altitude aircraft such as that considered in the non-precision approach operational scenario. However, at higher elevation angles, the coverage of an omnidirectional antenna is not uniform in the vertical direction. Since the aircraft altitude considered in the en-route navigation operational scenario is 1000 feet it will be at a high elevation angle relative to the UWB device located on the ground. Also at this altitude larger geographic areas and higher densities of UWB devices will be visible to the GPS receiver onboard the aircraft. Therefore, in the en-route operational scenario it is appropriate to include a factor to take into account the alignment of the UWB device antennas. Based on the pattern of a typical vertical dipole omnidirectional antenna, a factor of 2 dB is included in the analysis of the en-route navigation operational scenario for UWB device antenna alignment.

3.1.10 Aviation Safety Margin (L_{safety})

When the GPS/UWB operational scenario involves aviation applications using GPS (i.e., en-route navigation and non-precision approach landing) inclusion of a safety margin is appropriate. The aviation safety margin is used to account for uncertainties on the aviation side of the link budget that are real but not quantifiable, which include but are not limited to: multipath of the GPS signal; receiver implementation losses; antenna gain variations; and approach path

[55] NTIA Report 95-325, *Building Penetration Measurements From Low-height Base Stations at 912, 1920, and 5990 MHz*, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (Sept. 1995), at 43.

deviation. Since the GPS signal level cannot be increased, the aviation safety margin is implemented by lowering the allowable interference. A safety margin of 6 dB is included in the analysis for GPS receivers used in aviation applications.[56] The aviation safety margin included in this analysis is consistent with the value specified in ITU-R Recommendation M.1477.[57]

3.1.11 GPS Receiver Architecture

Interference susceptibility measurements reported in this addendum, were performed on a GPS receiver employing narrowly-spaced correlator architecture and a TSO-C129a compliant GPS receiver employing the C/A code architecture. The GPS receiver architecture examined in the analysis are different depending upon the operational scenario under consideration. In all operational scenarios, with the exception of the aviation operational scenarios, measured data for the narrowly-spaced correlator architecture was used. In the non-precision approach and en-route navigation aviation operational scenarios, measured data for the TSO-C129a compliant GPS C/A code receiver architecture was used.

3.2 DEVELOPMENT OF THE GPS/UWB OPERATIONAL SCENARIOS

As discussed in the previous section, the measurements of the maximum tolerable interference threshold at the input to the GPS receiver is used in this analysis to compute the maximum allowable EIRP of the UWB device. The operational scenario is necessary to relate the interference level at the input of the GPS receiver to the output of the UWB device. The GPS/UWB operational scenarios establish: the minimum distance separation between the GPS receiver and the UWB device; the appropriate antenna coupling; the applicable radio wave propagation model; whether single or multiple UWB devices should be considered; and any other scenario specific factors (e.g., building attenuation and aviation safety margin).

On August 31, 2000, NTIA published a notice in the Federal Register announcing a series of public meetings to be held to gather information to be used by NTIA in developing the operational scenarios for assessing the potential interference to GPS receivers from UWB devices.[58] Meetings were held on September 7 and 27, and December 7 giving the Federal agencies and the public opportunities to present documents related to the development of GPS/UWB operational scenarios. Documents were submitted by: Multispectral Solutions Inc., the National Oceanic and Atmospheric Administration/National Ocean Science/National Geodetic Survey, NTIA, Time Domain Corporation, the USCG, and the U.S. GPS Industry Council. The specific proposals for operational scenarios included GPS receivers used in the following

[56] The 6 dB aviation safety margin results in only a 2.5 dB margin in C/N+I, which is a critical GPS receiver performance parameter.

[57] ITU-R M.1477 at Annex 5.

[58] NTIA Notice at 1.

applications:[59]

- Public Safety (E-911 embedded in a cellular phone);
- Public Safety (emergency response vehicles);
- Geographic Information Systems;
- Precision Machine Control;
- Maritime (constricted waterway navigation, harbor navigation, docking and lock operations;)
- Railway (positive train control (PTC));
- Surveying;
- Aviation (en-route navigation and non-precision approach landings).

In addition to these specific GPS/UWB operational scenarios, NTIA proposed a general operational scenario for GPS receivers used for terrestrial applications that considered multiple UWB device interactions.

As a result of the three public meetings, five categories of GPS applications are considered in the development of the GPS/UWB operational scenarios: terrestrial, maritime, railway, surveying, and aviation. The operational scenario proposals also considered several UWB device applications. The UWB device applications include: embedded functions in a mobile phone, wireless local area networks, short-range communication systems, and intrusion-detection devices.

3.2.1 Terrestrial Applications

The specific operational scenario proposals for the terrestrial use of GPS receivers include: public safety, geographic information systems, and precision machine control.[60] The operational scenario proposals for terrestrial GPS receivers are all based on a minimum distance separation between the GPS receiver and UWB device of 2 meters. Although this minimum distance separation may in some cases be applicable for assessing interference from a single UWB device, it is not applicable when assessing interference to GPS receivers from multiple UWB devices (10 meter minimum distance separation). Both single UWB device and multiple UWB device operational scenarios for terrestrial applications are considered in this analysis.

[59] All of the documents from the public meetings are available upon request from the NTIA Office of Spectrum Management or from the NTIA website.

[60] U.S. GPS Industry Council Submission to NTIA GPS/UWB Operational Scenario Meeting (Sept. 7, 2000).

3.2.1.1 Single UWB Device

In the terrestrial operational scenario where a single UWB device interaction is considered, a minimum distance separation between the GPS receiver and the UWB device of 2 meters is used. At a minimum distance separation of 2 meters, it is appropriate to only consider the outdoor operation of UWB devices (i.e., no additional losses for building attenuation).

In the single UWB device terrestrial operational scenario, an antenna height of 3 meters is used for the GPS receiver and the UWB device. Based on the antenna model provided in Table 3-1, the antenna gain for the GPS receiver used in this operational scenario is 0 dBi.

For the GPS receiver and UWB device antenna heights of 3 meters, the expected propagation loss breakpoint radius is 568 meters. Since the minimum distance separation is much less than the expected propagation loss breakpoint radius, the free-space propagation model is applicable.

A summary of the technical factors associated with the single UWB device terrestrial operational scenario is provided in Table 3-2.

TABLE 3-2. Technical Factors for the Single UWB Device Terrestrial Operational Scenario

Technical Factors	Value
GPS Receiver Antenna Gain	0 dBi
GPS Antenna Height	3 meters
UWB Device Antenna Height	3 meters
Minimum Distance Separation	2 meters
Propagation Model	Free-space
Interference Allotment to UWB Devices	0 dB (100%)
Variations in GPS Receivers	3 dB
Multiple UWB Devices	1 UWB device
Activity Factor for Each UWB Device	0 dB (100%)
Building Attenuation	0 dB
GPS Receiver Architecture	Narrowly-Spaced Correlator

3.2.1.2 Multiple UWB Devices

After reviewing the operational scenario proposals it is clear that the use of GPS for terrestrial applications is extremely diverse. This makes it difficult to identify a single representative operational scenario to be used in assessing the potential interference to terrestrial GPS receivers from multiple UWB devices. At the December 7, 2000 GPS/UWB operational scenario meeting NTIA presented an operational scenario proposal that considered interference to a terrestrial GPS receiver from multiple UWB devices.[61] In the analysis of multiple UWB devices both indoor and outdoor operation of UWB devices is considered.

In the multiple UWB device terrestrial operational scenario, a minimum distance separation of 10 meters was established between the GPS receiver and each UWB device that is used outdoors. This was the distance separation that was presented at the GPS/UWB operational scenario meeting and is reasonable to use when multiple UWB devices are being considered. For indoor operation, the UWB device is positioned above the GPS receiver (e.g., second floor of a building). The minimum distance separation is computed from the slant range with the GPS receiver located 5 meters from the building and the UWB device 10 meters above the GPS receiver. The following equation is used to compute the minimum distance separation:

$$D_{min} = ((h_{GPS} - h_{UWB})^2 + D^2)^{0.5} \qquad (5)$$

where:

h_{GPS} is the height of the GPS receiver antenna (m);
h_{UWB} is the height of the UWB device antenna (m);
D is the horizontal separation between the GPS receiver and UWB device antennas (m).

Based on the model given in Table 3-1 the antenna gain for the GPS receiver is 0 dBi and 3 dBi for outdoor and indoor operation of UWB devices respectively.

For a distance separation of 10 meters it is reasonable to consider an interaction with multiple UWB devices. Four UWB devices each located 10 meters from the GPS receiver are considered in this operational scenario.

Based on the established operational scenario an antenna height of 3 meters for the GPS receiver is used. An antenna height of 3 meters (outdoor operation) and 10 meters (indoor operation) is used for the UWB devices. Using these antenna heights the expected propagation loss breakpoint radii are 568 meters for UWB devices with a 3 meter antenna height and 1.9 kilometers for UWB devices with a 10 meter antenna height. Since the distance separation used in the multiple UWB general terrestrial operational scenario is less than the expected propagation loss breakpoint radii, the free-space propagation model is applicable.

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[61] National Telecommunications and Information Administration, *Proposal for a General Operational Scenario for Assessing Potential Interference to Terrestrial Global Positioning System Receivers from Ultrawideband Transmission Systems* (Dec. 7, 2000).

A summary of the technical factors associated with the multiple UWB device terrestrial operational scenario is provided in Table 3-3.

TABLE 3-3. Technical Factors for the Multiple UWB Device Terrestrial Operational Scenario

Technical Factors	Value	
	Outdoor UWB Device Operation	Indoor UWB Device Operation
GPS Receiver Antenna Gain	0 dBi	3 dBi
GPS Antenna Height	3 meters	3 meters
UWB Device Antenna Height	3 meters	10 meters
Minimum Distance Separation	10 meters	8.6 meters
Propagation Model	Free-space	Free-space
Interference Allotment to UWB Devices	(3 dB) 50%	3 (dB) 50%
Variations in GPS Receivers	3 dB	3 dB
Multiple UWB Devices	4 UWB devices	4 UWB devices
Activity Factor for Each UWB Device	0 dB (100%)	0 dB (100%)
Building Attenuation	0 dB	9 dB
GPS Receiver Architecture	Narrowly-Spaced Correlator	

3.2.2 Maritime Applications

The operational scenario proposals for the maritime use of GPS receivers include: navigation in constricted waterways, harbor navigation, docking operations, navigation around bridges, and lock operations.[62] The USCG has indicated that the limiting operational scenario for maritime applications is when the GPS receiver is used for navigation in constricted waterways. In this analysis, indoor and outdoor UWB device operation is considered.

In the two operational scenario proposals for navigation in constricted waterways, the GPS receiver antenna is assumed to be mounted on the mast of the vessel. Therefore, the minimum distance separation has both a horizontal and vertical component. The minimum distance separation between the GPS receiver and the UWB device is computed from the slant range using Equation 5.

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[62] United States Coast Guard Navigation Center Submission to NTIA GPS/UWB Operational Scenario Meeting (Sept. 27, 2000).

The first restricted waterway operational scenario implementation uses an antenna height of 45 feet (13.5 meters) and a horizontal separation from the UWB devices of 125 feet (37.5 meters). The second implementation uses an antenna height of 25 feet (7.5 meters) and a horizontal separation from the UWB devices of 170 feet (51 meters). An antenna height of 3 meters (outdoor operation) and 10 meters (indoor operation) is used for the UWB devices. The computed minimum distance separations for the two implementations in the maritime navigation, constricted waterways operational scenario are given in Table 3-4.

TABLE 3-4. Minimum Distance Separations for the Maritime Navigation in Constricted Waterways Operational Scenario

GPS Receiver Antenna Height (Meters)	UWB Device Antenna Height (Meters)	Minimum Distance Separation (Meters)
13.5	3	38.9
7.5	3	51.2
13.5	10	37.7
7.5	10	51.1

For these minimum distance separations it is reasonable to consider multiple UWB devices. Four UWB devices each located at the minimum distance separations are considered in the maritime navigation in constricted waterways operational scenario.

Based on the model given in Table 3-1, when the off-axis angle is greater than -10 degrees the GPS antenna gain in the direction of the UWB device is 0 dBi. When the off-axis angle is less than -10 degrees the USCG has specified that the GPS antenna gain in the direction of the UWB device is -3 dBi.

Based on the GPS receiver antenna heights and the UWB device antenna heights the expected propagation loss breakpoint radii are computed and given in Table 3-5. Since the computed minimum distance separations are much less than the expected propagation loss breakpoint radii the free-space propagation model is applicable.

TABLE 3-5. Expected Propagation Loss Breakpoint Radii for the Maritime Navigation in Constricted Waterways Operational Scenario

GPS Receiver Antenna Height (Meters)	UWB Device Antenna Height (Meters)	Propagation Loss Breakpoint Radii (Kilometers)
13.5	3	2.5
7.5	3	1.4
13.5	10	8.5
7.5	10	4.7

A summary of the technical factors associated with the maritime navigation in constricted waterways operational scenario is provided in Table 3-6.

TABLE 3-6. Technical Factors for the Navigation in Constricted Waterways Operational Scenario

Technical Factors	Value	
	Outdoor UWB Device Operation	**Indoor UWB Device Operation**
GPS Receiver Antenna Gain	-3 and 0 dBi	0 dBi
GPS Antenna Height	13.5 and 7.5 meters	13.5 and 7.5 meters
UWB Device Antenna Height	3 meters	10 meters
Minimum Distance Separation	38.9 and 51.2 meters	37.7 and 51.1 meters
Propagation Model	Free-space	Free-space
Interference Allotment to UWB Devices	3 dB (50%)	3 dB (50%)
Variations in GPS Receivers	3 dB	3 dB
Multiple UWB Devices	4 UWB devices	4 UWB devices
Activity Factor for Each UWB Device	0 dB (100%)	0 dB (100%)
Building Attenuation	0 dB	9 dB
GPS Receiver Architecture	Narrowly-Spaced Correlator	

3.2.3 Railway Applications

The operational scenario proposal for the railway use of GPS receivers is for PTC.[63] PTC is a data system that utilizes a computer on board the locomotive to minimize collisions between trains. The locomotive computer obtains movement authorization from a host computer and calculates when it needs to stop the train based on the speed and weight of the train. If the limits of authority are going to be violated, the computer will stop the train automatically. The specifics of this operational scenario proposal were provided by the NTIA.[64] In this analysis, indoor and outdoor operation of UWB devices is considered.

In the operational scenario proposal for PTC the GPS receiver antenna is mounted on top of the train. Therefore, the minimum distance separation has both a horizontal and vertical

[63] U.S. Department of Transportation and U.S. Department of Defense 1999 Federal Radionavigation Plan (Dec. 1999) at 2-25.

[64] *Summary of GPS/UWB Operational Scenarios* Prepared by the NTIA (Nov. 20, 2000) (hereinafter "NTIA Summary").

component. The minimum distance separation between the GPS receiver and the UWB device is computed from the slant range using Equation 5.

The GPS receiver antenna in the railway PTC operational scenario has an antenna height of 10 meters and a horizontal separation from the UWB devices of 7 meters. An antenna height of 3 meters (outdoor operation) and 10 meters (indoor operation) is used for the UWB devices. The computed minimum distance separations are 9.8 meters for outdoor UWB device operation and 7 meters for indoor UWB device operation.

Using the model given in Table 3-1, the antenna gain for the GPS receiver antenna is 0 dBi for indoor UWB device operation and -4.5 dBi for outdoor UWB device operation.

For these minimum distance separations, it is reasonable to consider multiple UWB devices. Based on the operational scenarios presented at the NTIA GPS/UWB operational scenario meetings, three UWB devices each located at the minimum distance separation are considered in the railway PTC operational scenario.

Based on the GPS receiver antenna heights and the UWB device antenna heights the expected propagation loss breakpoint radii are 1.9 kilometers for outdoor UWB device operation and 6.3 kilometers for indoor UWB device operation. Since the computed minimum distance separations are much less than the expected propagation loss breakpoint radii the free-space propagation model is applicable.

A summary of the technical factors associated with the railway PTC operational scenario is provided in Table 3-7.

TABLE 3-7. Technical Factors for the Railway PTC Operational Scenario

Technical Factors	Value	
	Outdoor UWB Device Operation	**Indoor UWB Device Operation**
GPS Receiver Antenna Gain	-4.5 dBi	0 dBi
GPS Antenna Height	10 meters	10 meters
UWB Device Antenna Height	3 meters	10 meters
Minimum Distance Separation	9.8 meters	7 meters
Propagation Model	Free-space	Free-space
Interference Allotment to UWB Devices	3 dB (50%)	3 dB (50%)
Variations in GPS Receivers	3 dB	3 dB
Multiple UWB Devices	3 UWB devices	3 UWB devices
Activity Factor for Each UWB Device	0 dB (100%)	0 dB (100%)
Building Attenuation	0 dB	9 dB
GPS Receiver Architecture	Narrowly-Spaced Correlator	

3.2.4 Surveying Applications

Two operational scenario proposals were provided for the surveying use of GPS receivers.[65] The surveying operational scenarios considered interference from both single and multiple UWB device interactions.

In the surveying operational scenarios the GPS receiver is located below the antenna of the UWB device. When a single UWB device is considered a minimum distance separation of 30 meters was proposed. For multiple UWB devices it was proposed that the first UWB device be located 30 meters from the GPS receiver. Two additional UWB devices are located at distances of 300 and 750 meters respectively from the GPS receiver.

If an antenna height of 3 meters is used for the GPS receiver and 10 meters is used for the UWB device, the expected pathloss breakpoint radius is 1.2 kilometers. For the surveying operational scenarios the minimum distance separation is less than the expected pathloss breakpoint radius, therefore the free-space propagation model is applicable.

A summary of the technical factors associated with the surveying operational scenarios is provided in Table 3-8.

TABLE 3-8. Technical Factors for the Surveying Operational Scenarios

Technical Factors	Value	
	Single UWB Device	Multiple UWB Devices
GPS Receiver Antenna Gain	3 dBi	3 dBi, 0 dBi
GPS Antenna Height	3 meters	3 meters
UWB Device Antenna Height	10 meters	10 meters
Minimum Distance Separation	30 meters	30, 300, 750 meters
Propagation Model	Free-space	Free-space
Interference Allotment to UWB Devices	3 dB (50%)	3 dB (50%)
Variations in GPS Receivers	3 dB	3 dB
Multiple UWB Devices	1 UWB device	3 UWB devices
Activity Factor for Each UWB Device	0 dB (100%)	0 dB (100%)
Building Attenuation	0 dB	0 dB
GPS Receiver Architecture	Narrowly-Spaced Correlator	

[65] National Oceanic and Atmospheric Administration/National Ocean Service/National Geodetic Survey Submission to NTIA GPS/UWB Operational Scenario Meeting (Sept. 27, 2000).

3.2.5 Aviation Applications [66]

The operational scenario proposals for the aviation use of GPS receivers include: en-route navigation and non-precision approach landings.[67] En-route navigation is a phase of navigation covering operations between a point of departure and termination of the flight. Non-precision approach landing is a standard instrument approach procedure using a ground-based system in which no electronic glide slope is provided.[68]

3.2.5.1 En-Route Navigation

For the en-route navigation operational scenario, the aircraft with the GPS receiver is at an altitude of 1,000 feet.[69] The maximum LOS distance (d_{LOS}) for an aircraft at an altitude of 303 meters (1,000 feet) is given by:

$$d_{LOS} = 3.57\,(k)^{0.5}\,((h_{UWB})^{0.5} + (h_{GPS})^{0.5}) \qquad (6)$$

where:

k is the effective Earth radius factor;
h_{UWB} is the antenna height of the UWB device (m);
h_{GPS} is the height of the GPS receiver antenna located on the aircraft (m).

Using an antenna height of 3 meters for the UWB device and a typical value of k in a temperate climate of 1.33, the computed LOS distance for the aircraft is 78.5 kilometers. Since such a large geographic area is visible to an aircraft at this altitude, the impact of multiple UWB devices is considered for the aviation en-route navigation operational scenario.

To compute the aggregate emission level into the GPS receiver from multiple UWB devices a computer model developed by NTIA is used. This computer model computes the power-sum aggregate emission level from a surface density of UWB devices with the same emission frequency and emission level. The computer model assumes that all of the UWB devices are radiating in the direction of the airborne GPS receiver. The UWB devices are distributed uniformly in concentric rings on a spherical dome of the Earth's surface as shown in Figure 3-1 such that the distance from any UWB device to its closest neighbor remains

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[66] Another aviation application that was discussed at the NTIA operational scenario meetings, was the use of GPS receivers in airport surface movement operations. Sufficient information is not available at this time to include an assessment of this operational scenario in this report. This operational scenario is being actively addressed within RTCA and the results will be made available when the study is complete.

[67] NTIA Summary at 10.

[68] Glide slope is a descent profile determined for vertical guidance during a final approach.

[69] Document No. RTCA/DO-235, *Assessment of Radio Frequency Interference Relevant to the GNSS* (Jan. 27, 1997) at A-2 (hereinafter "DO-235 ").

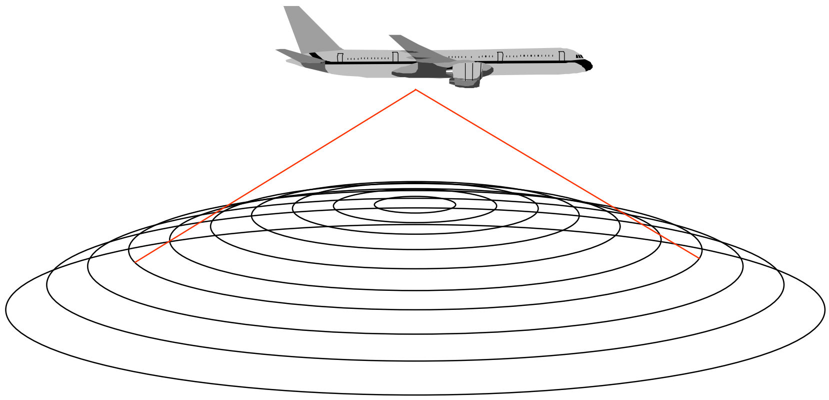

Figure 3-1. Airborne Geometry for the NTIA Aggregate Emitter Model

approximately constant throughout the distribution. The model employs the free-space model for the propagation loss computations. A detailed description of the computer model is provided in a separate NTIA report.[70]

Determining the density of a large number of UWB devices is a key factor affecting the aggregate interference to a GPS receiver used for en-route navigation. Factors that should be considered when estimating the density of a large number of UWB devices include: population; assumed rate for technology penetration; and activity factor. In the absence of such information, this analysis computes the maximum allowable EIRP as a function of active UWB device density.

Indoor and outdoor operation of UWB devices are considered in the aviation en-route navigation operational scenario. Since it is not possible to estimate what percentage of the UWB devices are operating indoor versus those operating outdoor, two cases are considered. In the first case all of the UWB devices are assumed to be operating outdoors and in the second case all of the UWB devices are assumed to be operating indoors.

In the en-route navigation operational scenarios, the GPS receiver antenna is located on top of the aircraft. In a previous analysis of terrestrial interference to GPS receivers, an antenna gain below the aircraft of -10 dBi was used.[71] Since there are no specifications on antenna gain below the aircraft and sufficient installed antenna pattern data is lacking on civil aircraft the value of antenna gain of -10 dBi is used in the aviation en-route navigation operational scenario.

A factor of 2 dB is included in the analysis to take into account the alignment of the UWB device antennas with respect to the airborne GPS receiver in the en-route navigation operational scenario.

Since en-route navigation is a safety-of-life function it is appropriate to include a 6 dB safety margin in this operational scenario.

[70] NTIA Report 01-43 at 5-5.

[71] DO-235 at F-13.

A summary of the technical factors associated with the aviation en-route navigation operational scenario is provided in Table 3-9.

TABLE 3-9. Technical Factors for the Aviation En-Route Navigation Operational Scenario

Technical Factors	Value	
	Outdoor UWB Device Operation	Indoor UWB Device Operation
GPS Receiver Antenna Gain	-10 dBi	-10 dBi
GPS Antenna Height	303 meters	303 meters
UWB Device Antenna Height	3 meters	3 meters
Minimum Distance Separation	303 meters	303 meters
Propagation Model	Free-space	Free-space
Interference Allotment to UWB Devices	10 dB (10%)	10 dB (10%)
Variations in GPS Receivers	3 dB	3 dB
Aviation Safety Margin	6 dB	6 dB
UWB Device Antenna Alignment	2 dB	2 dB
Multiple UWB Devices	Variable	Variable
Activity Factor for Each UWB Device	0 dB (100%)	0 dB (100%)
Building Attenuation	0 dB	9 dB
GPS Receiver Architecture	C/A-code (TSO-C129a Compliant)	

3.2.5.2 Non-Precision Approach Landing

The FAA distinguishes a precision approach landing from a non-precision approach landing by requiring that a precision approach have a combined lateral and vertical (glide slope) guidance. The term non-precision approach refers to landings at facilities without a glide slope capability. The FAA maintains the same level of flight safety for non-precision approaches as it does for precision approaches. They achieve this equity by requiring a much larger displacement area at the missed approach point and a higher minimum descent height (MDH) for the non-precision approach landings than they do for the precision approach landings. The MDH is the lowest altitude to which descent shall be authorized for procedures not using a glide slope (vertical guidance).[72]

[72] RTCA Special Committee 159, *Second Interim Report to the Department of Transportation: Ultra-Wideband Technology Radio Frequency Interference Effects to Global Positioning System Receivers and Interference Encounter Scenario Development* (March 14, 2001) at 46.

Associated with each non-precision approach landing segment there is a MDH. The MDH is computed by:

$$MDH = 250 \text{ feet} + (\text{Obstacle Height}) \quad (7)$$

If there are no obstructions, then the MDH is 250 feet. Assuming that a UWB device can be located on top of an obstacle, or at ground level within an obstacle-free zone, and assuming that the GPS antenna is located 7 feet above the aircraft control point[73], the following equation is used to compute the minimum distance separation between the GPS receiver used for non-precision approach landings and a UWB device:

$$D_{min} = 257 - TSE \quad (8)$$

where TSE is the Total System Error.

The TSE is comprised of both the aircraft and its navigation system tracking errors. It is the difference between true position and desired position. The TSE is computed from the root-sum-square of the Flight Technical Error (FTE) and the Navigation System Error (NSE):

$$TSE = ((FTE)^2 + (NSE)^2)^{0.5} \quad (9)$$

The FTE is the error contribution of the pilot using the presented information to control aircraft position. The NSE is the error attributable to the navigation system in use. It includes the navigation sensor error, receiver error, and path definition error.

The 95% probability (2σ) value for the FTE is 100 feet.[74] The NSE for the vertical guidance for the 3σ value is 103 feet corresponding to the minimum accuracy requirements for vertical guidance equipment.[75] Based on the 3σ value, the 2σ value for NSE is then 68.6 feet. Using Equation 9 the TSE is then 121.2 feet. Using Equation 8, the minimum distance separation between the GPS receiver used for the non-precision approach landings and a UWB device is 135.8 feet.

In the previous analyses that have been performed examining interference from terrestrial emitters to a GPS receiver used for precision approach landings it was assumed that a single emitter was below the aircraft and located at the Category I decision point.[76] The effect of multiple interfering emitters was not considered in this analysis. A methodology was presented in

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[73] The aircraft control point is the point on the aircraft at which vertical and lateral deviations of the aircraft are measured.

[74] Document No. RTCA/DO-208, *Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using GPS* (July 1991) at E-4.

[75] *Id.* at 34.

[76] DO-235 at Appendix F Annex 2.

RTCA Working Group 6 to address multiple interfering sources.[77] As an aircraft passes over the UWB devices, the antenna located on top of the aircraft projects a plane on the surface of the Earth as shown in Figure 3-2. As shown in Figure 3-2, point P represents the GPS receiver antenna. The surface E represents the plane containing the interfering sources. The parameter h is the minimum distance from point P to plane E. The parameter d is the distance from points on plane E whose propagation loss differs from the minimum loss at distance h by a fixed propagation loss ratio (LR). The parameter r is the radius of the plane (circle) containing the points of the fixed propagation loss ratio. The radius of this circle is given by:

$$r = h\,(LR-1)^{0.5} \qquad (10)$$

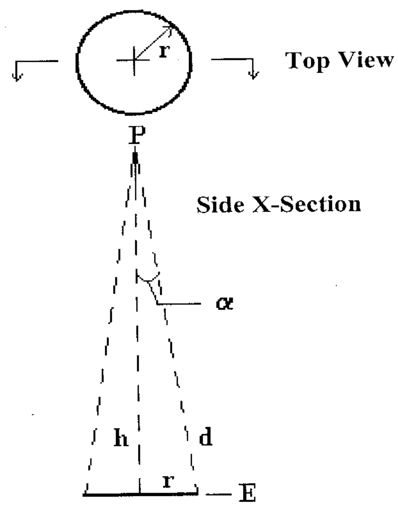

Figure 3-2. Airborne Antenna Projection Geometry

A derivation of Equation 10 is provided in Appendix A of NTIA Report 01-45. Another factor to be considered is the variation in antenna gain. This can be examined from the angle alpha in Figure 3-2 using the following equation:

$$\text{alpha} = \cos^{-1}\left(1/(LR)^{0.5}\right) \qquad (11)$$

A derivation for Equation 11 is also provided in Appendix A of the NTIA Report 01-45.

In determining a representative value for LR, the variation in antenna gain should be taken into consideration. Although the antenna gain specified in Table 3-1 shows a constant antenna gain in the region of -90 to -10 degrees, the actual antenna pattern contains many peaks and nulls

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[77] R. J. Erlandson, Rockwell Collins, *UWB Cumulative RFI Effects Aspects for Aviation Precision Approach Scenarios,* SC-159 WG 6 Presentation (Oct. 25, 2000).

(maximum and minimum values of antenna gain).[78] Therefore, the value of LR should be selected to minimize the variation in antenna gain, thereby permitting the use of a single representative antenna gain in the analysis. Using Equation 10 with the minimum distance separation of 136 feet and a propagation loss ratio of 0.1 dB, a circle with a radius of 20.7 feet (41.4 feet in diameter) is computed. For the fixed propagation loss ratio of 0.1 dB, the computed antenna cone angle (α) is 8.68 degrees. This angle is assumed to be small enough to neglect antenna gain variations and will permit the use of a single value of antenna gain in the analysis.

A circle with a diameter of 41.4 feet is large enough to contain several UWB devices. In the aviation non-precision approach landing operational scenario four UWB devices are considered.

In the non-precision approach landing operational scenario, the GPS receiver antenna is located on top of the aircraft. As discussed in the en-route navigation operational scenario, a previous analysis of terrestrial interference to GPS receivers used an antenna gain below the aircraft of -10 dBi. Since there are no specifications on antenna gain below the aircraft and sufficient installed antenna pattern data is lacking on civil aircraft an antenna gain of -10 dBi will be used in this operational scenario.

In this operational scenario, the minimum distance separation between the GPS receiver and the UWB devices is 136 feet. Typically, when the aircraft is at this altitude there are no buildings or structures that are located along the area approaching the runway. Therefore, this analysis only considers UWB devices that are operating outdoors.

Since non-precision approach landings are considered a safety-of-life function it is appropriate to include a 6 dB safety margin in this operational scenario.

A summary of the technical factors associated with the aviation non-precision approach landing operational scenario is provided in Table 3-10.

[78] DO-235 at Appendix E Annex 2.

TABLE 3-10. Technical Factors for the Aviation Non-Precision Approach Landing Operational Scenario

Technical Factors	Value
GPS Receiver Antenna Gain	-10 dBi
GPS Antenna Height	41.4 meters
UWB Device Antenna Height	3 meters
Minimum Distance Separation	41.4 meters
Propagation Model	Free-space
Interference Allotment to UWB Devices	10 dB (10%)
Variations in GPS Receivers	3 dB
Aviation Safety Margin	6 dB
Multiple UWB Devices	4 UWB devices
Activity Factor for Each UWB Device	0 dB (100%)
Building Attenuation	0 dB
GPS Receiver Architecture	C/A-code (TSO C-129a Compliant)

3.3 ANALYSIS RESULTS

The results of the analysis are presented in this section. Prior to using the measured interference susceptibility levels (I_{meas}) in the analysis, adjustments must be made based on the signal structure of the interfering signal to compute the UWB interference threshold (I_T).

For signals that have been characterized as causing CW-like interference, the value of I_T used in the analysis is based on the power in a single spectral line. As such, the computed values of maximum allowable EIRP represent the power in a single CW-line, independent of the modulation employed.

For interfering signals that have been characterized as causing pulse-like interference, the value of I_{meas} used to compute I_T, was the average measured value. Those cases where neither a break-lock (BL) or reacquisition (RQT) threshold could be measured were referred to as Did Not Break Lock (DNBL). The value of I_{meas} used in the analysis was the maximum available UWB power. It should be noted that the maximum available UWB power was limited by the peak power of the UWB generator. In the case of UWB signals employing 20% gating, where neither a BL or RQT condition was obtained, the maximum available UWB power was reduced by a factor of 10 Log (gating percentage) to obtain an average value for I_T. This can result in an incongruous situation, where the computed value of maximum allowable EIRP is lower for the gated UWB signal versus the non-gated signal.

The GPS receivers considered in the analysis employ one of two receiver architectures: C/A-code (TSO-C129a compliant) and narrowly-spaced correlator. A GPS receiver that employs C/A-code architecture processes the transmitted C/A-code signal, which has a null-to-null bandwidth of 2.046 MHz.[79] A GPS receiver that employs the narrowly-spaced correlator architecture, also processes the C/A-code signal. However, in order to attain a higher degree of accuracy by reducing the effects of mulipath, GPS receivers employing the narrowly-spaced correlator architecture process a wider portion of the transmitted C/A-code signal. GPS receivers employing narrowly-spaced correlator architecture process approximately 16 to 18 MHz of the C/A-code signal. Since the interference effects are different depending on the spectral characteristics of the UWB signals, adjustments must be made to the values of I_{meas} before they can be used in the analysis.

The C/A signal has an approximate $sinc^2$ power spectral envelope with a null-to-null bandwidth of 2.046 MHz. Each GPS satellite employs one of a family of short pseudo-random codes known as Gold codes to generate the C/A-code signal. Due to the short period (1 millisecond) length Gold code there are distinct spectral lines spaced 1 kHz apart. The spectral lines deviate from the $sinc^2$ envelope enough to create dominant spectral lines that are more vulnerable to CW-like interference. In the measurements when a UWB signal structure contains spectral lines, one of the lines is placed close (nominally 500 Hz) to a dominant GPS spectral line.[80] As discussed in Section 2.2 of NTIA Report 01-45, when a UWB signal structure contains spectral lines an adjustment is made to the measured interference susceptibility level to determine the power in the spectral line prior to using this level in the analysis.[81] An adjustment is also made to the measured interference susceptibility levels when the UWB signal is gated. When the UWB signal appears noise-like an adjustment must also be made to the measured interference susceptibility level to correct for the difference in the measurement bandwidth (20 MHz) and the bandwidth used in the analysis (1 MHz). Section 2.2.2.1 of NTIA Report 01-45 provides a more detailed discussion of the adjustments made to the measured susceptibility levels based on the UWB signal structure.[82] Tables 3-11 and 3-12 provide the equations as a function of the interfering signal structure that are necessary to compute the UWB interference thresholds used in the analysis for GPS receivers employing the narrowly-spaced correlator and C/A code (TSO-C129a) architectures respectively.

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[79] The L-band Standard Positioning Service (SPS) ranging signal is a 2.046 MHz null-to-null bandwidth signal centered on L1. The transmitted ranging signal that comprises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz.

[80] Due to the spectral content of each C/A code signal, the location of the dominant spectral line is different and could be close to a UWB spectral line that is present in the passband of the GPS receiver.

[81] NTIA Report 01-45 at 2-8.

[82] *Id.* at 2-12.

TABLE 3-11. Equations Used to Compute the Single-Entry UWB Interference Thresholds for the Narrowly-Spaced Correlator GPS Receiver Architecture

Interfering Signal Structure	UWB Interference Threshold Equation
Broadband Noise	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 100 kHz Modulation: None Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) - 30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 1, 5, and 20 MHz Modulation: None Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) 1 line (20 MHz), 5 lines (5 MHz), and 21 lines (1 MHz)
PRF: 100 kHz and 1MHz Modulation: None Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) - 30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating %)
PRF: 5 and 20 MHz Modulation: None Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) + 10 Log (Gating %) - 7 dB[1] 1 line (20 MHz) and 5 lines (5 MHz)
PRF: 100 kHz, 1, 5, and 20 MHz Modulation: 2% Rel. and 50% Abs. Dithering Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 100 kHz, 1, 5, and 20 MHz Modulation: 2% Rel. and 50% Abs. Dithering Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating%)
PRF: 100 kHz Modulation: OOK Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 1, 5, and 20 MHz Modulation: OOK Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -3dB[2] - 30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) 1 line (20 MHz) 5 lines (5 MHz), and 21 lines (1 MHz)
PRF: 100 kHz and 1MHz Modulation: OOK Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating %)
PRF: 5 and 20 MHz Modulation: OOK Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -3dB[2] - 30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) + 10 Log (Gating %) - 7dB[1] 1 line (20 MHz) and 5 lines (5 MHz)

Notes:
1. Adjustment to compute the power in a single spectral line that is spread in frequency by the gating period resulting in a $sinc^2$ shape around each line.
2. Adjustment for the division of power between discrete spectral lines and continuous spectrum for OOK modulated UWB signal.

TABLE 3-12. Equations Used to Compute the Single-Entry UWB Interference Thresholds for the C/A Code GPS Receiver Architecture (TSO-C129a Compliant)

Interfering Signal Structure	UWB Interference Threshold Equation
Broadband Noise	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 100 kHz Modulation: None Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) - 30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 1, 5, and 20 MHz Modulation: None Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) 1 line (20 MHz), 5 lines (5 MHz), and 21 lines (1 MHz)
PRF: 100 kHz Modulation: None Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) - 30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating %)
PRF: 1, 5, and 20 MHz Modulation: None Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) + 10 Log (Gating %) - 7 dB[1] 1 line (20 MHz), 5 lines (5 MHz), and 21 lines (1 MHz)
PRF: 100 kHz, 1, 5, and 20 MHz Modulation: 2% Rel. and 50% Abs. Dithering Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 100 kHz, 1, 5, and 20 MHz Modulation: 2% Rel. and 50% Abs. Dithering Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating%)
PRF: 100 kHz Modulation: OOK Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz)
PRF: 1, 5, and 20 MHz Modulation: OOK Gating: 100%	$I_T = I_{meas}$ (dBm/20MHz) -3dB[2] - 30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) 1 line (20 MHz), 5 lines (5 MHz), and 21 lines (1 MHz)
PRF: 100 kHz Modulation: OOK Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -30 (dBW/dBm) - 10 Log (20 MHz/1 MHz) + 10 Log (Gating %)
PRF: 1, 5, and 20 MHz Modulation: OOK Gating: 20%	$I_T = I_{meas}$ (dBm/20MHz) -3dB[2] - 30 (dBW/dBm) - 10 Log (# of lines in a 20 MHz bandwidth) + 10 Log (Gating %) - 7dB[1] 1 line (20 MHz), 5 lines (5 MHz), and 21 lines (1 MHz)

Notes:
1. Adjustment to compute the power in a single spectral line that is spread in frequency by the gating period resulting in a $sinc^2$ shape around each line.
2. Adjustment for the division of power between discrete spectral lines and continuous spectrum for OOK modulated UWB signal.

Tables 3-13 and 3-14 provide the UWB interference thresholds for each of the GPS receiver architectures measured. The UWB interference threshold and the GPS receiver criteria used to determine the levels are shown for the different interfering signal structures considered in this analysis for both single-entry and multiple-entry (aggregate) UWB device interactions.

TABLE 3-13. UWB Interference Thresholds for Narrowly-Spaced Correlator Receiver Architecture

Interfering Signal Structure	Category of Interfering Signal (Single-Entry)	UWB Interference Threshold (Single-Entry)	Category of Interfering Signal (Aggregate)	UWB Interference Threshold (Aggregate)
Broadband Noise	Noise-Like	-132.2 dBW/MHz	Noise-Like	-132.2 dBW/MHz
0.1 MHz PRF, No Mod, 100% Gate	Pulse-Like	-100.2 dBW/MHz[a]	Pulse-Like	-100.2 dBW/MHz[a]
0.1 MHz PRF, No Mod, 20% Gate	Pulse-Like	-107.1 dBW/MHz[a]	Pulse-Like	-107.1 dBW/MHz[a]
0.1 MHz PRF, OOK, 100% Gate	Pulse-Like	-103.2 dBW/MHz[a]	Pulse-Like	-103.2 dBW/MHz[a]
0.1 MHz PRF, OOK. 20% Gate	Pulse-Like	-110.2 dBW/MHz[a]	Pulse-Like	-110.2 dBW/MHz[a]
0.1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	-100.1 dBW/MHz[a]	Pulse-Like	-100.1 dBW/MHz[a]
0.1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	-107.1 dBW/MHz[a]	Pulse-Like	-107.1 dBW/MHz[a]
0.1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	-100.1 dBW/MHz[a]	Pulse-Like	-100.1 dBW/MHz[a]
0.1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	-107.1 dBW/MHz[a]	Pulse-Like	-107.1 dBW/MHz[a]
1 MHz PRF, No Mod, 100% Gate	CW-Like	-144.1 dBW	CW-Like	-144.1 dBW
1 MHz PRF, No Mod, 20% Gate	Pulse-Like	-94.8 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
1 MHz PRF, OOK, 100% Gate	CW-Like	-139.9 dBW	CW-Like	-139.9 dBW
1 MHz PRF, OOK, 20% Gate	Pulse-Like	-97.8 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	-105.9 dBW/MHz	Noise-Like	-132.2 dBW/MHz[b]
1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	-94.8 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	-87.8 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	-94.7 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
5 MHz PRF, No Mod, 100% Gate	CW-Like	-145.7 dBW	CW-Like	-145.7 dBW
5 MHz PRF, No Mod, 20% Gate	CW-Like	-146.6 dBW	CW-Like	-146.6 dBW
5 MHz PRF, OOK, 100% Gate	CW-Like	-146.7 dBW	CW-Like	-146.7 dBW
5 MHz PRF, OOK, 20% Gate	CW-Like	-142.6 dBW	CW-Like	-142.6 dBW
5 MHz PRF, 50% abs, 100% Gate	Noise-Like	-127.7 dBW/MHz	Noise-Like	-127.7 dBW/MHz
5 MHz PRF, 50% abs, 20% Gate	Pulse-Like	-88.5 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
5 MHz PRF, 2% rel, 100% Gate	Noise-Like	-127.6 dBW/MHz	Noise-Like	-127.6 dBW/MHz
5 MHz PRF, 2% rel, 20% Gate	Pulse-Like	-88.5 dBW/MHz[a]	Noise-Like	-132.2 dBW/MHz[b]
20 MHz PRF, No Mod, 100% Gate	CW-Like	-146.1 dBW	CW-Like	-146.1 dBW
20 MHz PRF, No Mod, 20% Gate	CW-Like	-146.9 dBW	CW-Like	-146.9 dBW
20 MHz PRF, OOK, 100% Gate	CW-Like	-146.5 dBW	CW-Like	-146.5 dBW
20 MHz PRF, OOK, 20% Gate	CW-Like	-145.4 dBW	CW-Like	-145.4 dBW
20 MHz PRF, 50% abs, 100% Gate	Noise-Like	-133.6 dBW/MHz	Noise-Like	-133.6 dBW/MHz

20 MHz PRF, 50% abs, 20% Gate	Pulse-Like	-100.5 dBW/MHz	Noise-Like	-132.2 dBW/MHz[b]
20 MHz PRF, 2% rel, 100% Gate	Noise-Like	-135.5 dBW/MHz	Noise-Like	-135.5 dBW/MHz
20 MHz PRF, 2% rel, 20% Gate	Pulse-Like	-122.2 dBW/MHz	Noise-Like	-132.2 dBW/MHz[b]

Note: a. Interference threshold not reached at maximum available UWB generator power.
b. Based on more than three UWB devices.

TABLE 3-14. UWB Interference Thresholds for C/A-Code (TSO-C129a Compliant) Receiver Architecture

Interfering Signal Structure	Category of Interfering Signal (Single-Entry)	UWB Interference Threshold (Single-Entry)	Category of Interfering Signal (Aggregate)	UWB Interference Threshold (Aggregate)
Broadband Noise	Noise-Like	-136 dBW/MHz	Noise-Like	-136 dBW/MHz
0.1 MHz PRF, No Mod, 100% Gate	Pulse-Like	-117.9 dBW/MHz[a]	Pulse-Like	-117.9 dBW/MHz[a]
0.1 MHz PRF, No Mod, 20% Gate	Pulse-Like	-106.8 dBW/MHz[a]	Pulse-Like	-106.8 dBW/MHz[a]
0.1 MHz PRF, OOK, 100% Gate	Pulse-Like	-103.1 dBW/MHz[a]	Pulse-Like	-103.1 dBW/MHz[a]
0.1 MHz PRF, OOK. 20% Gate	Pulse-Like	-109.9 dBW/MHz[a]	Pulse-Like	-109.9 dBW/MHz[a]
0.1 MHz PRF, 50% abs, 100% Gate	Pulse-Like	-115 dBW/MHz[a]	Pulse-Like	-115 dBW/MHz[a]
0.1 MHz PRF, 50% abs, 20% Gate	Pulse-Like	-106.8 dBW/MHz[a]	Pulse-Like	-106.8 dBW/MHz[a]
0.1 MHz PRF, 2% rel, 100% Gate	Pulse-Like	-97.9 dBW/MHz[a]	Pulse-Like	-97.9 dBW/MHz[a]
0.1 MHz PRF, 2% rel, 20% Gate	Pulse-Like	-106.9 dBW/MHz[a]	Pulse-Like	-106.9 dBW/MHz[a]
1 MHz PRF, No Mod, 100% Gate	CW-Like	-140.8 dBW	CW-Like	-140.8 dBW
1 MHz PRF, No Mod, 20% Gate	CW-Like	-146.7 dBW	CW-Like	-146.7 dBW
1 MHz PRF, OOK, 100% Gate	CW-Like	-140.8 dBW	CW-Like	-140.8 dBW
1 MHz PRF, OOK, 20% Gate	CW-Like	-140.7 dBW	CW-Like	-140.7 dBW
1 MHz PRF, 50% abs, 100% Gate	Noise-Like	-142 dBW/MHz	Noise-Like	-142 dBW/MHz
1 MHz PRF, 50% abs, 20% Gate	Noise-Like	-139.5 dBW/MHz	Noise-Like	-139.5 dBW/MHz
1 MHz PRF, 2% rel, 100% Gate	Noise-Like	-141.5 dBW/MHz	Noise-Like	-141.5 dBW/MHz
1 MHz PRF, 2% rel, 20% Gate	Noise-Like	-133.5 dBW/MHz	Noise-Like	-133.5 dBW/MHz
5 MHz PRF, No Mod, 100% Gate	CW-Like	-138.4 dBW	CW-Like	-138.4 dBW
5 MHz PRF, No Mod, 20% Gate	CW-Like	-143.2 dBW	CW-Like	-143.2 dBW
5 MHz PRF, OOK, 100% Gate	CW-Like	-139.4 dBW	CW-Like	-139.4 dBW
5 MHz PRF, OOK, 20% Gate	CW-Like	-143.3 dBW	CW-Like	-143.3 dBW
5 MHz PRF, 50% abs, 100% Gate	Noise-Like	-142 dBW/MHz	Noise-Like	-142 dBW/MHz
5 MHz PRF, 50% abs, 20% Gate	Noise-Like	-141.9 dBW/MHz	Noise-Like	-141.9 dBW/MHz
5 MHz PRF, 2% rel, 100% Gate	Noise-Like	-143 dBW/MHz	Noise-Like	-143 dBW/MHz
5 MHz PRF, 2% rel, 20% Gate	Noise-Like	-142.4 dBW/MHz	Noise-Like	-142.4 dBW/MHz
20 MHz PRF, No Mod, 100% Gate	CW-Like	-139.8 dBW	CW-Like	-139.8 dBW
20 MHz PRF, No Mod, 20% Gate	CW-Like	-147.8 dBW	CW-Like	-147.8 dBW
20 MHz PRF, OOK, 100% Gate	CW-Like	-138.2 dBW	CW-Like	-138.2 dBW

20 MHz PRF, OOK, 20% Gate	CW-Like	-142.1dBW	CW-Like	-142.1 dBW
20 MHz PRF, 50% abs, 100% Gate	Noise-Like	-141 dBW/MHz	Noise-Like	-141 dBW/MHz
20 MHz PRF, 50% abs, 20% Gate	Noise-Like	-140.4 dBW/MHz	Noise-Like	-140.4 dBW/MHz
20 MHz PRF, 2% rel, 100% Gate	Noise-Like	-141 dBW/MHz	Noise-Like	-141 dBW/MHz
20 MHz PRF, 2% rel, 20% Gate	Noise-Like	-139.9 dBW/MHz	Noise-Like	-139.9 dBW/MHz
Note: a. Interference threshold not reached at maximum available UWB generator power.				

Sections 3.3.1 through 3.3.5 present the results of the maximum allowable EIRP scenario dependent analysis. Each section gives the analysis results for one of the five categories of GPS receiver applications considered. For each GPS receiver application several operational scenarios were analyzed. The analysis results are presented in the form of graphs where the bar represents the value of maximum allowable EIRP (i.e., a longer bar represents a lower value of maximum allowable EIRP). Both single-entry and multiple-entry UWB device interactions were considered. In a multiple-entry UWB device interaction, the maximum allowable EIRP level of a single-entry UWB device as shown on the graph was determined by partitioning the total interference allotment in accordance with the multiple (aggregate) UWB device factor as discussed in Section 3.1.4.

The maximum allowable EIRP (based on average power) of a single UWB device is displayed on the x-axis. The UWB signal permutations examined are displayed on the y-axis. Each UWB signal permutation is identified by three parameters: PRF, gating percentage, and modulation type. For example, a UWB signal employing a PRF of 1 MHz, 20% gating, and on-off keying modulation is identified as: 1 MHz, 20%, OOK. For UWB signals that employ gating, the threshold (I_T), used to compute the maximum allowable EIRP, is based on the average power measured over the entire gating period.

In addition to identifying the UWB signal parameters, each entry on the y-axis identifies the criteria used in the single-entry interference measurements, which were then used to compute the UWB interference thresholds. As discussed in Section 1.3.1, the two GPS receiver criteria used in this assessment are break-lock and reacquisition identified on the y-axis as BL and RQT respectively. UWB signal permutations for which neither a break-lock or reacquisition condition could be measured are identified on the y-axis as DNBL. For these signal permutations, the maximum available UWB signal power was used in the analysis. When multiple UWB devices were considered, resulting in noise-like interference, the UWB interference threshold was computed based on the broadband noise break-lock threshold. This is identified as NBL on the y-axis.

The results of the spreadsheet analysis program used to generate the graphs are provided in Appendix A.

There is a vertical dashed line shown on each graph that represents the current Part 15 level of -71.3 dBW/MHz. UWB signals that have been characterized as causing noise-like or pulse-like interference can be directly compared to the current Part 15 level. UWB signals that have been characterized as causing CW-like interference can be compared to the current level, if it is assumed that there is only a single spectral line in the measurement bandwidth. When the value of maximum allowable EIRP associated with a UWB signal permutation is located on the left side of the dashed line, additional attenuation below the current Part 15 level is not necessary in order to protect the GPS receiver architecture under consideration. When the value of maximum allowable EIRP associated with a UWB signal permutation is located on the right side of the dashed line, additional attenuation below the current Part 15 level is necessary to protect the GPS receiver architecture under consideration. For example, if the value of maximum allowable EIRP is -93 dBW/MHz, 21.7 dB of additional attenuation below the current Part 15 level is necessary to protect the GPS receiver architecture under consideration.

Three graphs are given for each of the operational scenarios that were analyzed. The first graph presents the analysis results for the UWB signal permutations that were characterized as causing pulse-like interference. The second graph presents the analysis results for the UWB signal permutations that were characterized as causing noise-like interference. The third graph presents the analysis results for the UWB signal permutations that were characterized as causing CW-like interference.

3.3.1 Terrestrial Applications

In the operational scenarios for terrestrial applications, the narrowly-spaced correlator receiver architecture is considered. The analysis results for the narrowly-spaced correlator receiver architecture are given in Figures 3-3 through 3-11. The operational scenarios considered both single and multiple UWB device interactions as well as indoor and outdoor UWB device operation. The values of maximum allowable EIRP shown in Figures 3-3 through 3-11 are for a single UWB device and are based on average power.

The values of maximum allowable EIRP that are required to protect the narrowly-spaced correlator receiver architecture considered in the terrestrial application operational scenarios will vary depending on the UWB signal parameters, single-entry versus multiple-entry UWB device interactions, and whether the UWB devices are used indoors or outdoors. The analysis results for the operational scenarios associated with terrestrial applications can be discussed in terms of the characterization of the UWB signal interference effects. As shown in Figure 3-3 the maximum allowable EIRP levels for the UWB signals that have been characterized as causing pulse-like interference range from -82.8 to -48.4 dBW/MHz for single UWB device interactions. Figures 3-6 and 3-9 show that for multiple-entry UWB device interactions resulting in pulse-like interference, the values of maximum allowable EIRP range from -59.9 to -49.8 dBW/MHz for outdoor UWB device operation and from -55.2 to -45.1 dBW/MHz for indoor UWB device operation. As shown in Figure 3-4 for UWB signals that have been characterized as causing noise-like interference, the values of maximum allowable EIRP range from -96.1 to -88.2 dBW/MHz for single-entry UWB device interactions. As shown in Figures 3-7 and 3-10, for multiple-entry UWB interactions resulting in noise-like interference, the values of maximum allowable EIRP range from -86.5 to -78.6 dBW/MHz for indoor UWB operation and from -91.2 to -83.3

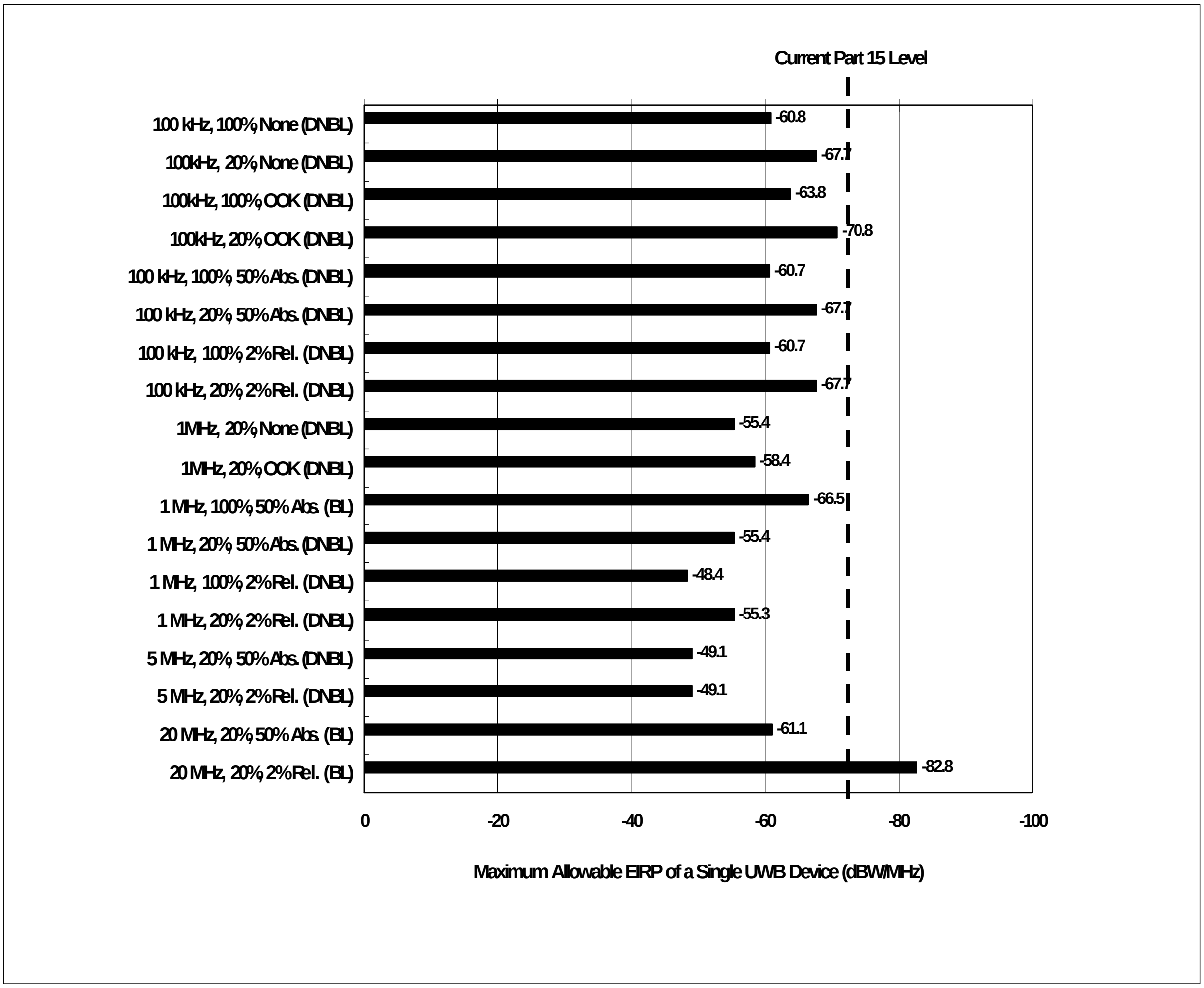


Figure 3-3. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (Pulse-Like UWB Signals)

dBW/MHz for outdoor UWB device operation. Figures 3-5, 3-8, and 3-11 give the analysis results for the UWB signals that have been characterized as causing CW-like interference. As shown in Figure 3-5, the values of maximum allowable EIRP range from -107.5 to -100.5 dBW for single-entry UWB device interactions. Figures 3-8 and 3-11 show that for multiple-entry UWB device interactions, the values of maximum allowable EIRP range from -91.9 to -84.9 dBW for indoor UWB device operation and from -96.6 to -89.6 dBW for outdoor UWB operation.

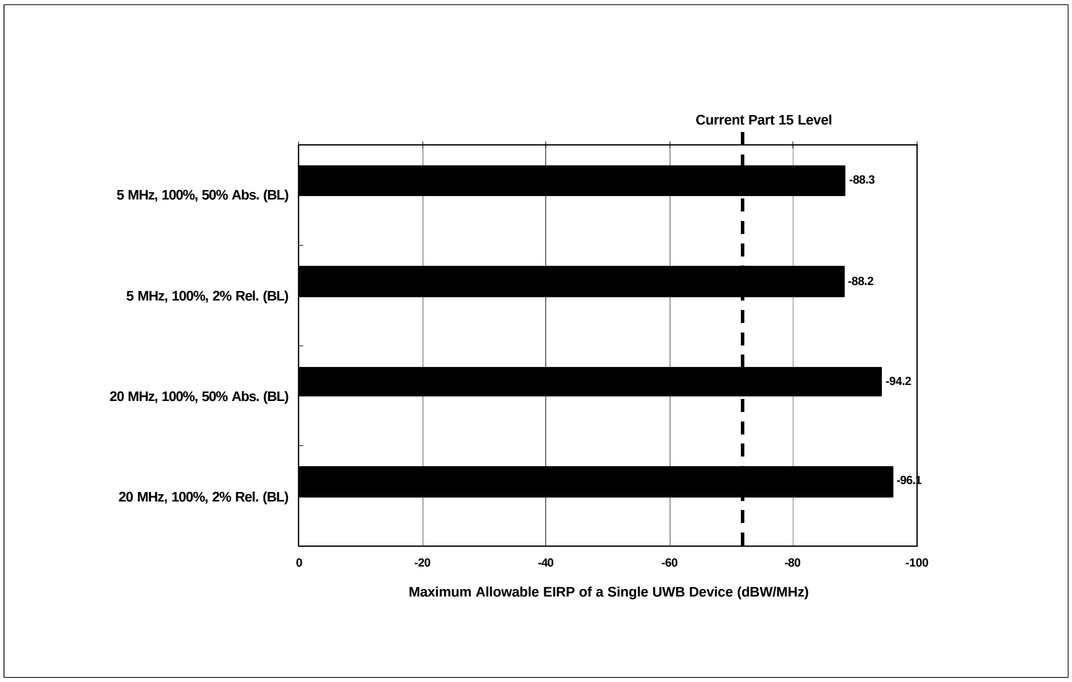


Figure 3-4. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (Noise-Like UWB Signals)

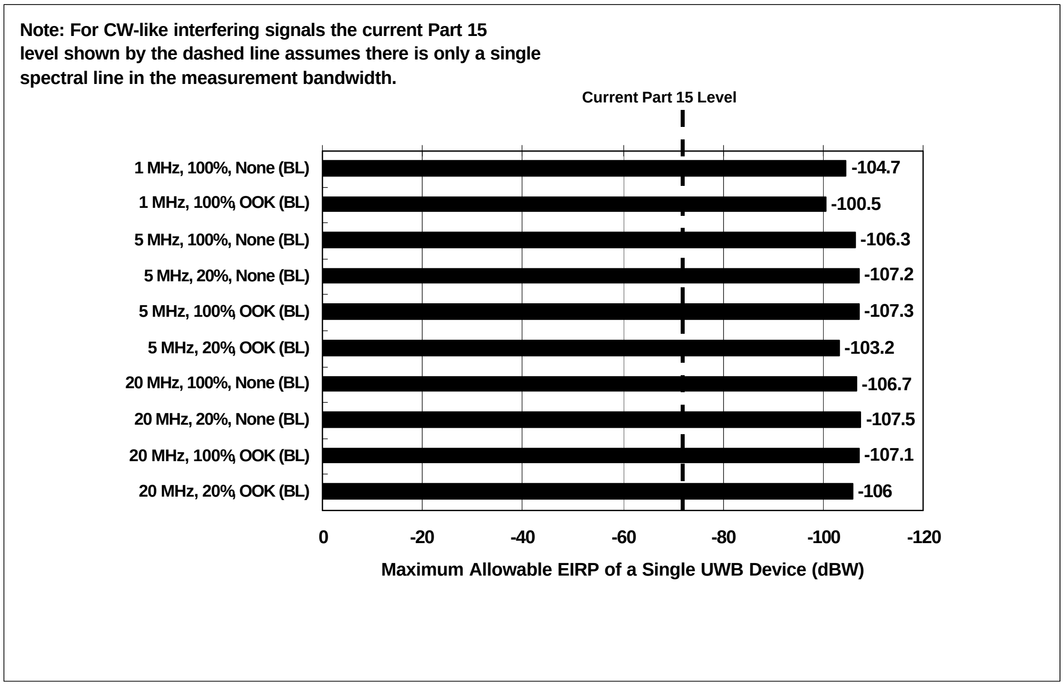


Figure 3-5. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (CW-Like UWB Signals)

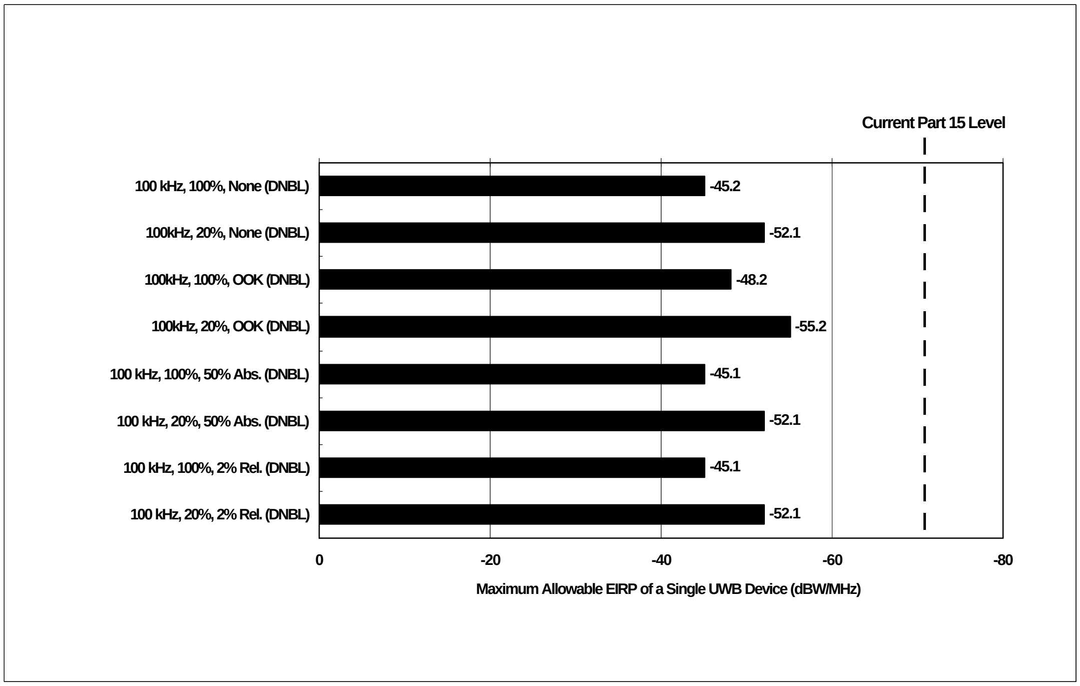


Figure 3-6. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Pulse-Like UWB Signals)

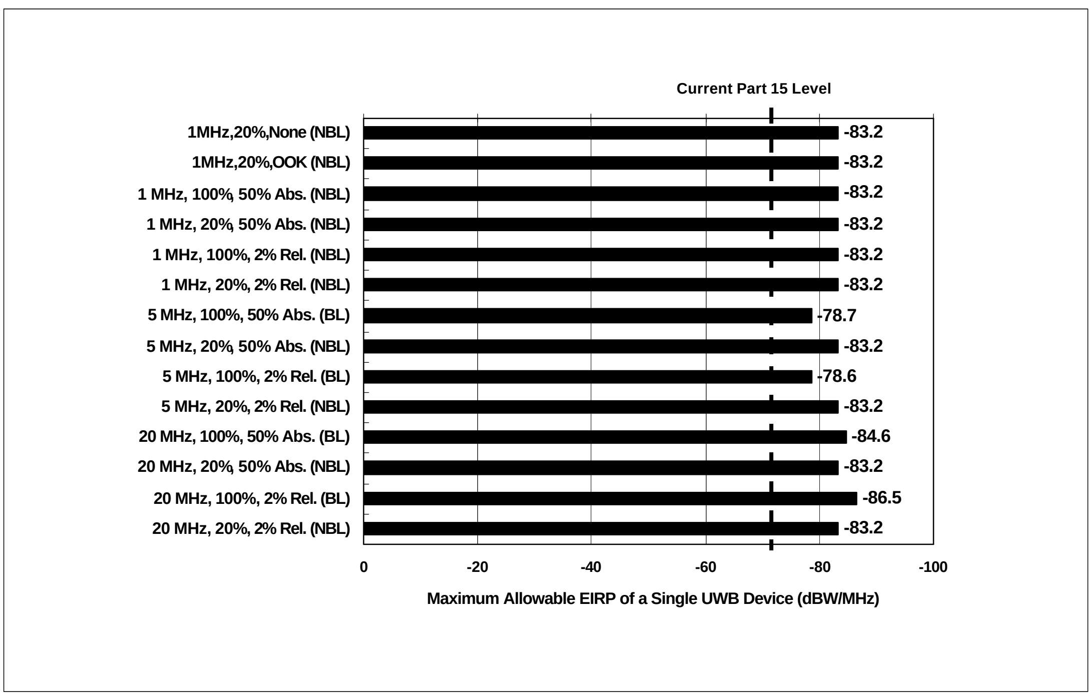


Figure 3-7. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Noise-Like UWB Signals)

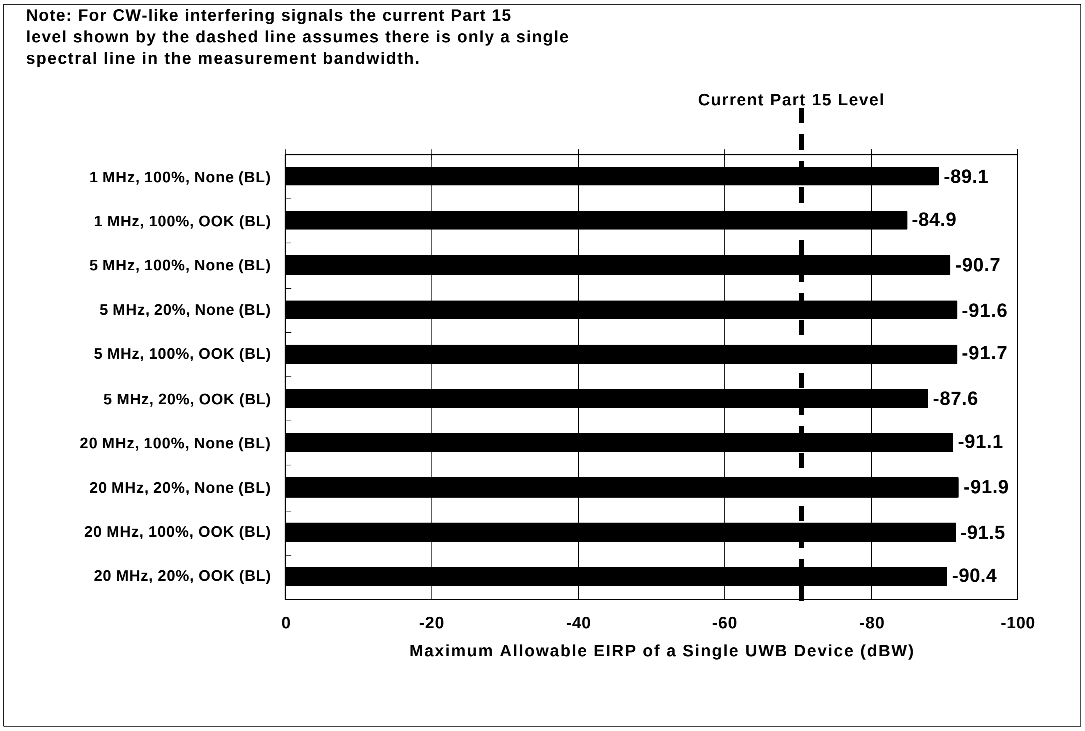


Figure 3-8. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (CW-Like UWB Signals)

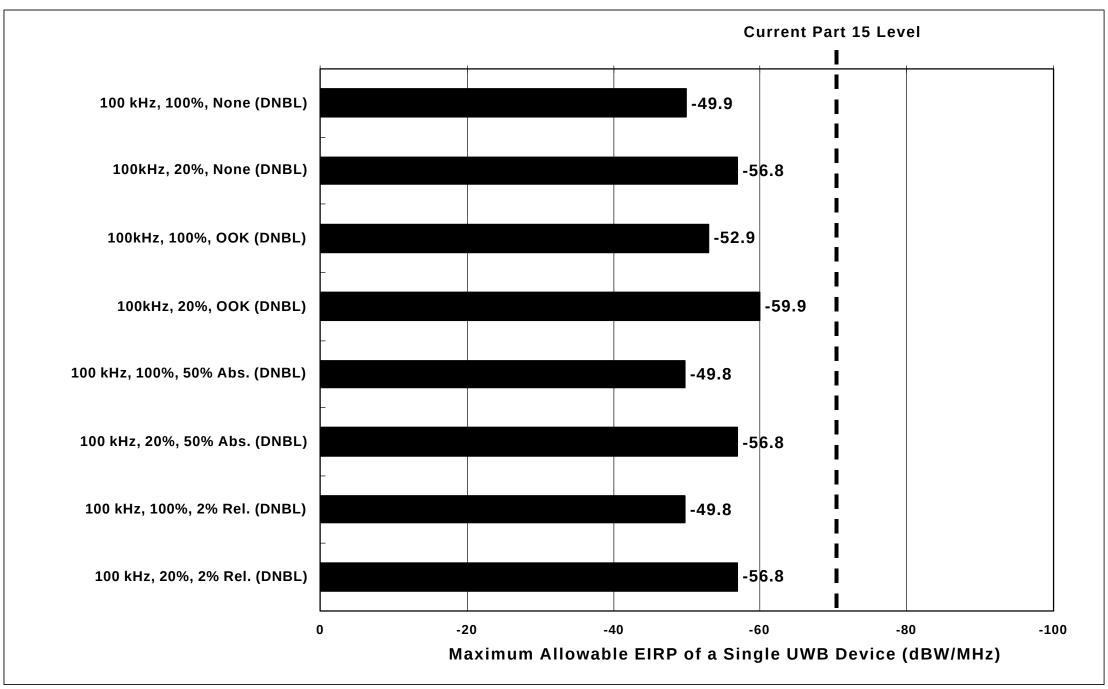


Figure 3-9. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Pulse-Like UWB Signals)

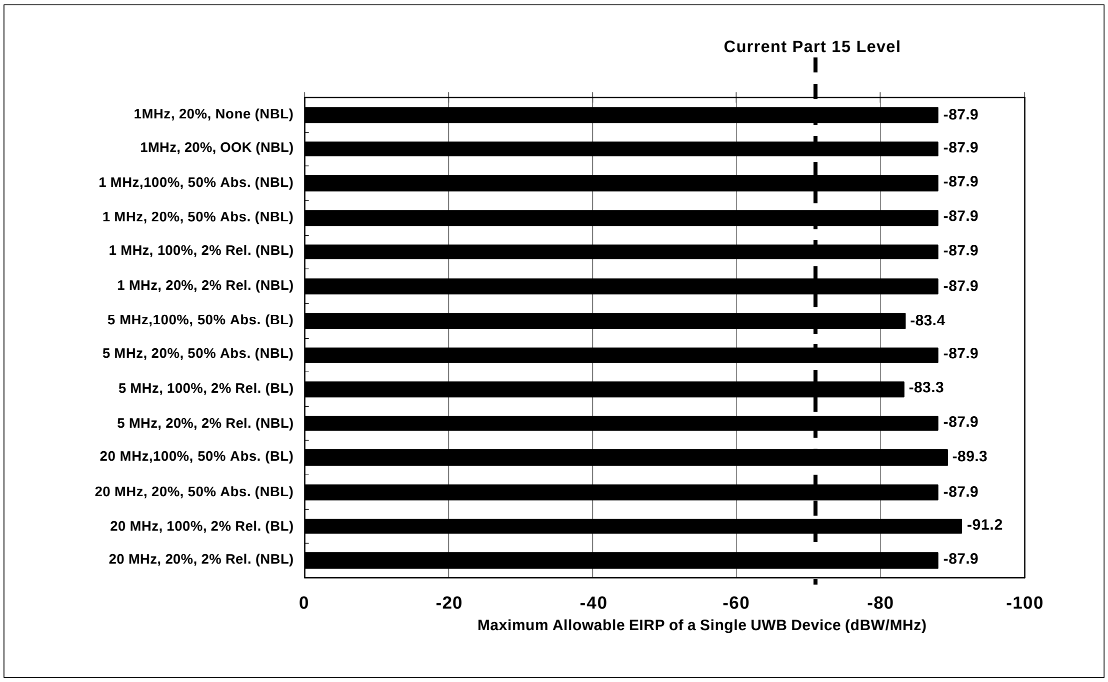


Figure 3-10. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Noise-Like UWB Signals)

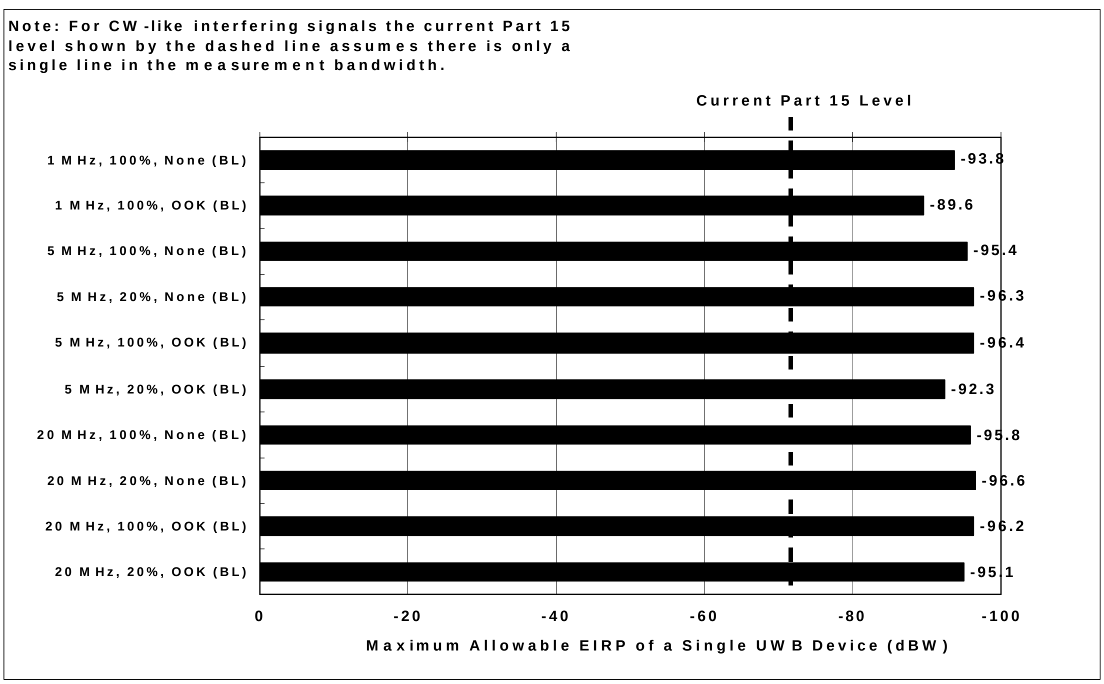


Figure 3-11. Analysis Results for Terrestrial Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (CW-Like UWB Signals)

3.3.2 Maritime Applications

In the operational scenarios for the maritime GPS applications, the narrowly-spaced correlator receiver architecture is considered. The analysis results for the narrowly-spaced correlator receiver architecture are given in Figures 3-12 through 3-23. Two antenna locations for the maritime use of GPS receivers were analyzed. The operational scenarios are designated as Maritime Operational Scenario I and II. The operational scenarios considered multiple-entry UWB device interactions as well as indoor and outdoor UWB device operation. The values of maximum allowable EIRP shown in Figures 3-12 through 3-23 are for a single UWB device and are based on average power.

The values of maximum allowable EIRP that are required to protect the narrowly-spaced correlator receiver architecture considered in the maritime application operational scenarios will vary depending on the UWB signal parameters and whether the UWB devices are used indoors or outdoors. The analysis results for the operational scenarios associated with maritime applications can be discussed in terms of the characterization of the UWB signal interference effects. As shown in Figures 3-12, 3-15, 3-18, and 3-21, the values of maximum allowable EIRP for the UWB signals that have been characterized as causing pulse-like interference range from -39.3 to -26.6 dBW/MHz for indoor UWB device operation and from -45.7 to -34.9 dBW/MHz for outdoor UWB device operation. Figures 3-13, 3-16, 3-19, and 3-22 show that for the UWB signals that have been characterized as causing noise-like interference, the values of maximum allowable EIRP range from -70.6 to -60.1 dBW/MHz and from -77 to -68.4 dBW/MHz for indoor and outdoor use of UWB devices respectively. Figures 3-14, 3-17, 3-20, and 3-23 show that for the UWB signals that have been characterized as causing CW-like interference, the values of maximum allowable EIRP range from -76 to -66.4 dBW for indoor UWB operation and from -82.4 to -74.7 dBW for outdoor UWB device operation.

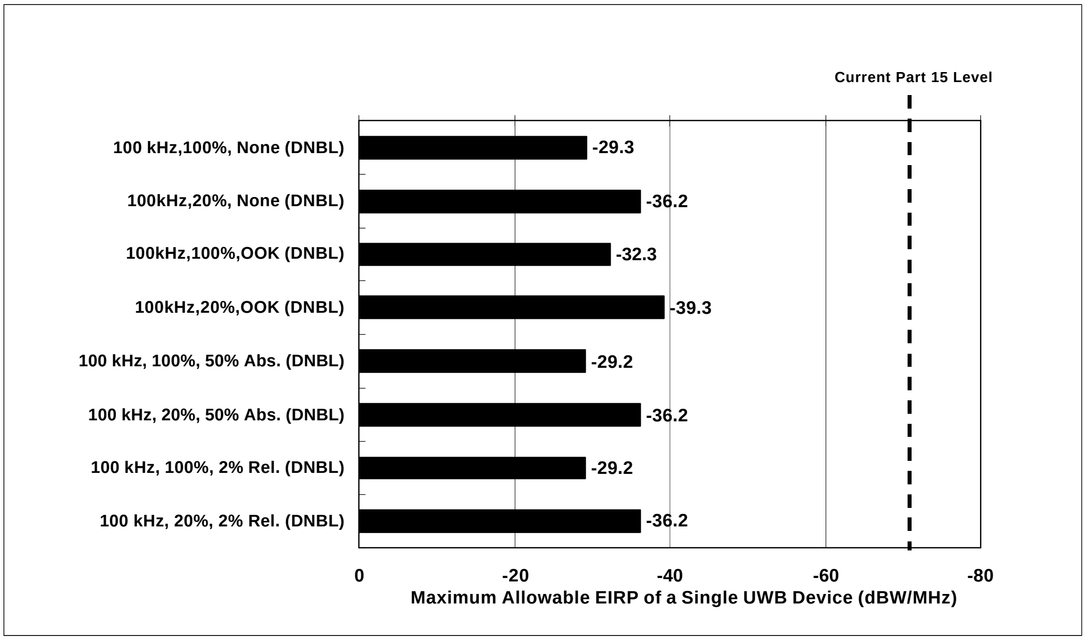


Figure 3-12. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Pulse-Like UWB Signals)

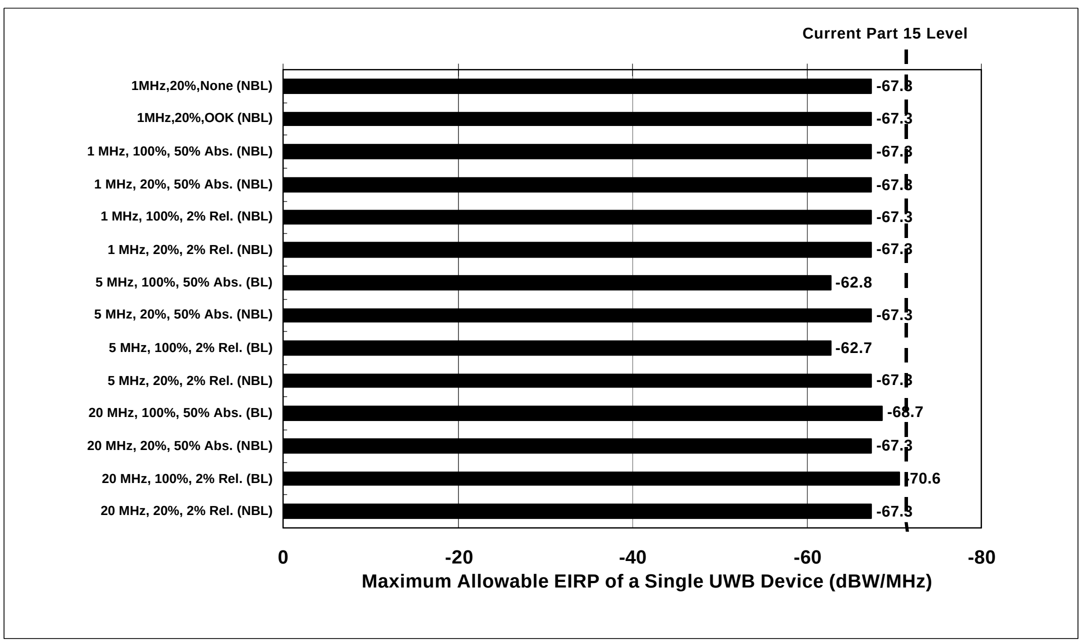


Figure 3-13. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Noise-Like UWB Signals)

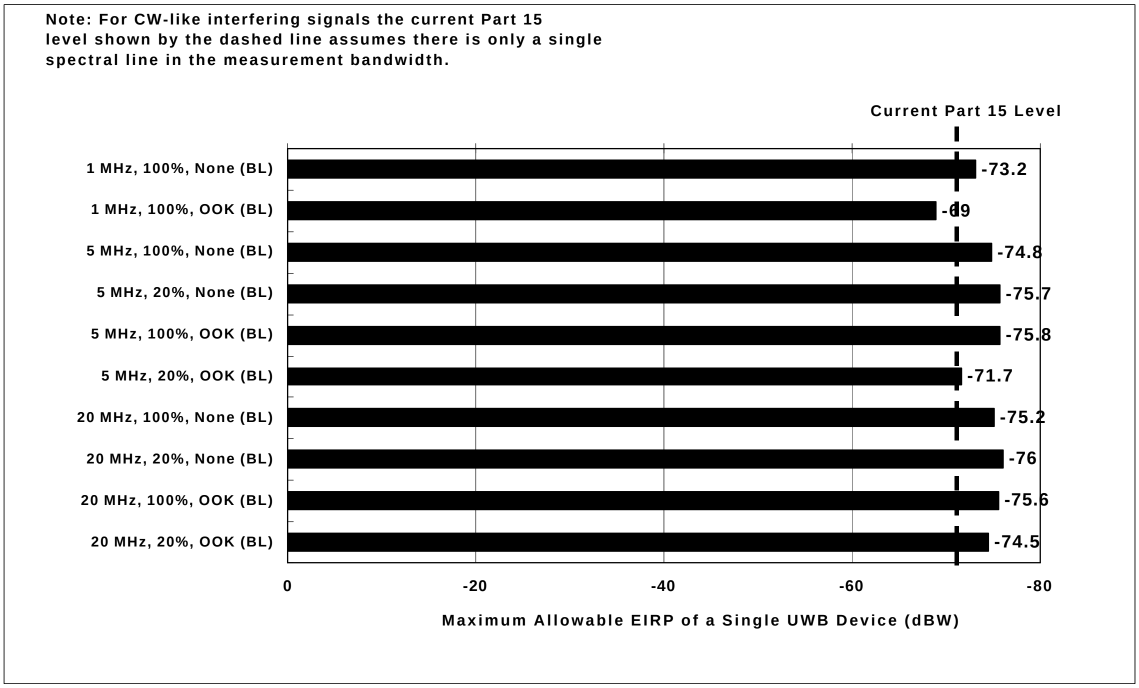


Figure 3-14. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (CW-Like UWB Signals)

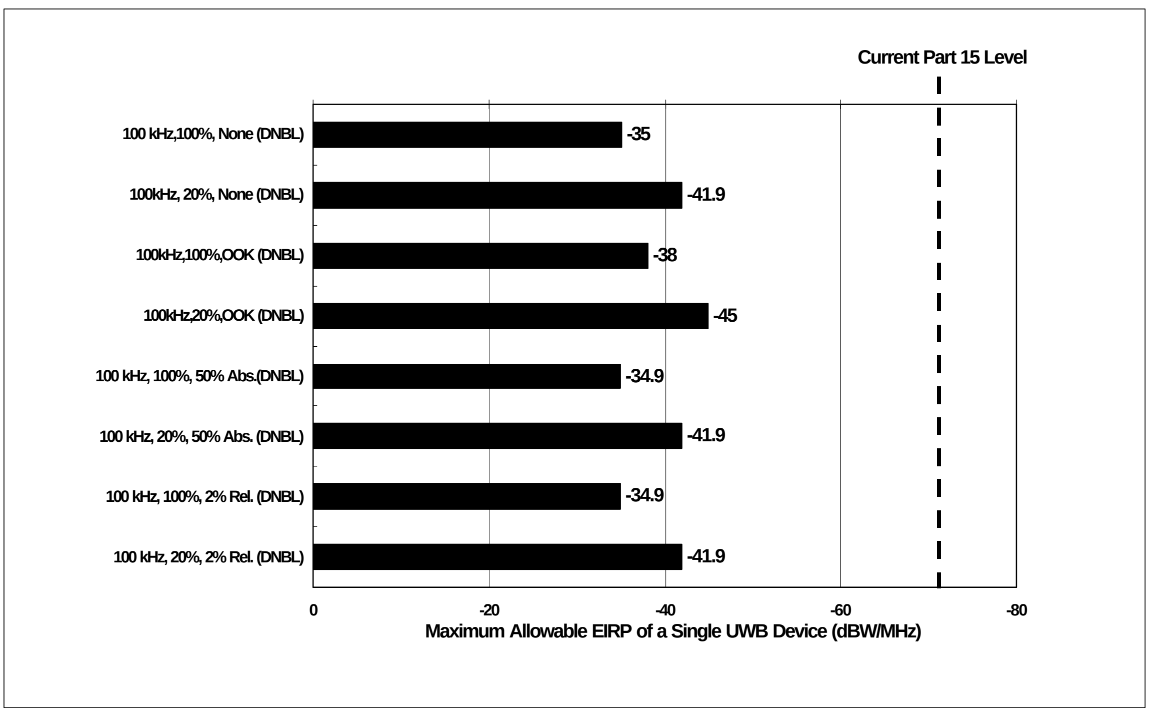


Figure 3-15. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Pulse-Like UWB Signals)

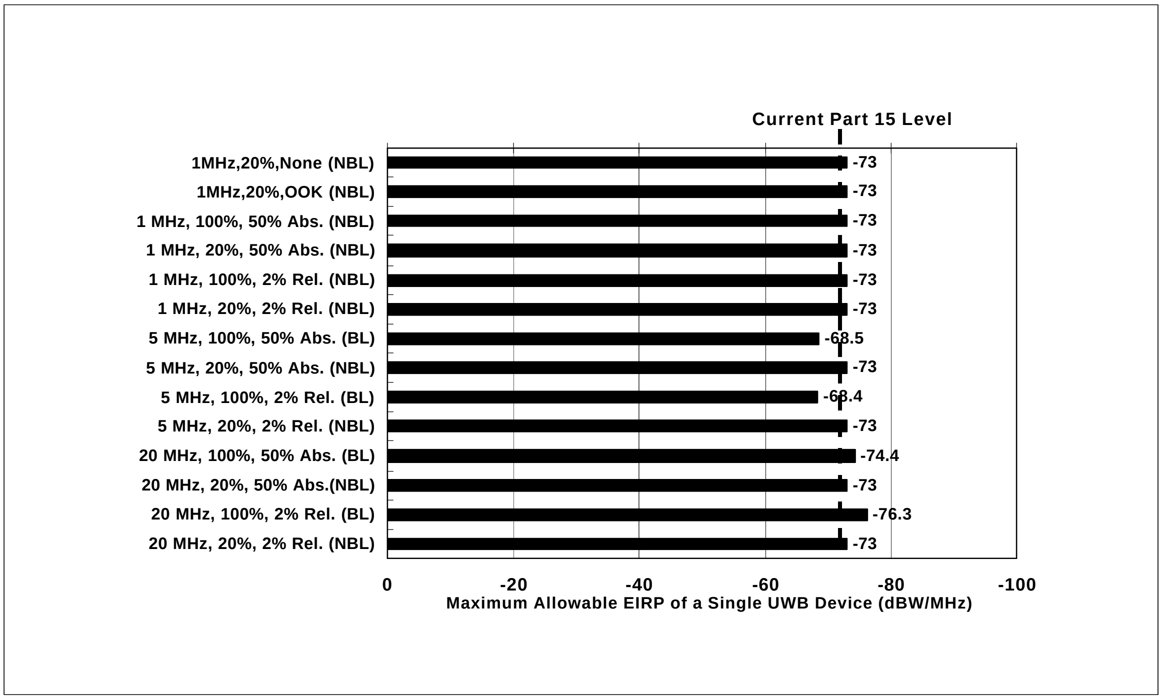


Figure 3-16. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Noise-Like UWB Signals)

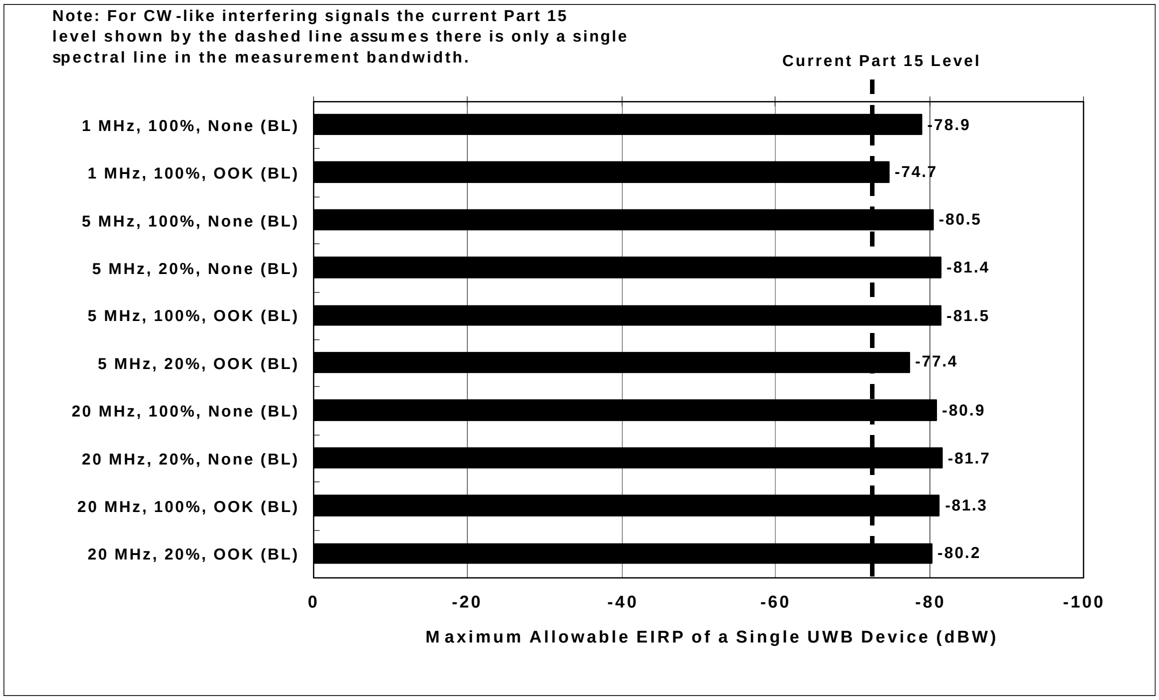


Figure 3-17. Analysis Results for Maritime Operational Scenario I: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (CW-Like UWB Signals)

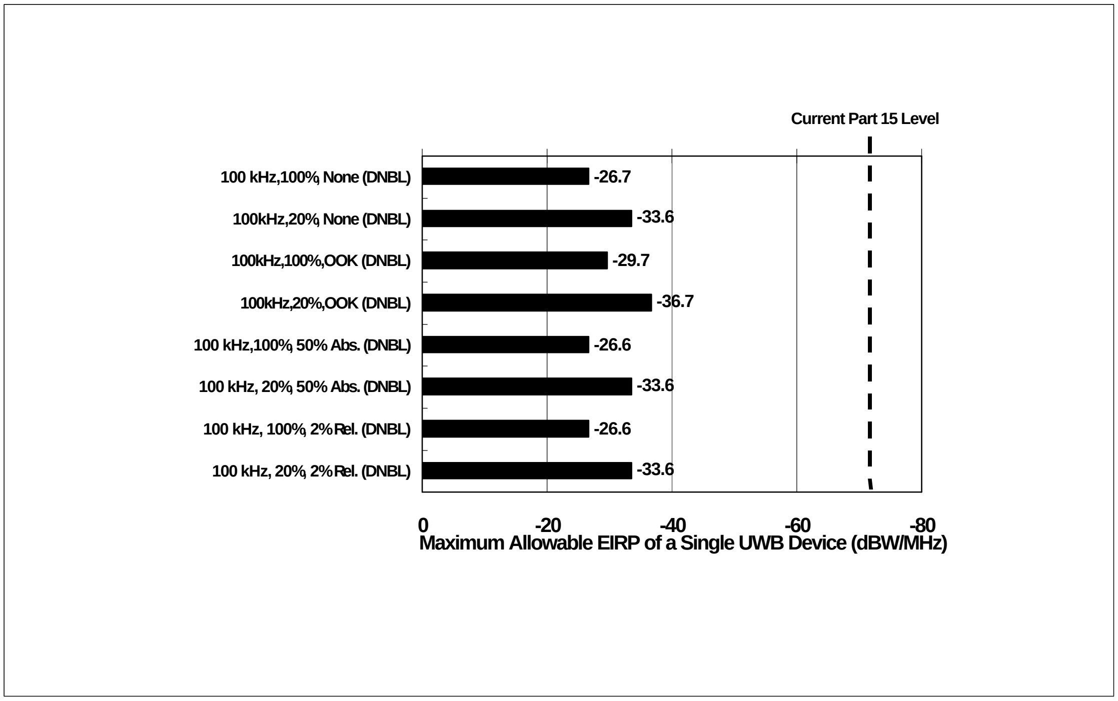


Figure 3-18. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Pulse-Like UWB Signals)

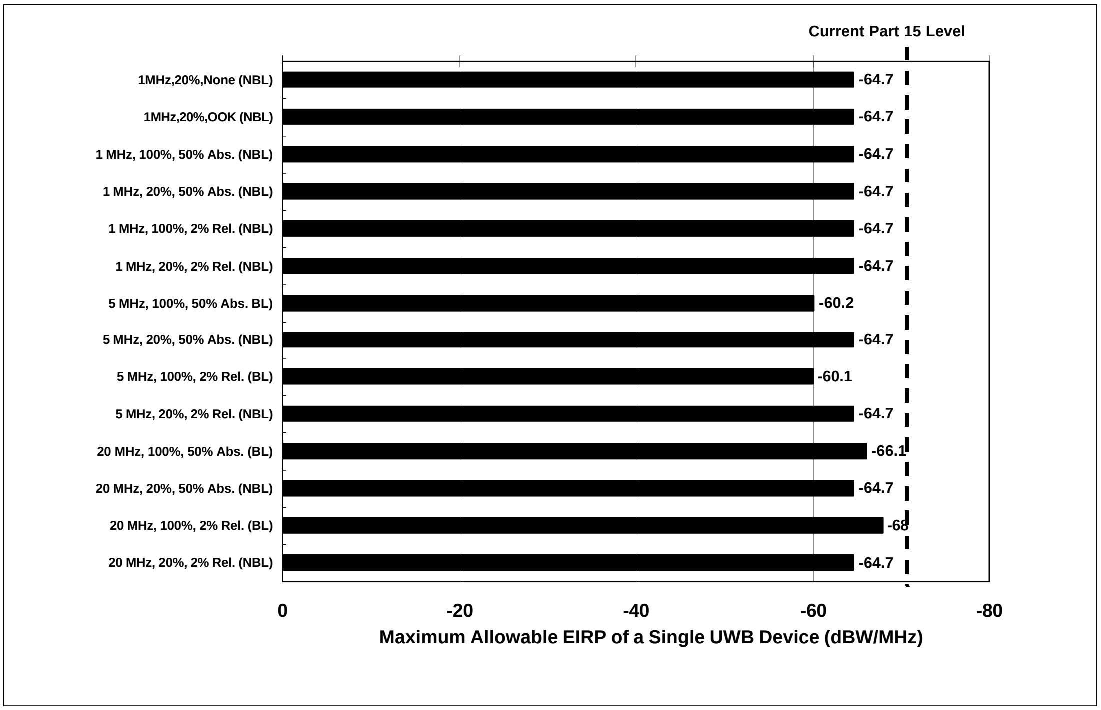


Figure 3-19. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (Noise-Like UWB Signals)

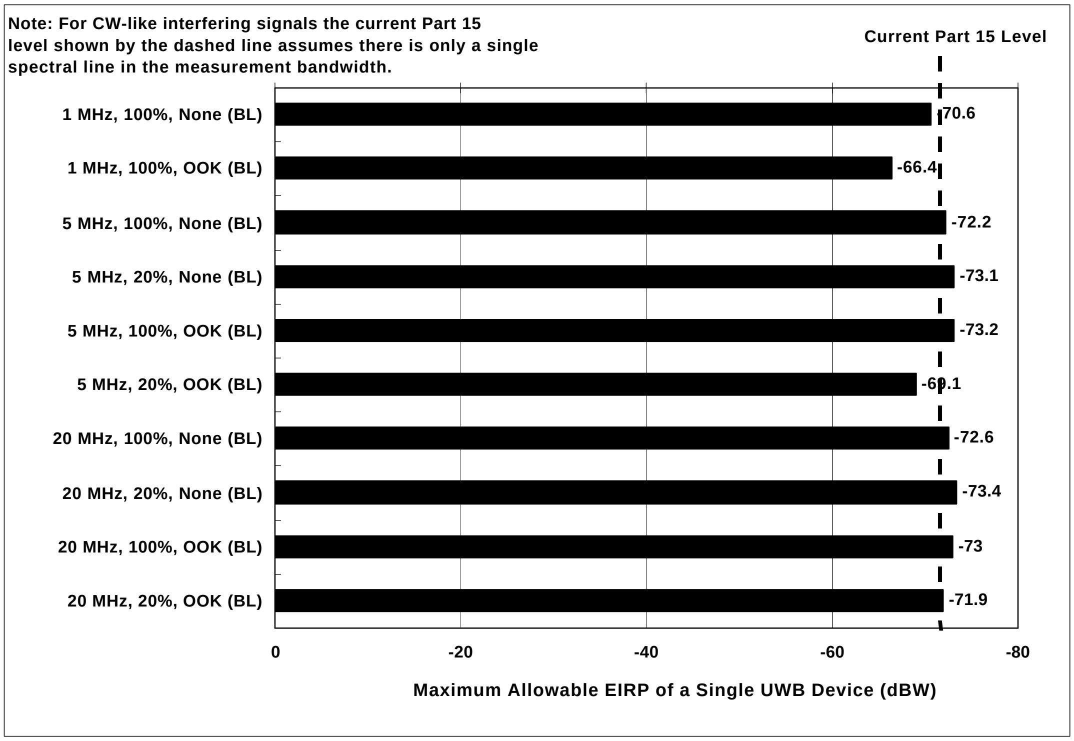


Figure 3-20. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (CW-Like UWB Signals)

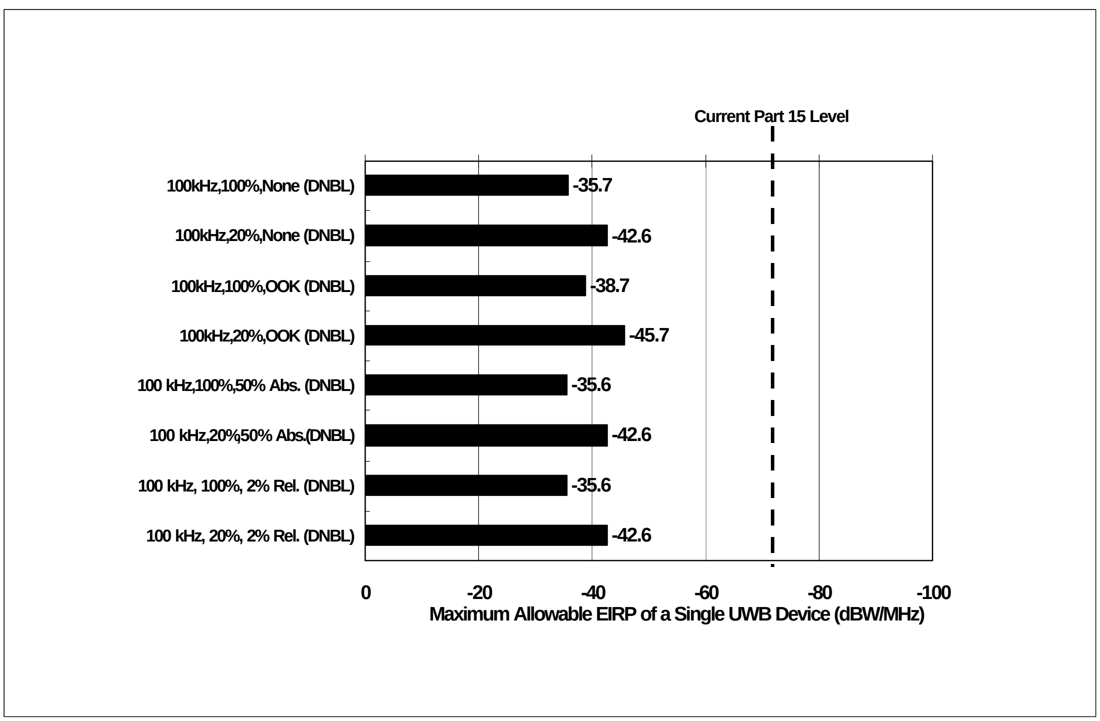


Figure 3-21. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices -Outdoor Operation (Pulse-Like UWB Signals)

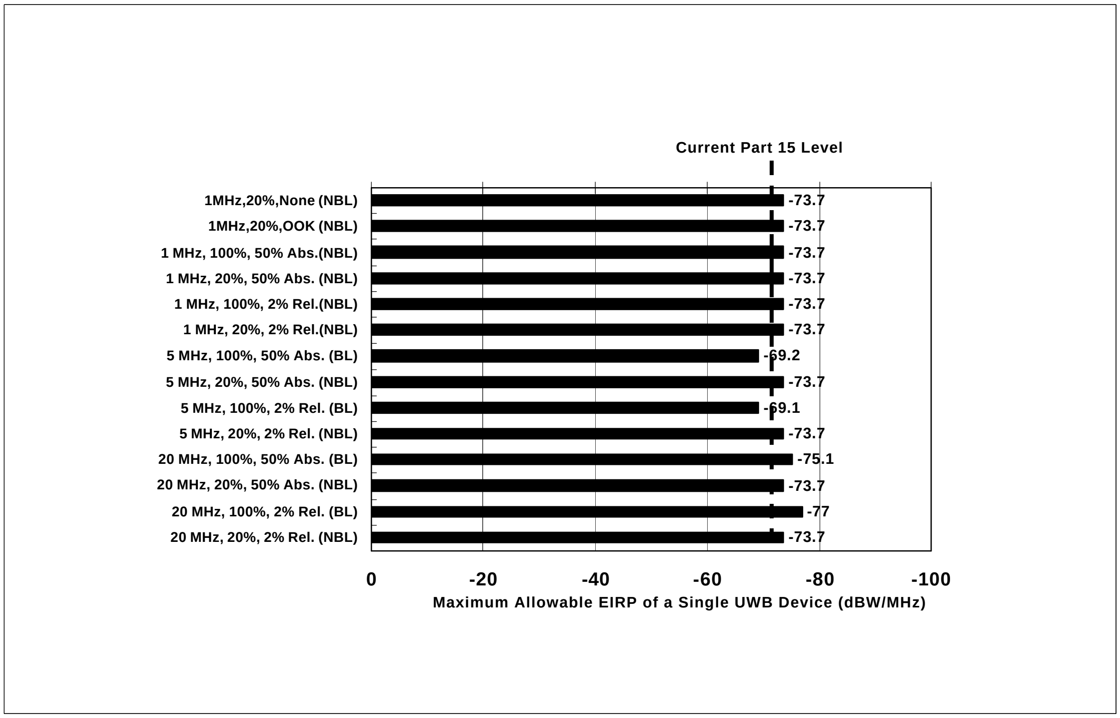


Figure 3-22. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices -Outdoor Operation (Noise-Like UWB Signals)

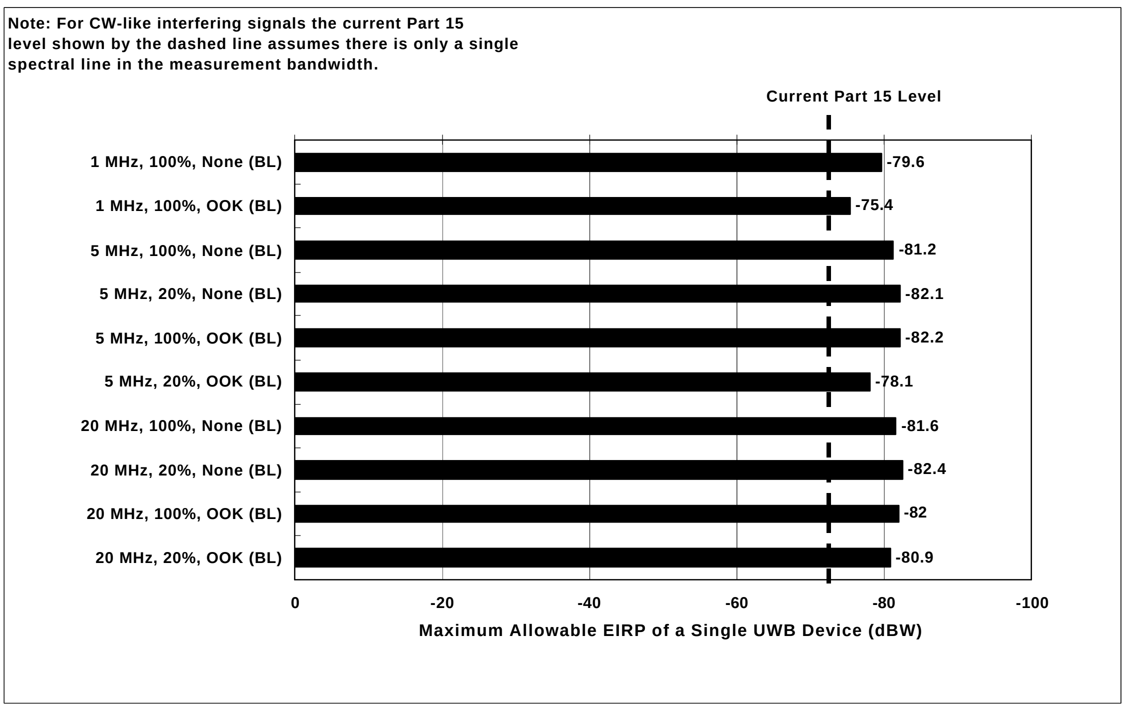


Figure 3-23. Analysis Results for Maritime Operational Scenario II: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (CW-Like UWB Signals)

3.3.3 Railway Applications

In the operational scenarios for the railway GPS applications, the narrowly-spaced correlator receiver architecture is considered. The analysis results for the narrowly-spaced correlator receiver architecture are given in Figures 3-24 through 3-29. The operational scenarios considered multiple UWB device interactions as well as indoor and outdoor UWB device operation. The values of maximum allowable EIRP shown in Figures 3-24 through 3-29 are for a single UWB device and are based on average power.

The values of maximum allowable EIRP that are required to protect the narrowly-spaced correlator receiver architecture considered in the railway operational scenarios will vary depending on the UWB signal parameters and whether the UWB devices are being used indoors or outdoors. The analysis results can be discussed in terms of the characterization of the UWB signal interference effects. As shown in Figures 3-24 and 3-27, the values of maximum allowable EIRP for UWB signals that have been characterized as causing pulse-like interference range from -53.9 to -43.8 dBW/MHz for indoor UWB device operation and from -55.4 to -45.3 dBW/MHz for outdoor UWB device operation. Figures 3-25 and 3-28 show that for UWB signals that have been characterized as causing noise-like interference, the values of maximum allowable EIRP range from -84 to -76.1 dBW/MHz for indoor UWB device operation and from -85.5 to -77.6 dBW/MHz for outdoor UWB device operation. Figures 3-26 and 3-29 show that for UWB signals that have been characterized as causing CW-like interference, the values of maximum allowable EIRP range from -90.6 to -83.6 dBW for indoor UWB device operation and from -92.1 to -85.1 dBW for outdoor UWB device operation.

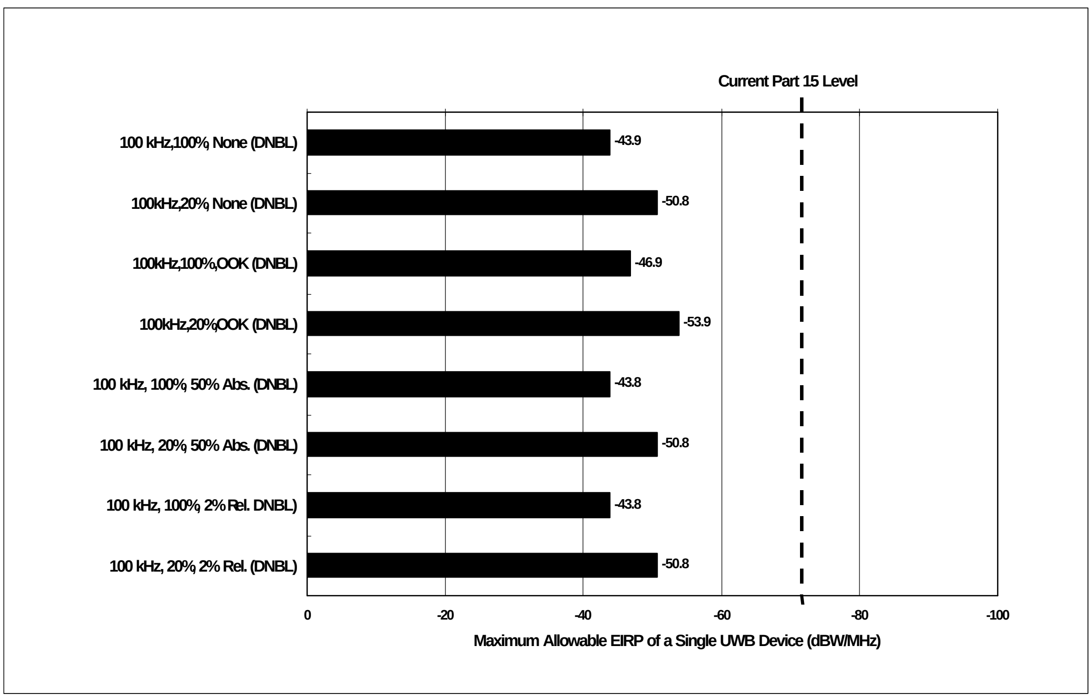


Figure 3-24. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices -Indoor Operation (Pulse-Like UWB Signals)

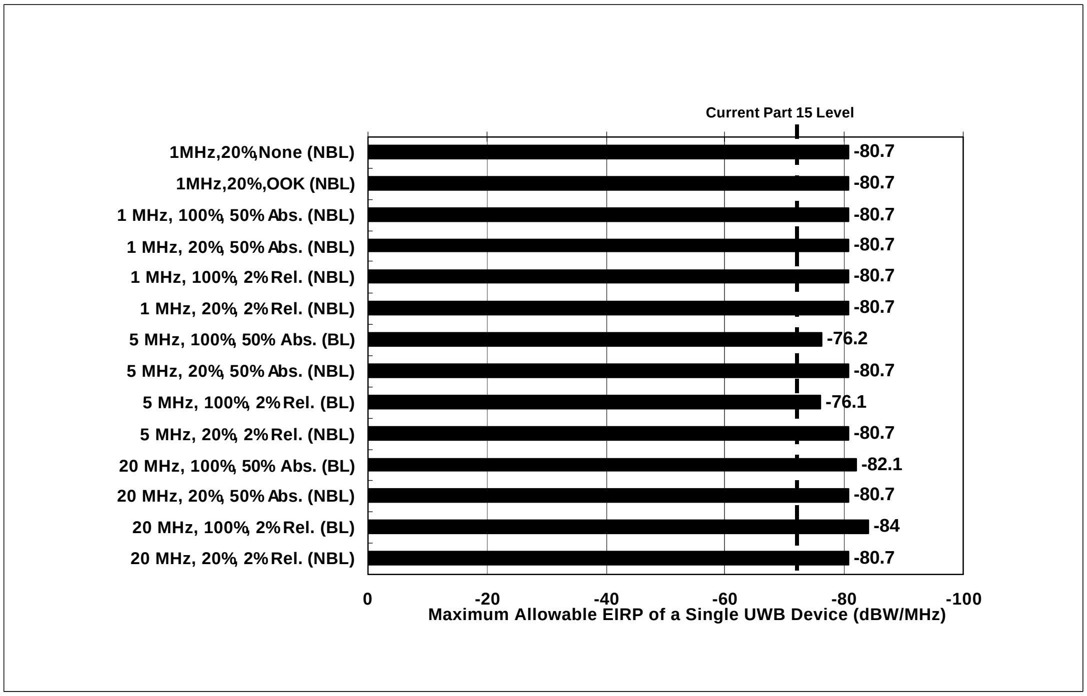


Figure 3-25. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices -Indoor Operation (Noise-Like UWB Signals)

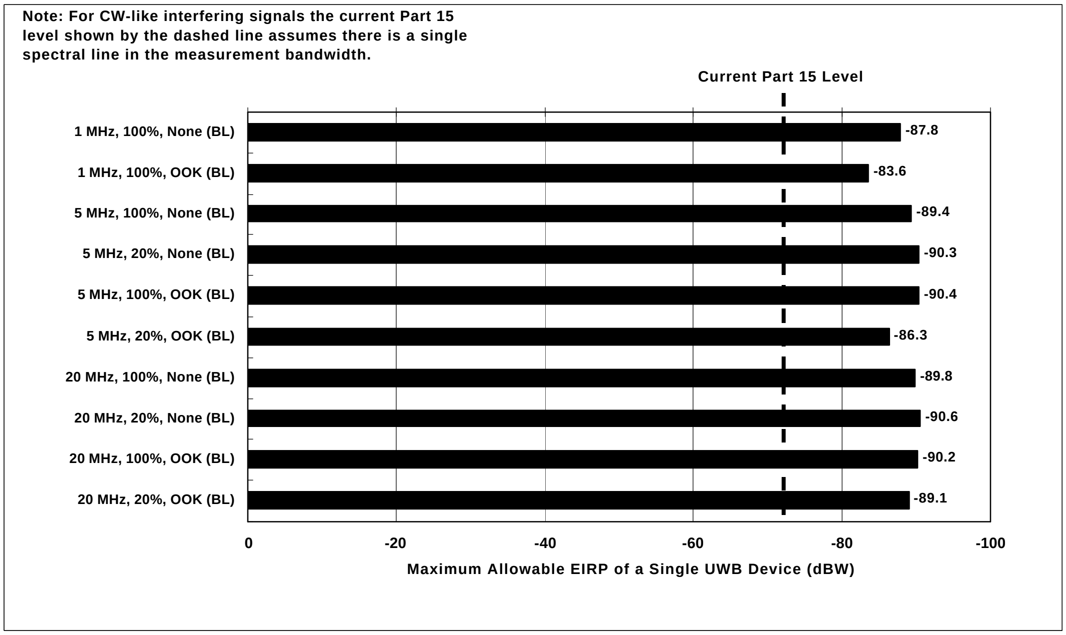


Figure 3-26. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Indoor Operation (CW-Like UWB Signals)

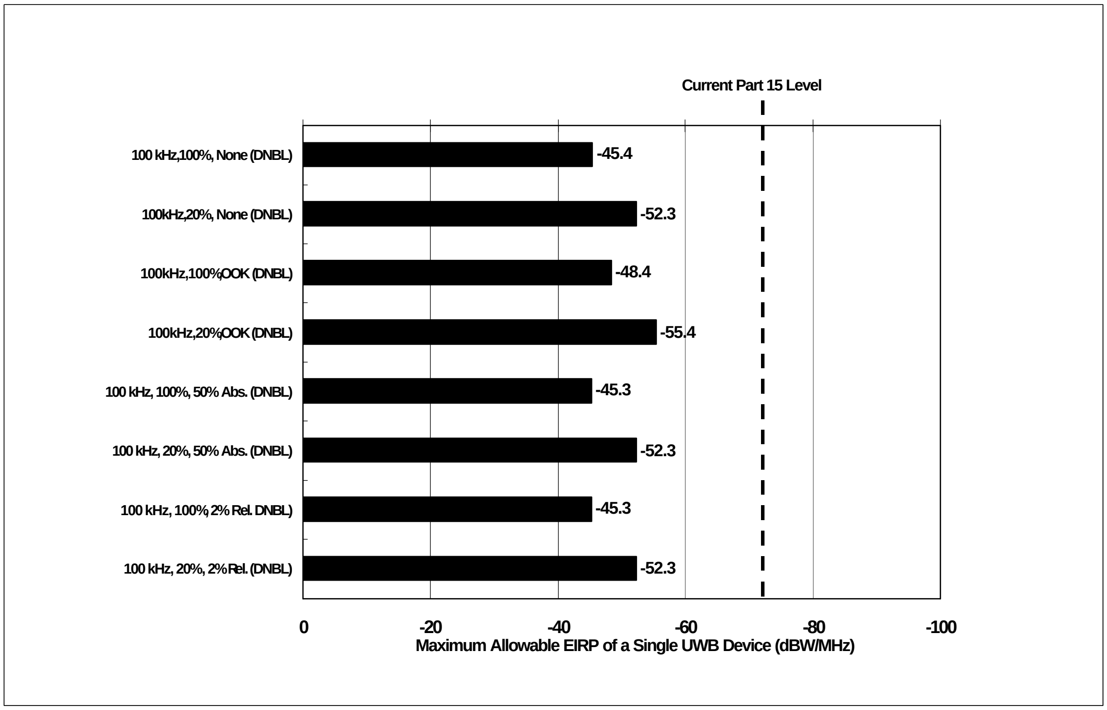


Figure 3-27. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Pulse-Like UWB Signals)

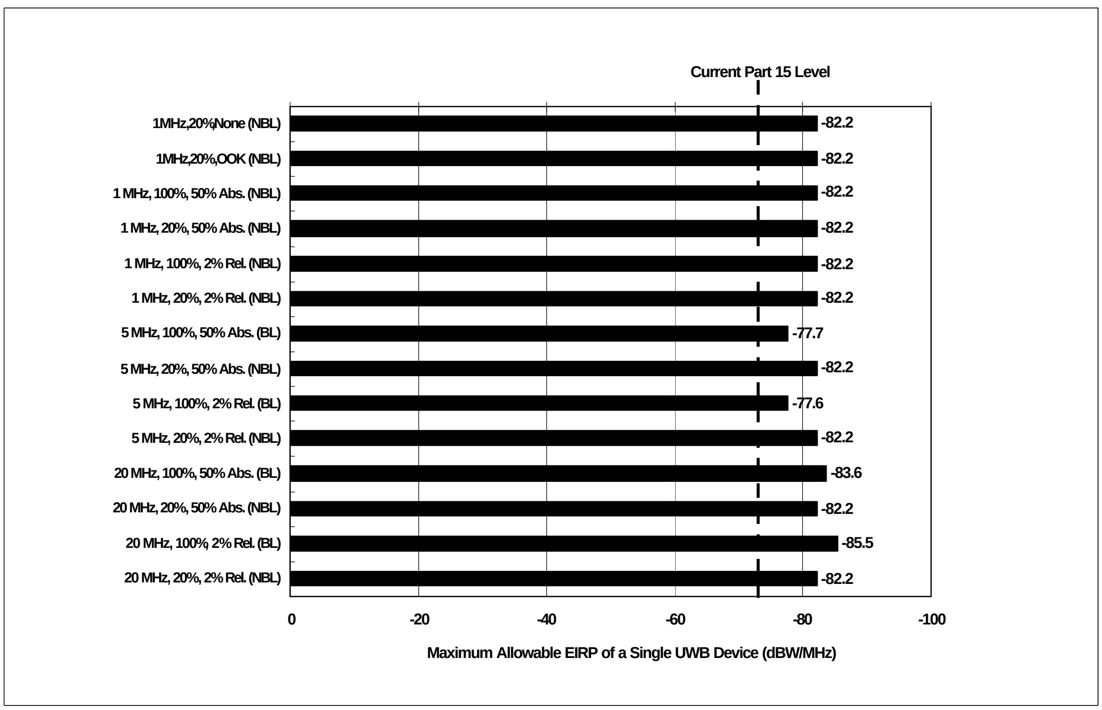


Figure 3-28. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (Noise-Like UWB Signals)

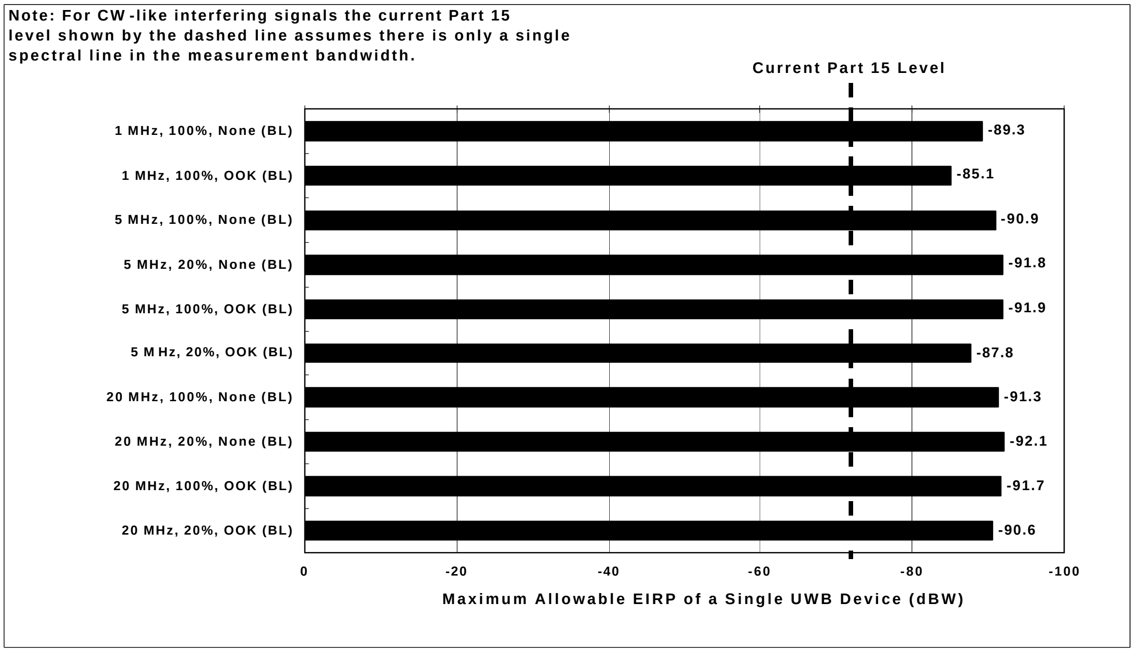


Figure 3-29. Analysis Results for Railway Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices - Outdoor Operation (CW-Like UWB Signals)

3.3.4 Surveying Applications

In the operational scenarios for the surveying GPS applications, the narrowly-spaced correlator receiver architecture is considered. The analysis results are given in Figures 3-30 through 3-35. The operational scenarios considered single-entry and multiple-entry UWB device interactions. The values of maximum allowable EIRP shown in Figures 3-30 through 3-35 are for a single UWB device and are based on average power. For the narrowly-spaced correlator receiver architecture the UWB signals have been characterized as causing pulse-like, noise-like, or CW-like interference. As shown in Figure 3-30, the maximum allowable EIRP for the UWB signals that were characterized as causing pulse-like interference range from -65.3 to -30.9 dBW/MHz for single-entry UWB device interactions. Figure 3-31 shows that the maximum allowable EIRP for the UWB signals that were characterized as causing noise-like interference range from -78.6 to -70.7 dBW/MHz for single-entry UWB device interactions. For the UWB signals that have been characterized as causing CW-like interference, Figure 3-32 shows that the maximum allowable EIRP ranges from -90 to -83 dBW for single-entry UWB device interactions. As shown in Figure 3-33, the maximum allowable EIRP for the UWB signals that have been characterized as causing pulse-like interference range from -53.4 to -43.3 dBW/MHz for multiple-entry UWB device interactions. Figure 3-34 shows that the maximum allowable EIRP for the UWB signals that have been characterized as causing noise-like interference range from -78.7 to -70.8 dBW/MHz for multiple UWB device interactions. For the UWB signals that have been characterized as causing CW-like interference, Figure 3-35 shows that the maximum allowable EIRP ranges from -90.1 to -83.1 dBW for multiple UWB device interactions.

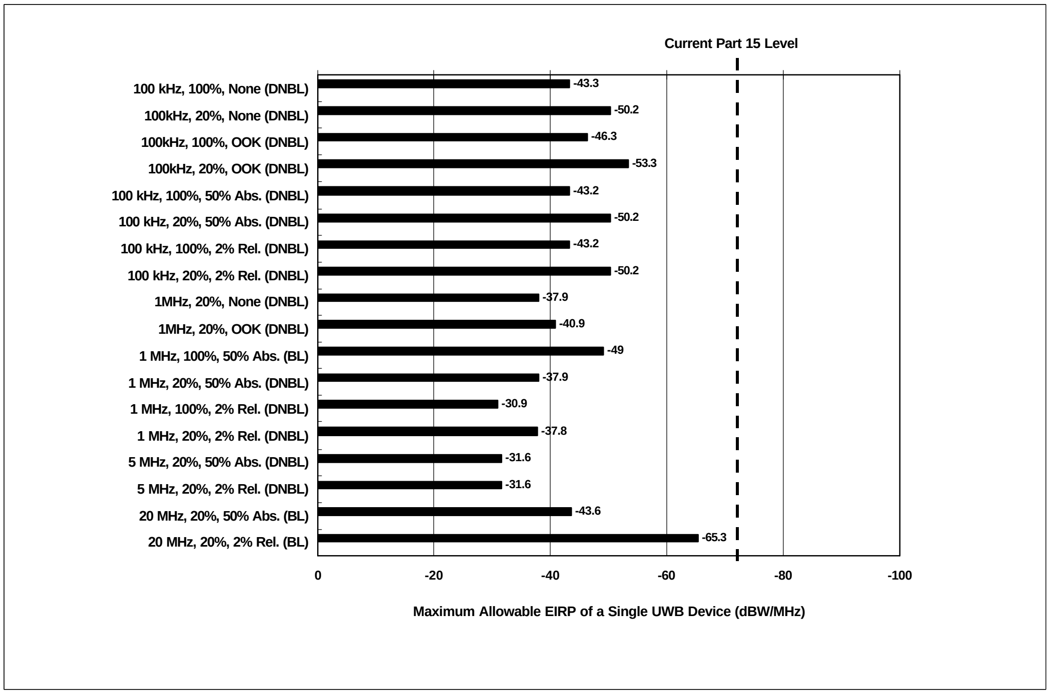


Figure 3-30. Analysis Results for the Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (Pulse-Like UWB Signals)

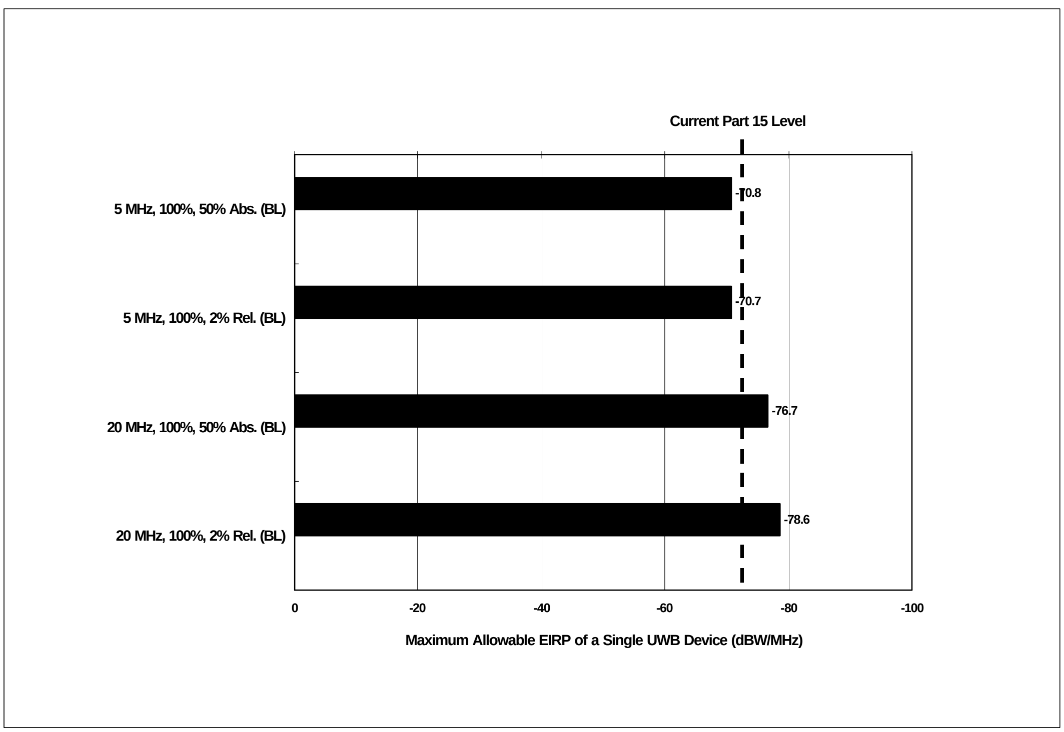


Figure 3-31. Analysis Results for the Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (Noise-Like UWB Signals)

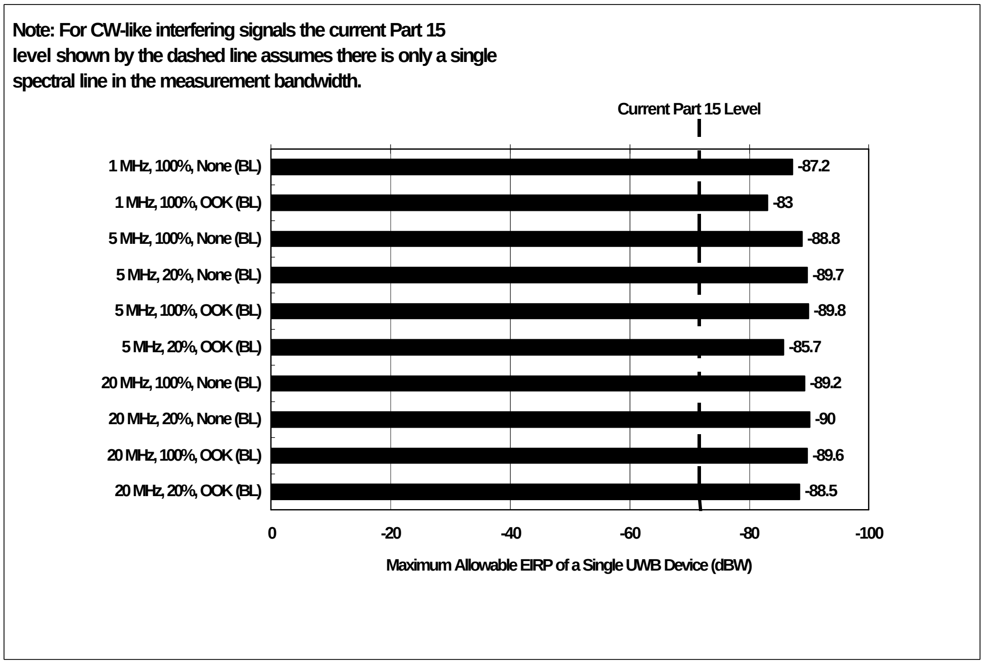


Figure 3-32. Analysis Results for Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Single UWB Device (CW-Like UWB Signals)

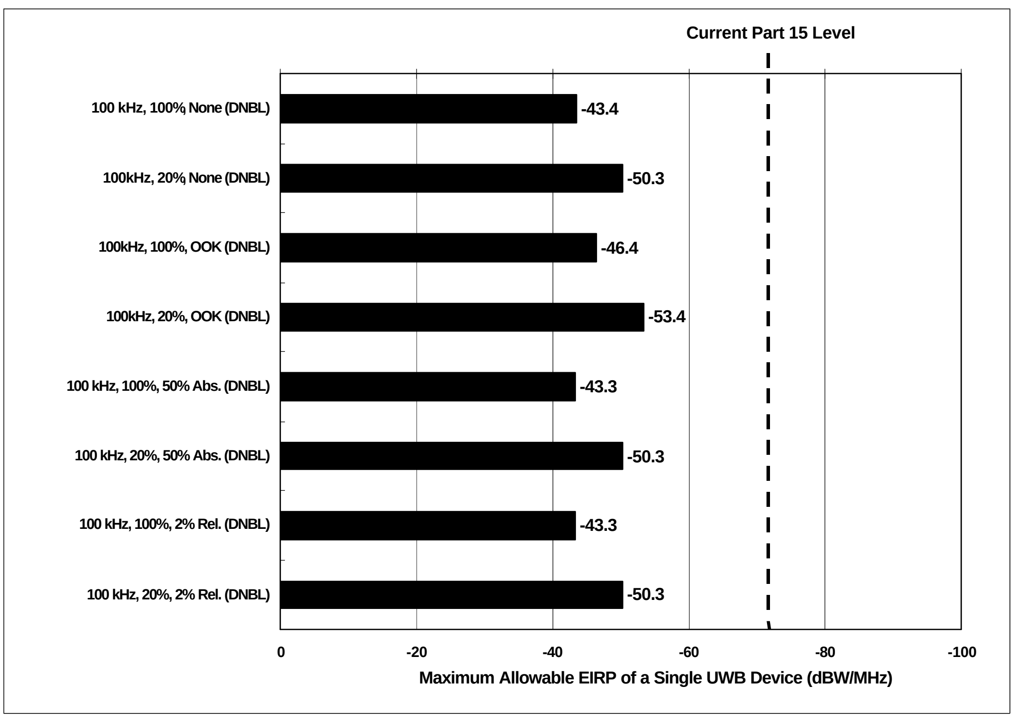


Figure 3-33. Analysis Results for the Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices (Pulse-Like UWB Signals)

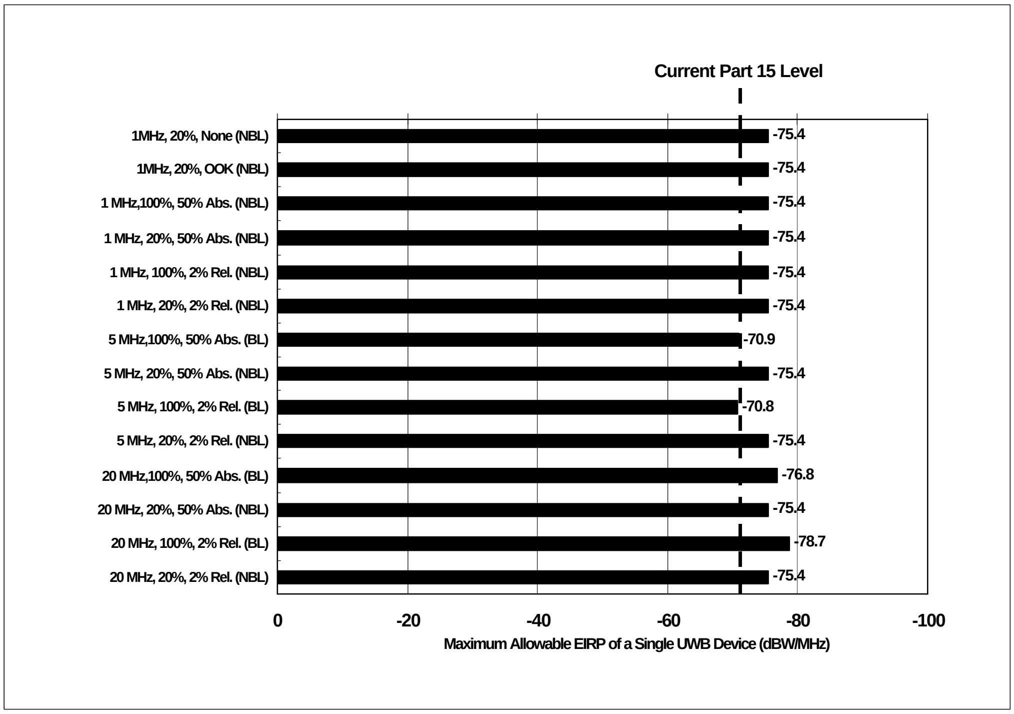


Figure 3-34. Analysis Results for the Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices (Noise-Like UWB Signals)

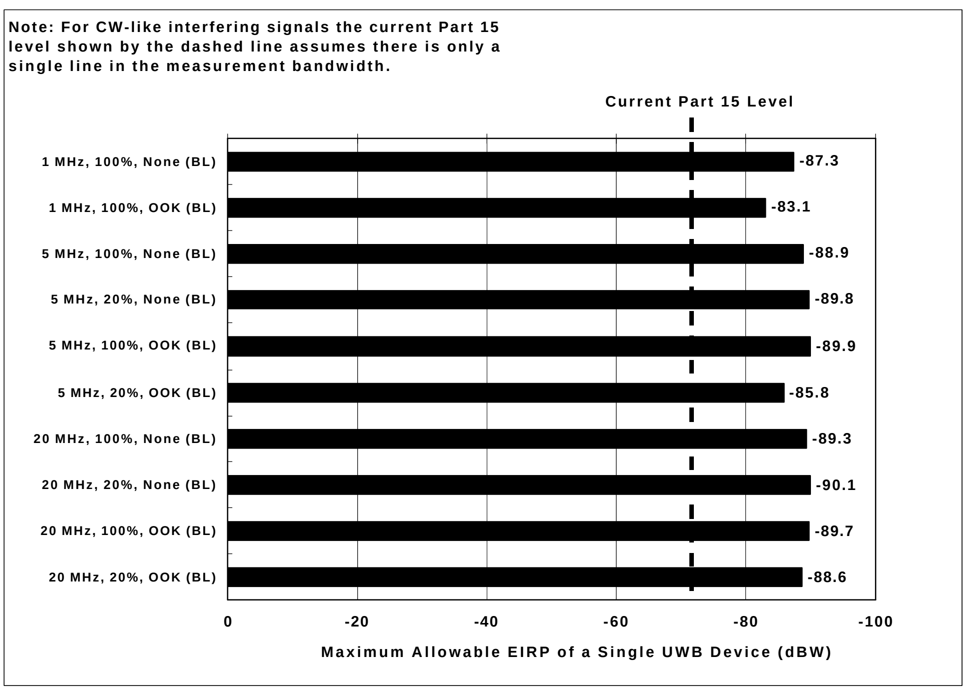


Figure 3-35. Analysis Results for the Surveying Operational Scenario: Narrowly-Spaced Correlator Receiver and Multiple UWB Devices (CW-Like UWB Signals)

3.3.5 Aviation Applications

In the aviation non-precision approach landing operational scenario, the TSO-C129a compliant C/A-code receiver architecture is considered. The analysis results for the non-precision approach operational; scenario using the TSO-C129a compliant C/A-code receiver architecture are given in Figures 3-36, 3-37, and 3-38. The values of maximum allowable EIRP shown in Figures 3-36 through 3-38 are for a single UWB device and are based on average power. As shown in Figure 3-36, for UWB signals that were characterized as causing pulse-like interference, the values of maximum allowable EIRP range from -58.2 to -38.2 dBW/MHz. For UWB signals that were characterized as causing noise-like interference, Figure 3-37 shows that the values of maximum allowable EIRP range from -89.3 to -79.8 dBW/MHz. As shown in Figure 3-38, the values of maximum allowable EIRP for UWB signals that were characterized as causing CW-like interference range from -88.1 to -78.5 dBW.

In the aviation en-route navigation operational scenario, the TSO-C129a compliant C/A-code receiver architecture is considered. The analysis results for the en-route navigation operational scenario using the TSO-C129a compliant C/A-code receiver architecture are given in Figures 3-39 and 3-40. The analysis results are presented in terms of the maximum EIRP as a function of active UWB device density. In this operational scenario, the aircraft is at an altitude of 1,000 feet. The operational scenarios consider both the indoor and outdoor operation of UWB devices. In these operational scenario it is assumed that there is a large enough number of UWB devices, such that independent of the parameters of the individual UWB signals the aggregate effect causes noise-like interference. The values of maximum allowable EIRP shown in Figures 3-39 and 3-40 are for a single UWB device and are based on average power. Figure 3-39 shows the analysis results when all of the UWB devices are operating outdoor. Figure 3-40 shows the analysis results when all of the UWB devices are operating indoors. As discussed earlier, determining the active number of UWB devices to consider when establishing the maximum allowable EIRP level is difficult and depends on factors such as population, the rate of penetration of the technology, and the appropriate activity factor. For example, assuming a population density of 2000 people per square kilometer and an assumed technology penetration of 10%, the UWB device density would be 200 devices per square kilometer. Based on this UWB device density, the EIRP of a single UWB device would be -84.9 dBW/MHz for outdoor UWB device operation (Figure 3-39) and -75.9 dBW/MHz for indoor UWB device operation (Figure 3-40). These values of maximum allowable EIRP were calculated under the assumption that the UWB devices are transmitting simultaneously. If an appropriate value for the activity factor could be determined, the calculated values of maximum allowable EIRP would be reduced accordingly.

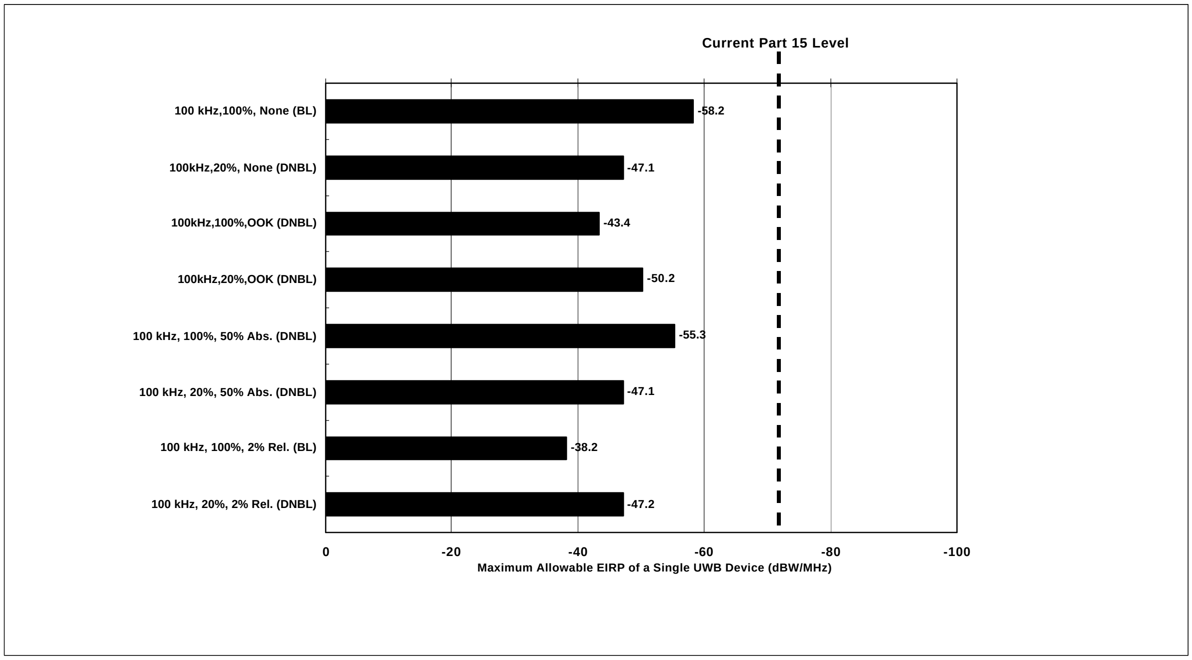


Figure 3-36. Analysis Results for Aviation (Non-Precision Approach Landing) Operational Scenario: TSO-C129a Compliant Receiver and Multiple UWB Devices (Pulse-Like UWB Signals)

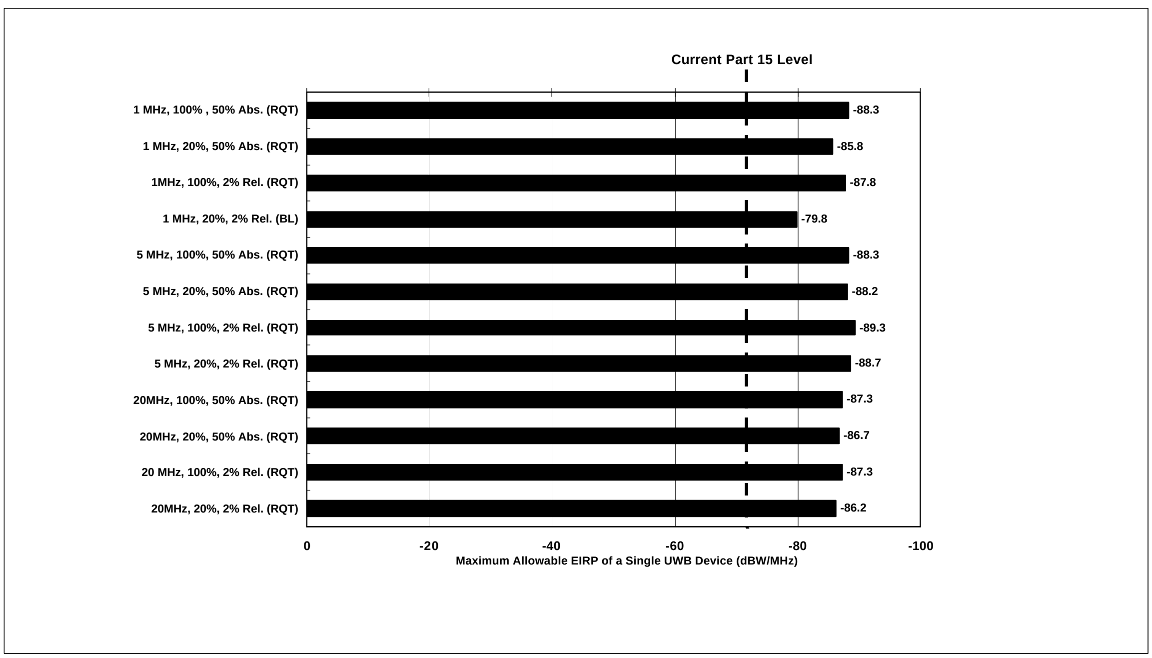


Figure 3-37. Analysis Results for Aviation (Non-Precision Approach Landing) Operational Scenario: TSO-C129a Compliant Receiver and Multiple UWB Devices (Noise-Like UWB Signals)

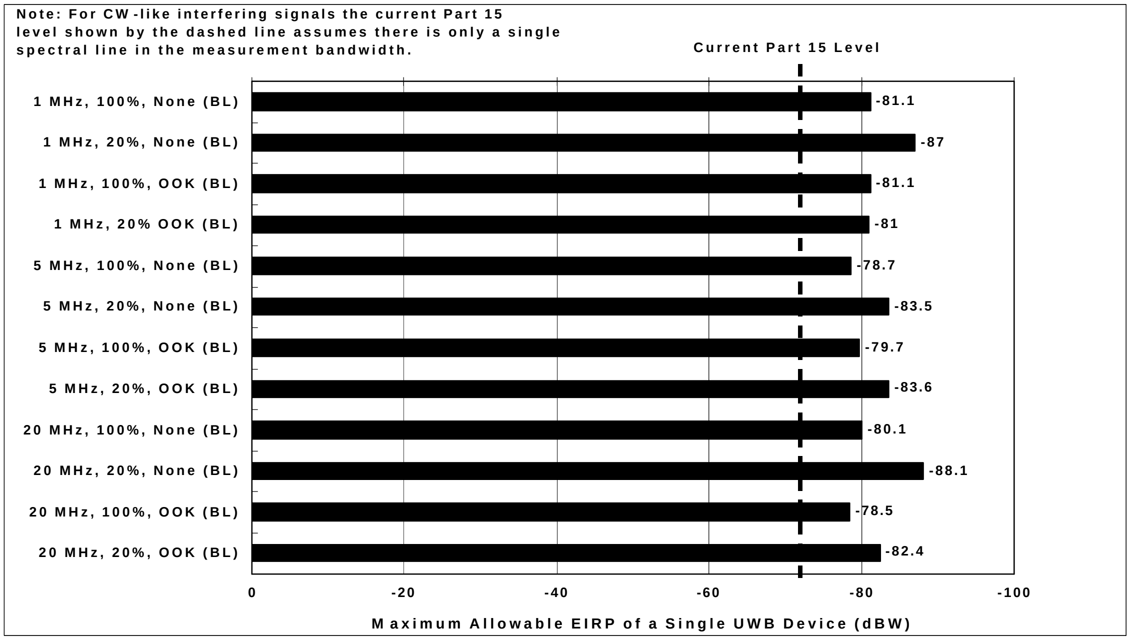


Figure 3-38. Analysis Results for Aviation (Non-Precision Approach Landing) Operational Scenario: TSO-C129a Compliant Receiver and Multiple UWB Devices (CW-Like UWB Signals)

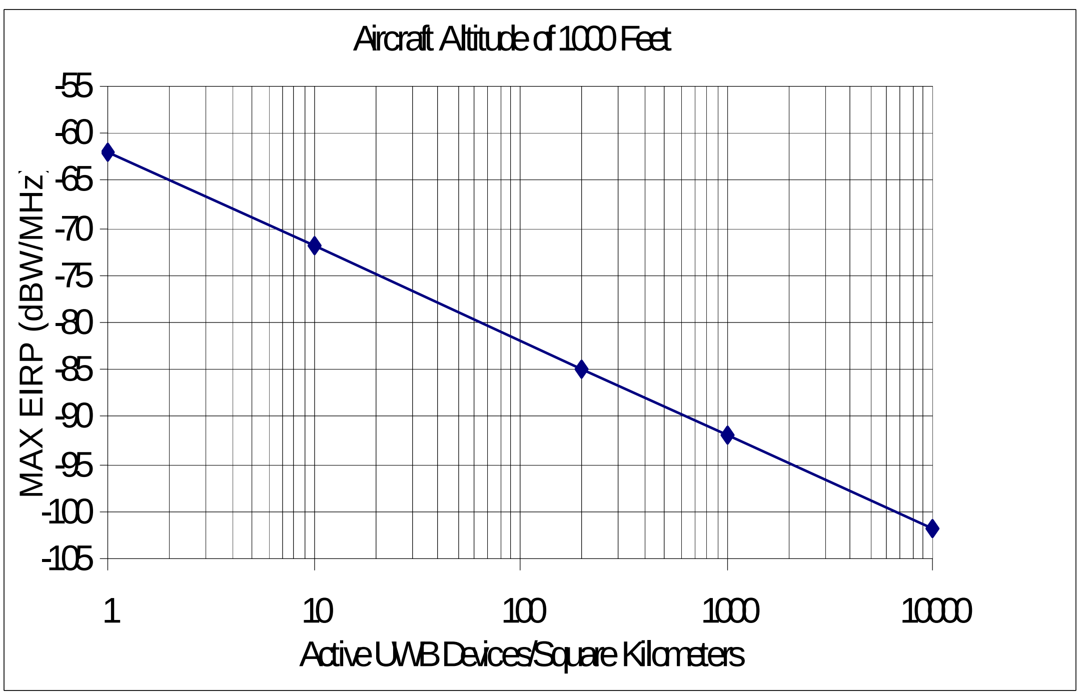


Figure 3-39. Analysis Results for Aviation (En-Route Navigation) Operational Scenario: TSO-C129a Compliant Receiver and Multiple UWB Devices - Outdoor Operation

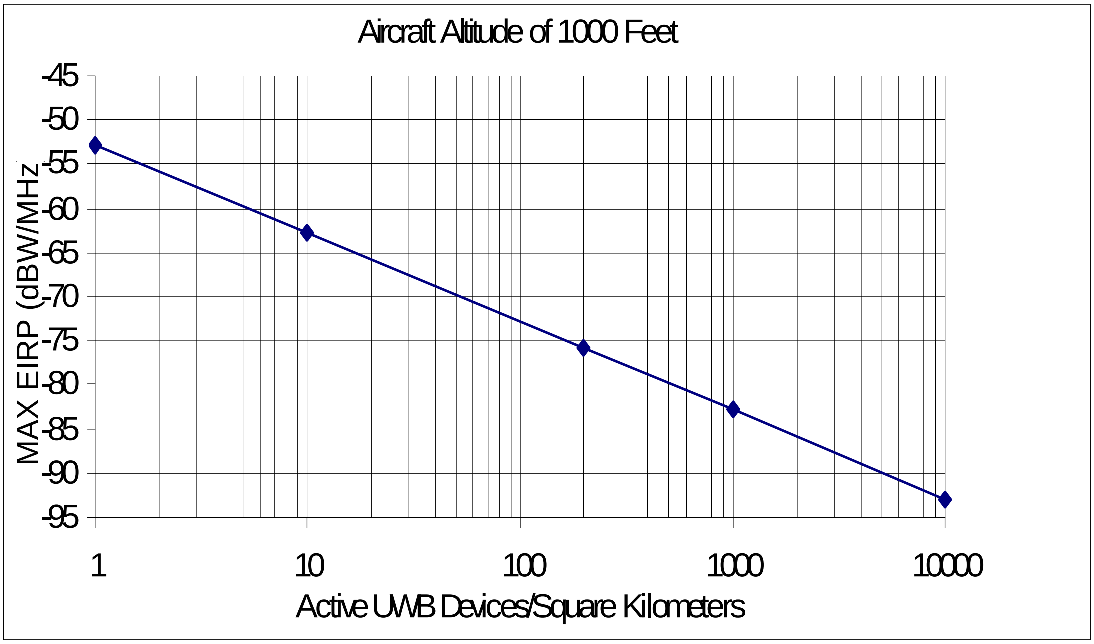


Figure 3-40. Analysis Results for Aviation (En-Route Navigation) Operational Scenario: TSO-C129a Compliant Receiver and Multiple UWB Devices - Indoor Operation

3.4 DISTANCE SEPARATION ANALYSIS

Section 15.209 of the FCC's rules establishes a field strength limit for intentional radiators above 1000 MHz of 500 microvolts/meter (measured in a 1 MHz bandwidth) at a reference distance of 3 meters. This field strength emission limit can be converted to an EIRP level of -71.3 dBW/MHz.[83] In this section, the measured UWB interference thresholds will be used to determine the distance separations that are required to preclude interference to different GPS receiver architectures, if the UWB device is operating at the current Part 15 level of -71.3 dBW/MHz. The interference thresholds for both single-entry and multiple-entry (aggregate) UWB device interactions are considered. For the single-entry UWB device interactions, the distance separations are computed for each UWB signal permutation. For the multiple-entry UWB device interactions, the specific measurement cases and interference thresholds analyzed are documented in NTIA Report 01-45. The UWB interference thresholds are based on measurements performed by NTIA's Institute for Telecommunication Sciences.

The following equation is used to compute the distance separation:

$$D_{sep} = 10^{(EIRP + Gr - 20\,LogF + 27.55 + 10\,LogN + Lman + Lallot + Lsafety - I_T)/20} \qquad (12)$$

[83] The field strength emission limits can be converted to an EIRP level in dBW using the following equation: EIRP(dBW) = E_o(dBμV/m) + 20 Log D(m) -134.8.

where:

D_{sep} is the distance separation between the UWB device and the GPS receiver that would preclude interference (m);
EIRP is the current Part 15 emission level (dBW/MHz);
Gr is the GPS receive antenna gain in the direction of the UWB device (dBi);
F is the GPS center frequency (MHz);
N is the number of UWB devices for the noise-like multiple-entry UWB device interactions;
Lman is the factor to account for manufacturer variations in GPS receivers (dB);
Lallot is the factor for interference allotment (dB);
Lsafety is the aviation safety margin (dB);
I_T is the interference threshold of the UWB signal at the input of the GPS receiver (dBW or dBW/MHz).

To compute the distance separation, the free-space propagation loss model is used. Based on Equation 4, using 3 meters for the GPS and UWB antenna heights, for land-based GPS receiver applications, the use of the free-space propagation model is valid for all distance separations less than 568 meters. The free-space propagation model is also applicable to the aviation GPS receiver applications.

Table 3-15 provides the parameters that are used in the distance separation analysis.

Table 3-15. Parameters Used in the Distance Separation Analysis

Parameter	Value
EIRP	-71.3 dBW/MHz (Part 15 Level)
Gr	3, 0, and -4.5 dBi (non-aviation) -10 dBi (aviation)
F	1575.42 MHz
Lman	3 dB
Lallot	3 dB (non-aviation) 10 dB (aviation)
Lsafety	6 dB (aviation)
I_T[84]	**Single-Entry:** Table 3-13 (Narrowly-Spaced Correlator), Table 3-14 (TSO-C129a Compliant), Table 3-16 (C/A Code), Table 3-17 (Semi-Codeless) **Multiple-Entry:** Table 3-18

[84]The interference thresholds for CW-like interfering signals use a worst case assumption where there is only one spectral line within the measurement bandwidth.

The single-entry UWB interference thresholds for the GPS C/A code receiver architecture used in this analysis are provided in Table 3-16.[85]

The single-entry UWB interference thresholds for the semi-codeless receiver architecture used in this analysis are provided in Table 3-17.[86]

Prior to using the interference thresholds for the multiple entry interactions that are presented in Table 2-4 of NTIA Report 01-45[87] in the analysis, the values must be adjusted to: 1) convert from a 20 MHz measurement bandwidth to a 1 MHz analysis bandwidth; 2) convert from dBm to dBW; 3) determine the power contained in a spectral line for CW-like signals; 4) account for the gate on-time relative to the total time. The adjusted values of the UWB interference threshold are given in Table 3-18.

[85] NTIA Report 01-45 at 3-26.

[86] *Id.* at 3-27.

[87] *Id.* at 2-7.

TABLE 3-16. Single-Entry UWB Interference Thresholds for C/A Code Receiver Architectures

Interfering Signal Structure	UWB Interference Threshold	GPS Receiver Criteria
Broadband Noise	-134.5 dBW/MHz	Reacquisition
0.1 MHz PRF, No Mod, 100% Gate	-112.6 dBW/MHz	Break-Lock
0.1 MHz PRF, No Mod, 20% Gate	-106.5 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, OOK, 100% Gate	-102.6 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, OOK. 20% Gate	-109.4 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 50% abs, 100% Gate	-100 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 50% abs, 20% Gate	-107 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 2% rel, 100% Gate	-100 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 2% rel, 20% Gate	-107 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
1 MHz PRF, No Mod, 100% Gate	-143.7 dBW	Break-Lock
1 MHz PRF, No Mod, 20% Gate	-97.6 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
1 MHz PRF, OOK, 100% Gate	-121.2 dBW/MHz	Break-Lock
1 MHz PRF, OOK, 20% Gate	-101.1 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
1 MHz PRF, 50% abs, 100% Gate	-113 dBW/MHz	Reacquisition
1 MHz PRF, 50% abs, 20% Gate	-97.5 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
1 MHz PRF, 2% rel, 100% Gate	-131 dBW/MHz	Reacquisition
1 MHz PRF, 2% rel, 20% Gate	-97 dBW/MHz	Reacquisition
5 MHz PRF, No Mod, 100% Gate	-145.5 dBW	Break-Lock
5 MHz PRF, No Mod, 20% Gate	-145.2 dBW	Break-Lock
5 MHz PRF, OOK, 100% Gate	-144.5 dBW	Break-Lock
5 MHz PRF, OOK, 20% Gate	-144.2 dBW	Break-Lock
5 MHz PRF, 50% abs, 100% Gate	-137 dBW/MHz	Reacquisition
5 MHz PRF, 50% abs, 20% Gate	-105 dBW/MHz	Reacquisition
5 MHz PRF, 2% rel, 100% Gate	-136.5 dBW/MHz	Reacquisition
5 MHz PRF, 2% rel, 20% Gate	-89 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
20 MHz PRF, No Mod, 100% Gate	-145 dBW	Break-Lock
20 MHz PRF, No Mod, 20% Gate	-145.8 dBW	Break-Lock
20 MHz PRF, OOK, 100% Gate	-144.5 dBW	Break-Lock
20 MHz PRF, OOK, 20% Gate	-146.3 dBW	Break-Lock
20 MHz PRF, 50% abs, 100% Gate	-138 dBW/MHz	Reacquisition
20 MHz PRF, 50% abs, 20% Gate	-135 dBW/MHz	Reacquisition
20 MHz PRF, 2% rel, 100% Gate	-136 dBW/MHz	Reacquisition
20 MHz PRF, 2% rel, 20% Gate	-133 dBW/MHz	Reacquisition

TABLE 3-17. Single-Entry UWB Interference Thresholds for Semi-Codeless Receiver Architectures

Interfering Signal Structure	UWB Interference Threshold	GPS Receiver Criteria
Broadband Noise	-150 dBW/MHz	Reacquisition
0.1 MHz PRF, No Mod, 100% Gate	-118 dBW/MHz	Reacquisition
0.1 MHz PRF, No Mod, 20% Gate	-116.5 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, OOK, 100% Gate	-112 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, OOK. 20% Gate	-118.5 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 50% abs, 100% Gate	-121 dBW/MHz	Reacquisition
0.1 MHz PRF, 50% abs, 20% Gate	-116 dBW/MHz	Did Not Break-Lock At Maximum UWB Power
0.1 MHz PRF, 2% rel, 100% Gate	-119 dBW/MHz	Reacquisition
0.1 MHz PRF, 2% rel, 20% Gate	-138 dBW/MHz	Reacquisition
1 MHz PRF, 50% abs, 100% Gate	-151 dBW/MHz	Reacquisition
1 MHz PRF, 50% abs, 20% Gate	-132 dBW/MHz	Reacquisition
1 MHz PRF, 2% rel, 100% Gate	-149 dBW/MHz	Reacquisition
1 MHz PRF, 2% rel, 20% Gate	-134 dBW/MHz	Reacquisition
5 MHz PRF, 50% abs, 100% Gate	-151 dBW/MHz	Reacquisition
5 MHz PRF, 50% abs, 20% Gate	-151 dBW/MHz	Reacquisition
5 MHz PRF, 2% rel, 100% Gate	-149 dBW/MHz	Reacquisition
5 MHz PRF, 2% rel, 20% Gate	-142.5 dBW/MHz	Reacquisition
20 MHz PRF, No Mod, 100% Gate	-145 dBW/MHz	Break-Lock
20 MHz PRF, No Mod, 20% Gate	-148 dBW/MHz	Break-Lock
20 MHz PRF, OOK, 100% Gate	-137 dBW/MHz	Break-Lock
20 MHz PRF, OOK, 20% Gate	-146 dBW/MHz	Break-Lock
20 MHz PRF, 50% abs, 100% Gate	-149.5 dBW/MHz	Reacquisition
20 MHz PRF, 50% abs, 20% Gate	-148 dBW/MHz	Reacquisition
20 MHz PRF, 2% rel, 100% Gate	-149.5 dBW/MHz	Reacquisition
20 MHz PRF, 2% rel, 20% Gate	-143.5 dBW/MHz	Reacquisition

TABLE 3-18. UWB Interference Thresholds for the Multiple-Entry Measurement Cases

PRF (MHz)	Gating Percentage	Modulation	Number of UWB Signal Generators	UWB Interference Threshold	GPS Receiver Criteria
10	100	Dithering 2% Rel.	6	-137.5 dBW/MHz	Reacquisition
10	20	Dithering 2% Rel.	6	-136 dBW/MHz	Reacquisition
10 3 3	100 100 20	None None Dithering 2% Rel.	2 1 3	-149.6 dBW	Reacquisition
3 3	20 20	None Dithering 2% Rel.	4 2	-143.5 dBW	Reacquisition
1	100	Dithering 2% Rel.	1	-131 dBW/MHz	Reacquisition
1	100	Dithering 2% Rel.	2	-136 dBW/MHz	Reacquisition
1	100	Dithering 2% Rel.	3	-136 dBW/MHz	Reacquisition
1	100	Dithering 2% Rel.	4	-136 dBW/MHz	Reacquisition
1	100	Dithering 2% Rel.	5	-137 dBW/MHz	Reacquisition
1	100	Dithering 2% Rel.	6	-136 dBW/MHz	Reacquisition

Figures 3-41, 3-42, and 3-43 present the distance separations that would preclude interference from single-entry UWB device interactions as a function of UWB device PRF for the C/A code, semi-codeless, and narrowly-spaced correlator receiver architectures. The distances shown correspond to the maximum distance separation for all of the signal permutations employing that particular PRF. The three curves correspond to the different values of GPS antenna gain considered in this analysis.

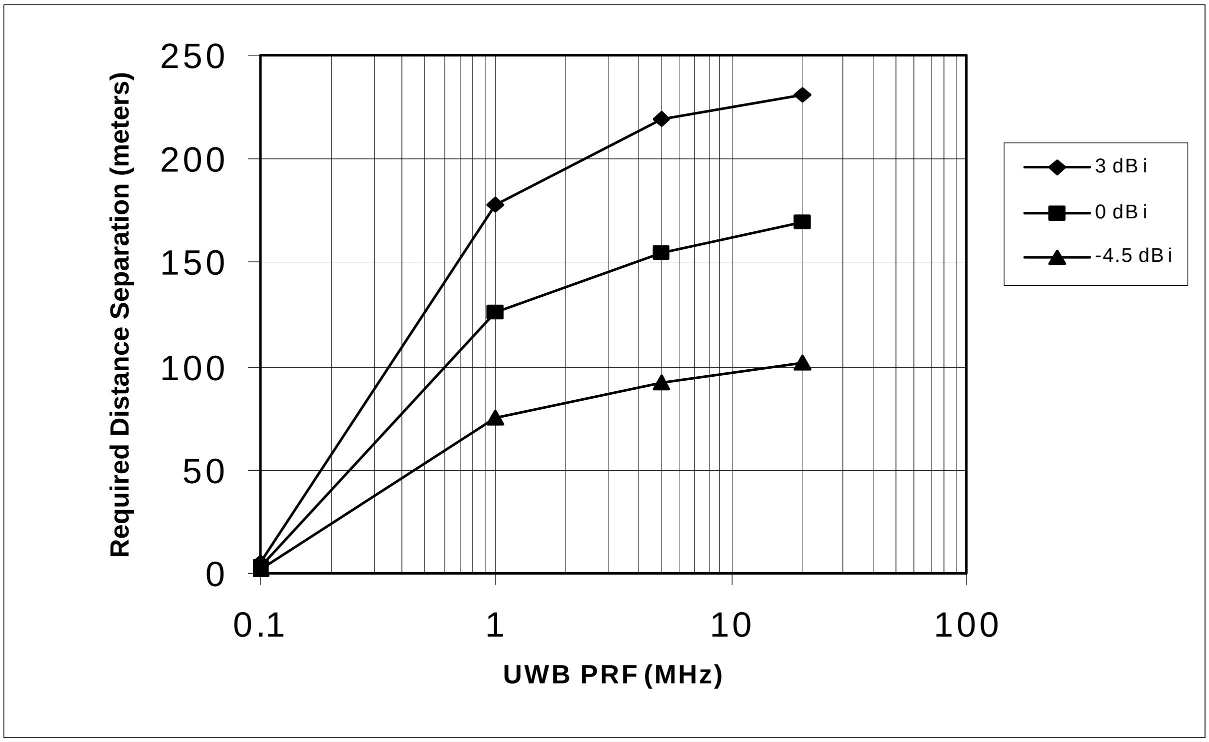


Figure 3-41. Calculated Distance Separations for Single-Entry UWB Device Interactions (C/A Code Receiver Architecture) Based on the Current Part 15 Emission Level

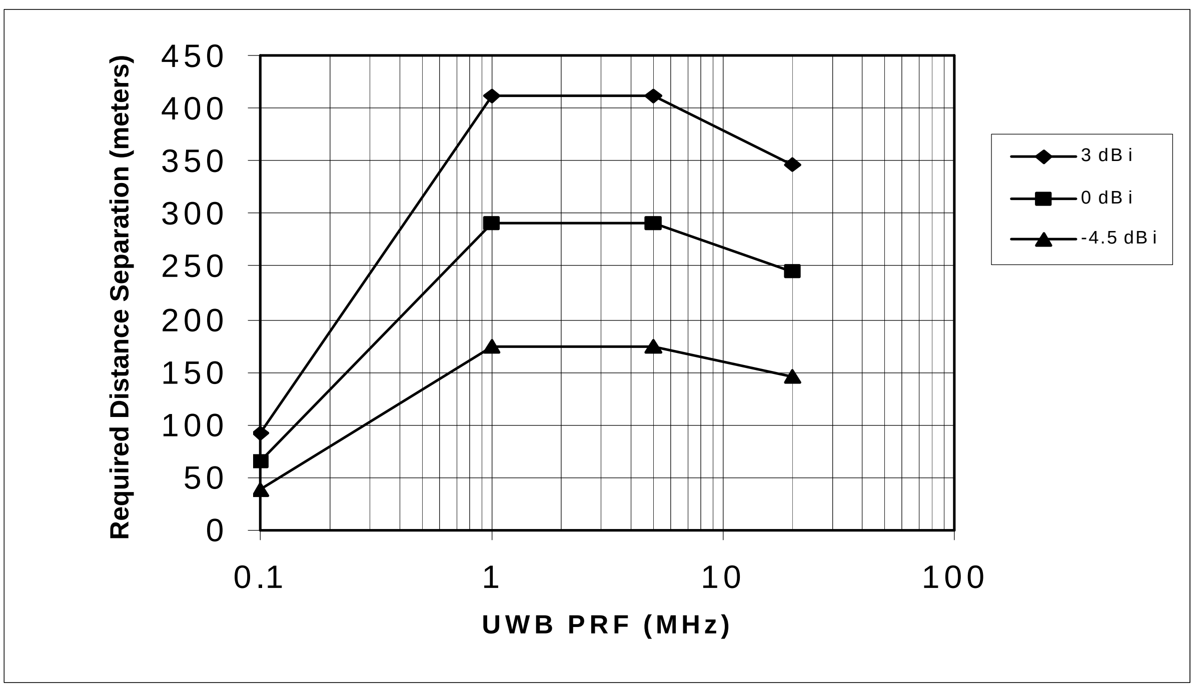


Figure 3-42. Calculated Distance Separations for Single-Entry UWB Device Interactions (Semi-Codeless Receiver Architecture) Based on the Current Part 15 Emission Level

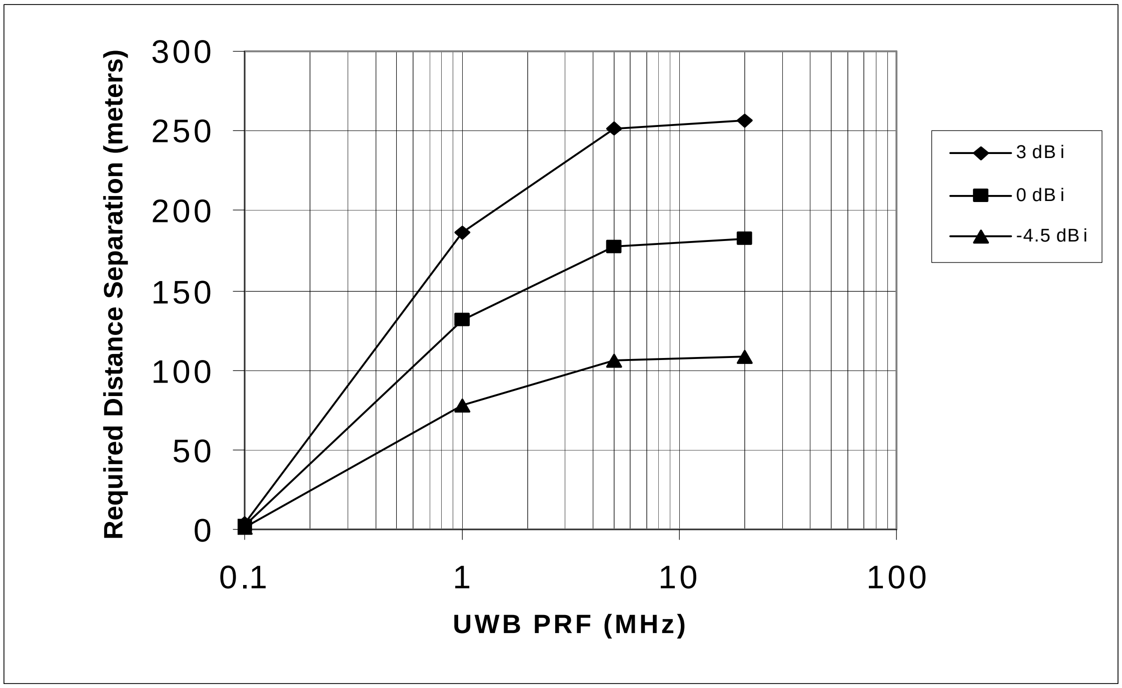


Figure 3-43. Calculated Distance Separations for Single-Entry UWB Device Interactions (Narrowly-Spaced Correlator Receiver Architecture) Based on the Current Part 15 Emission Level

Table 3-19 gives the distance separations for the multiple-entry UWB device interactions for the C/A code receiver architecture.

Figure 3-44 presents the distance separations that would preclude interference from single-entry UWB device interactions as a function of UWB device PRF for the TSO-C129a compliant C/A code GPS receiver architecture. The distances shown correspond to the maximum distance separation for all of the signal permutations employing that particular PRF.

The spreadsheets used to determine the distance separations given in Figures 3-41 through 3-44 and Table 3-19 are provided in Appendix B.

TABLE 3-19. Calculated Distance Separations to Preclude Interference from Multiple-Entry UWB Device Interactions Based on the Current Part 15 Emission Limit (C/A Code Receiver Architecture)

PRF	Gating Percent	Modulation	Number of UWB Signal Generators	Distance Separation (meters)		
				Gr = 3 dBi	Gr = 0 dBi	Gr = -4.5 dBi
10 MHz	100	Dithering 2% Rel.	6	213	151	90
10 MHz	20	Dithering 2% Rel.	6	180	127	76
10 MHz 3 MHz 3 MHz	100 100 20	None None Dithering 2% Rel.	2 1 3	351	248	148
3 MHz 3 MHz	20 20	None Dithering 2% Rel.	4 2	174	123	73
1 MHz	100	Dithering 2% Rel.	1	41	29	17
1 MHz	100	Dithering 2% Rel.	2	104	73	44
1 MHz	100	Dithering 2% Rel.	3	127	90	54
1 MHz	100	Dithering 2% Rel.	4	147	104	62
1 MHz	100	Dithering 2% Rel.	5	184	130	78
1 MHz	100	Dithering 2% Rel.	6	180	127	76

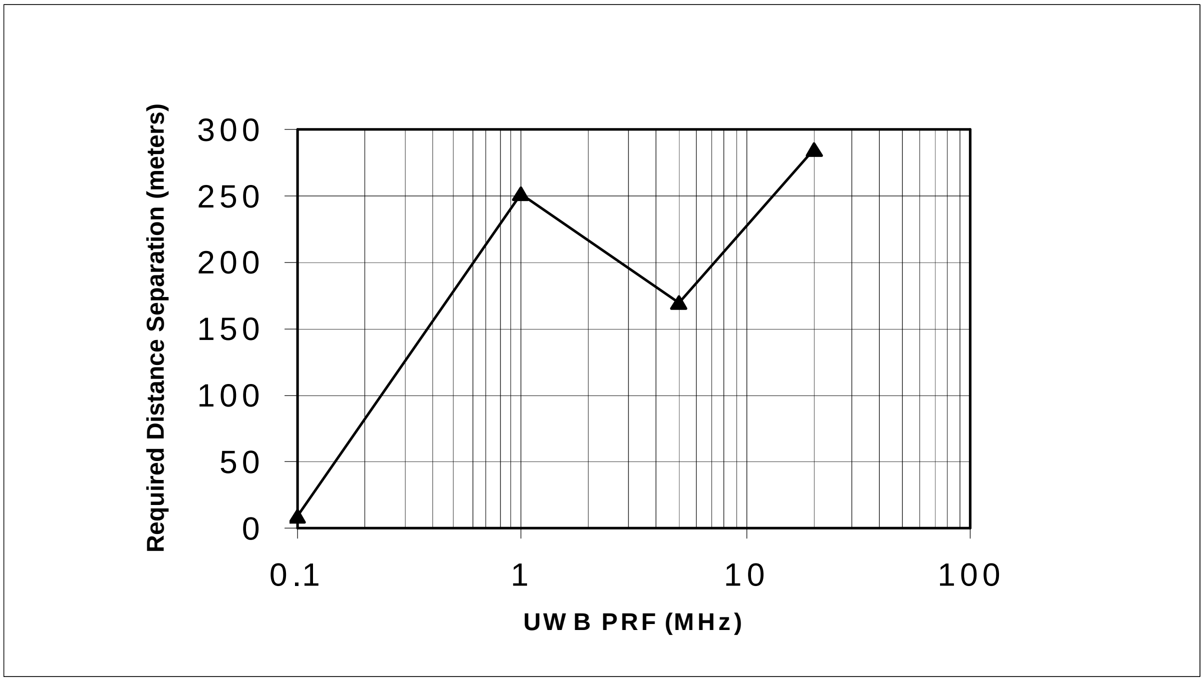


Figure 3-44. Calculated Distance Separations for Single-Entry UWB Device Interactions (TSO-C129a Compliant C/A Code Receiver Architecture) Based on the Current Part 15 Emission Level

SECTION 4.0
SUMMARY/CONCLUSIONS

4.1 SUMMARY OF MEASUREMENT FINDINGS

In the measurement component of this assessment, 32 UWB signal permutations were identified for examination with respect to the interference potential to GPS receivers. For each of four pulse repetition frequencies (PRFs);100 kHz, 1 MHz, 5 MHz, and 20 MHz, eight distinct UWB waveforms were generated by combining four modulation types (constant PRF, On-Off Keying (OOK), 2% relative dither, and 50% absolute dither) and two states of gating (100% and 20%). Each of these UWB parameters are described in the paragraphs below.

The PRF defines the number of pulses transmitted per unit time (seconds). The PRF governs both the magnitude and spacing of the spectral lines in an unmodulated UWB signal. For example, a 5 MHz PRF signal produces spectral lines that are spaced every 5 MHz in the frequency domain. As the PRF is increased, the spectral lines become spaced further apart, but the energy contained in each spectral line is increased. Within the context of this report, "constant PRF" refers to an unmodulated UWB signal.

Gating refers to the process of distributing pulses in bursts by employing a programmed set of periods where the UWB transmitter is turned on or off for a period of pulses. For the measurements performed in this study, the gated UWB signal utilized a scheme where a burst of pulses lasting 4 ms was followed by a 16 ms period when no pulses were transmitted. This is referred to as 20% gating, because the UWB pulses are transmitted 20% of the time. The signal permutations depicted within this report as 100% gating, define a signal where pulses are transmitted 100% of the time.

OOK refers to the process of selectively turning off or eliminating individual pulses to represent data bits. With OOK modulation, the energy in the spectrum is equally divided between the spectral line components and the noise continuum component.

Dithering refers to the random or pseudo-random spacing of the pulses. Two forms of dithered UWB signals were considered in this effort. These are an absolute referenced dither, where the pulse period is varied in relation to the absolute clock, and a relative referenced dither, where the pulse spacing is varied relative to the previous pulse. The PRF of a relative dithered pulse train is equal to the reciprocal of the mean pulse period. The PRF of an absolute dithered pulse train is equal to the frequency of the clock. Dithering of the pulses in the time domain spreads the spectral line content of a UWB signal in the frequency domain making the signal appear more noise-like.

For illustration, Figure 4-1 shows the spectral content for a 1 MHz PRF UWB signal as measured in a 24 MHz bandpass filter when: unmodulated, OOK modulated, 50% absolute reference dithered, and 2% relative referenced dithered.

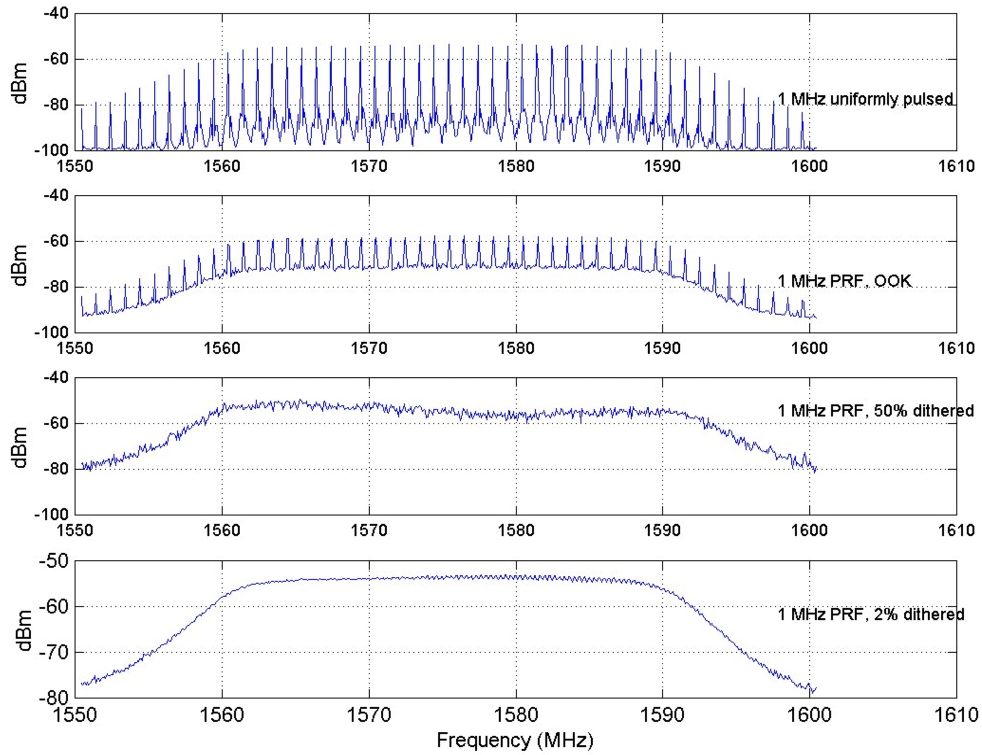


Figure 4-1. Illustration of Modulation Effects on a UWB Signal as Measured in a 24 MHz Bandpass Filter

The results of this measurement effort were found to be UWB signal-dependent and are strongly related to the PRF examined. Thus, in this section, the summary of the measurement results, and the conclusions drawn from them, will be grouped by UWB signal PRF for each of the GPS receivers measured.

4.2 ANALYSIS OF C/A-CODE GPS RECEIVER INTERFERENCE SUSCEPTIBILITY DATA

Previous work in quantifying interference to GPS receivers has been performed in RTCA and ITU-R technical working groups. Much of this work has focused on the effect of different interference signal types upon C/A-code receivers, since these represent the predominant receiver architecture in the civilian marketplace. This work has determined that GPS C/A-code receivers are most susceptible to CW-like interference. This is due to the potential for interfering spectral lines to become aligned with the 1 kHz spaced spectral lines of the GPS C/A-code, produced as a result of the relatively short, periodic nature of the Gold codes used to generate the pseudo-random sequences necessary for code division multiple access (CDMA) operation. RTCA and ITU-R have documented an interference protection level -150.5 dBW, at the input of the GPS receiver, as necessary to protect GPS receivers from this type of interfering signal. GPS C/A-code receivers are also susceptible to broadband noise-like interference where the documented protection level, at the input of the GPS receiver is -140.5 dBW/MHz. Both of the above protection levels are based on a GPS signal level of -134.5 dBm at the input to the GPS receiver.

RTCA has also determined that GPS C/A-code receivers are less sensitive to low duty cycle pulse-like interfering signals. The interference protection level documented for this type of interference is +20 dBm (peak pulse power), at the input to the receiver, for duty cycles less than 10%.

In the analysis of measurements results reported in this addendum report and in NTIA Report 01-45, it was found that the interference effects on GPS C/A-code receivers from each of the UWB signals considered could be classified as either CW-like, noise-like or pulse-like interference. In each case where the interference effect was classified as CW- or noise-like, a specific interference threshold value could be determined from the measured data. The susceptibility threshold values that were analyzed for CW-like interference effects were the UWB power in a single spectrum line (in dBW) that caused the GPS receiver to break-lock. For noise-like interference effects, a set of susceptibility threshold values were analyzed where the GPS receiver was caused to break-lock and a separate set of values where the GPS receiver reacquisition time was increased due to interference. For both data sets, the susceptibility values were the power spectral density (in dBW/MHz) of the UWB signal that resulted in the interference effect.

The data collected under this addendum report effort were for a GPS receiver employing a narrowly spaced correlator and a TSO-C129a (aviation) compliant GPS receiver. The C/A-code GPS receiver that was the subject of the NTIA Report 01-45 is referred as C/A-code receiver.

The susceptibility values for each of the three receivers and for each interference effect/criterion (i.e., CW-like/break-lock, noise-like/break-lock, and noise-like/reacquisition) were examined to gain insight into the variability, reliability, and accuracy of the measured data. The susceptibility data analyzed herein was referenced to a desired signal level of -130 dBm and for the noise-like interference effects the power of the UWB signal was added to the -93 dBm/20 MHz noise signal that was also input to the GPS receiver as required in the test plan. These data conversions were used to facilitate the comparison of measured data resulting from this program and from other GPS interference measurement efforts.

The susceptibility data was analyzed by determining the median along with the range of data for each receiver and the results are shown Table 4-1. The median for the CW-like interference effects might indicate that performance of the TSO-C129a compliant receiver is more robust (can withstand a higher interference level before a break-lock condition is realized) than the other receivers. However, examination of the range of data for CW-like effects would indicate the data is consistent across the three receivers that process the L1 C/A code signal. The noise-like susceptibility values are similarly consistent across the three GPS receivers.

TABLE 4-1. Median and Range of Data Values for the Interference Thresholds

Data Set	Interference Threshold Values		
	C/A Code	Narrowly-Spaced Correlator	TSO-C129a Compliant
Median for CW-Like Interference (Break-Lock)	-145 dBW	-145.9 dBW	-140.8 dBW
Range of Data	-143.7 to -146.5 dBW	-139.9 to -147 dBW	-138.2 to -147.8 dBW
Median for Noise-Like Interference (Break-Lock)	-129 dBW/MHz	-131.6 dBW/MHz	-134.4 dBW/MHz
Range of Data	-127.8 to -130.9 dBW/MHz	-127 to -132.7 dBW/MHz	-131.6 to -135 dBW/MHz
Median for Noise-Like Interference (Reacquisition)	-133 dBW/MHz	No Measured Data	-134.9 dBW/MHz
Range of Data	-129.8 to -133.9 dBW/MHz		-131.6 to -136 dBW/MHz

Table 4-2 shows the overall median and range for the combined data for the three receivers. This shows the range of the data varies over a fairly small range relative to the median values. This again is an indication of data consistency across the three receivers. The data in Table 4-2 was used to compare the NTIA data with GPS/UWB measurement data collected by other entities.

TABLE 4-2. Overall Median and Range of Data Values for the Interference Thresholds

Data Set	Interference Threshold Values (Data Combined for the Three Receivers)
Median for CW-Like Interference (Break-Lock)	-144.5 dBW
Range of Data	-138.2 to -147.8 dBW
Median for Noise-Like Interference (Break-Lock)	-133.2 dBW/MHz
Range of Data	-127 to -135 dBW/MHz
Median for Noise-Like Interference (Reacquisition)	-134.6 dBW/MHz
Range of Data	-129.8 to -136 dBW/MHz

In order to make a comparison between the NTIA and SU data, data sets had to be identified where similar measurement procedures, interference criteria, and UWB signal characteristics are used. Where measurement procedures, interference criteria, and UWB signal characteristics were similar, appropriate comparisons were made. The comparison of the NTIA and SU data is presented in Table 4-3.

As indicated in Table 4-3, the SU GPS/UWB interference measurement program considered two types of GPS receivers. These are referred to as a high-grade GPS aviation receiver and a low-cost Original Equipment Manufacturer (OEM) receiver. Several interference criteria were also used including break-lock and pseudo-range accuracy. The interference effects for the SU data examined in this analysis can be characterized as noise-like or CW-like. The SU measured interference threshold data is reported in units of dBm (average power) as measured in a 24 MHz bandwidth filter. For comparison purposes the SU data was adjusted to units of dBW/MHz for noise-like interference cases and referenced to a GPS signal level of -130 dBm. Similarly, the CW-like cases were adjusted to determine power in a single spectral line in dBW and referenced to a GPS signal level of -130 dBm. Both SU measured CW-like interference cases in Table 4-3 used a UWB signal that resulted in only one line within the 24 MHz measurement filter. The NTIA data is primarily for the break-lock condition either for CW-like or noise-like interference effects and is compared to the SU CW-like and noise-like data as appropriate. For the SU test that used pseudo-range accuracy as the interference criterion, the NTIA median interference threshold value for reacquisition was used for comparison. Table 4-3 also contains the range of data associated with each NTIA median threshold level.

A review of the Table 4-3 information indicates that the SU data is consistent (comparing the adjusted threshold level columns) with the NTIA measured receiver input threshold data. The high-grade aviation receiver is slightly more robust than the receivers tested by NTIA under break-lock conditions. However, the SU break-lock thresholds are within 2 dB of the range of the NTIA data. For the aviation receiver pseudo-range measurement and both the OEM receiver measurements, the SU data is within the range of the NTIA data.

The interference threshold data reported in the ARL:UT report as analyzed by the JSC was also compared to the NTIA data. Again, because of differences in the measurement approach and the interference threshold criteria, only a subset of the ARL:UT data could be used in this comparison. These differences in measurement approach are explained in the JSC Report. The comparison of NTIA data with ARL:UT data is shown in Table 4-4. The interference threshold for the ARL:UT results are the values shown in the JSC Report with an appropriate correction (-43 dB) to convert from dBm/20 MHz to dBW/MHz for comparison purposes. Most of the ARL:UT cases shown in Table 4-4 are consistent with the NTIA data particularly if one compares the ARL:UT data to the range associated with the NTIA median value. A possible exception to this consistency is observed in the data for Receiver Number One with UWB interference and a loss of one SV (-142.3 dBW/MHz for UWB Mode 7 and -142.7 dBW/MHz for UWB Mode 13). For these conditions, the receiver seems to be more susceptible to UWB interference. As discussed in the JSC Report, there is evidence for possible CW-like interference effects having occurred during the ARL:UT tests for these conditions. As shown in many of the GPS interference tests, GPS receivers are more susceptible to CW-like interference than noise-like interference. The NTIA data shows a median value of -144.5 dBW for CW-like interference for a break-lock condition. This is consistent with the ARL:UT test results for these two cases.

TABLE 4-3. Comparison of SU and NTIA Interference Threshold Levels

SU Receiver Type	Interference Criteria	Category of Interfering Signal Effect	SU Report Threshold Level	SU Adjusted Threshold Level	Comparable NTIA Adjusted Threshold Overall Median Level	Range of Data Associated with NTIA Median Levels
Aviation	Break-Lock	Noise-like	-83.8 dBm/24 MHz	-126.3 dBW/MHz	-133.2 dBW/MHz	-127 to -135 dBW/MHz
	Break-Lock	CW-like	-101.27 dBm/24 MHz	-136.5 dBW	-144.5 dBW	-138.2 to -147.8 dBW
	15 cm Pseudo-Range Error	Noise-like	-89.7 dBm/24 MHz	-132.2 dBW/MHz	-134.6 dBW/MHz	-129.8 to -136 dBW/MHz
OEM	Break-Lock	Noise-like	-87.8 dBm/24 MHz	-130.3 dBW/MHz	-133.2 dBW/MHz	-127 to -135 dBW/MHz
	Break-Lock	CW-like	-104.27 dBm/24 MHz (4 dB backoff)	-139.5 dBW	-144.5 dBW	-138.2 to -147.8 dBW

TABLE 4-4. Comparison of ARL:UT and NTIA Interference Threshold Levels

ARL:UT Receiver	Interference Effects*	ARL:UT Interference Signals and Threshold Interference Levels			Comparable NTIA Median Threshold Levels with Associated Range of Data
		White Noise (dBW/MHz)	UWB Mode 7 (dBW/MHz)	UWB Mode 13 (dBW/MHz)	
1	Loss of 1 SV	-126.8	-142.3	-142.7	-133.2 dBW/MHz Median Break-Lock Level for Noise-Like Interference
	Loss of Multiple SVs	-124.8	-131.3	-133.7	
2	Loss of 1 SV	-126.2	-129.7	-131.1	
	Loss of Multiple SVs	-126.2	-127.7	-129.1	-127 to -135 dBW/MHz Range of Data Associated with Median
3	Loss of 1/Multiple SVs	-127.9	-127.4	-128.8	
4	Loss of 1 SV	-129.9	-129.4	-133.8	
	Loss of Multiple SVs	-127.9	-129.4	-133.8	

* The ARL:UT data shows, among many other performance measures, the interference power level at the input of the GPS at which the signal from one and/or more than one GPS SV cannot be tracked. This performance measure compares with the break-lock measure used by NTIA.

Finally, if one subtracts 4.5 dB from the median values of Table 4-2 to correct the GPS reference signal from -130 dBm to -134.5 dBm, the NTIA data can be compared to the existing RTCA and ITU GPS interference limits. The adjusted median value for CW-like interference would be -149 dBW and for noise-like interference for reacquisition would be -139.1 dBW/MHz. These values can be compared to the existing protection limits for GPS receivers of -150.5 dBW for CW-like interference and -140.5 dBW/MHz for noise-like interference.

In summary, the GPS receiver interference threshold data is consistent across the three receivers tested in the NTIA measurement program. These receivers are those that process the C/A code L1 signal. The NTIA data was shown to be comparable to the SU and ARL:UT test results. Admittedly, these comparisons can only be made for a subset of the SU and ARL:UT data because of differences in the UWB characteristics considered and the measurement procedures used. Finally, the NTIA data was compared favorably to existing interference protection limits for GPS. For the parameter sets tested, this data defines the limit of the power level of the UWB signal that can be tolerated at the GPS receiver input to protect the desired performance. This body of susceptibility data can be used in source-path-receiver analysis to determine the interference impact of GPS/UWB operations in various scenarios.

4.3 SUMMARY OF ANALYSIS FINDINGS

There are literally hundreds of applications of GPS, with additional applications being defined on a seemingly daily basis. To attempt to define a unique operational scenario for each of these applications would be a massive, if not impossible undertaking. Therefore, within the context of this assessment, an effort was made to define a set of operational scenarios, in conjunction with the GPS user and UWB communities, that could be used to bound the possible GPS applications.

The two main parameters needed to perform the analyses, which are defined by the operational scenarios, are the likely separation distance between a GPS receiver and UWB transmitter, and the likely orientation of the antennas with respect to one another. The likely separation distance is used to assess the propagation path loss, to formulate an assumption as to the likelihood of multiple UWB devices in view of the GPS receiver, and to determine the interference allotment for UWB devices within the constraints defined by the application. The likely antenna orientation is used to estimate the antenna gain realized by the GPS antenna in the direction of the UWB devices.

In the public meetings that were held, a set of operational scenarios were defined that NTIA accepts as bounding the parameters of interest. For example, the terrestrial scenarios involving the public safety use of GPS, define a minimum separation distance of 2 meters. The en-route aviation operational scenario defines a minimum separation distance of 1000 feet (approximately 300 meters). These two cases bound the minimum distance separation of the remaining operational scenarios. Furthermore, it appears reasonable that these two scenarios will also bound operational scenarios not specifically considered within this effort, with respect to the minimum distance separation. Additionally, it is reasonable to assume that there will be a limited number of UWB devices operating at a distance of 2 meters from a GPS receiver, as defined by the terrestrial operational scenario discussed in Section 3. However, when the en-route aviation scenario is considered, a larger number of UWB devices can be in view from an aircraft at an altitude of 1000 feet. Therefore, it is believed that the operational scenarios considered also bound the GPS applications with respect to the potential aggregation of UWB devices.

In this analysis, NTIA determined the maximum allowable EIRP for the different UWB signal permutations, using the operational scenarios proposed in the public meetings. The results of the analysis are summarized in Tables 4-5 through 4-8. Each table corresponds to a UWB PRF examined in the analysis. The tables provide a description of the: operational scenario; UWB signal characteristics; GPS receiver architecture; interfering signal characterization; interference threshold; and the computed values of maximum allowable EIRP. The values of maximum allowable EIRP shown in the Tables 4-5 through 4-8 are for a single UWB device, and represent the highest EIRP at which UWB devices can operate and still provide protection to the GPS receiver architecture under consideration for the conditions specified in the operational scenarios.

Tables 4-5 through 4-8 also include a comparison of the computed values of maximum allowable EIRP with the current Part 15 level of -71.3 dBW/MHz. When the interference effects are classified as being pulse-like or noise-like, the values of maximum allowable EIRP can be directly compared to the current Part 15 level. When the interference effect is classified as being CW-like, the maximum allowable EIRP can be compared to the Part 15 level, if it is assumed that there is only a single spectral line in the measurement bandwidth. If the difference between the current Part 15 level and the computed maximum allowable EIRP is negative, no additional attenuation below the current Part 15 level is necessary to protect the GPS receiver architecture under consideration. If the difference is positive, this value specifies the additional attenuation below the current Part 15 level that is necessary to protect the GPS receiver architecture under consideration.

Table 4-5 summarizes the analysis results for UWB devices that operate with a PRF of 100 kHz. For the narrowly-spaced correlator receiver architecture, when the operational scenario includes either a single UWB device or a small number of UWB devices operating with a PRF of 100 kHz, the interference effect was categorized as being pulse-like. The computed values of maximum allowable EIRP range from -70.8 to -39.3 dBW/MHz depending upon the operational scenario under consideration.

In the aviation non-precision approach operational scenario the TSO-C129a compliant C/A code receiver architecture was considered. For the TSO-C129a compliant C/A code receiver architecture, when the operational scenario includes a small number of UWB devices operating with a PRF of 100 kHz, the interference effect was categorized as being pulse-like. As shown in Table 4-5, the computed maximum allowable EIRP is -58.2 dBW/MHz. In the aviation en-route navigation operational scenarios, it is assumed that there is a large number of UWB devices present such that, independent of the individual UWB signal parameters, the interference effect can be characterized as being noise-like (i.e., central limit theorem). The computed values of maximum allowable EIRP are -75.9 dBW/MHz when all of the UWB devices were assumed to be operating inside of a building and -84.9 dBW/MHz when all of the UWB devices were assumed to be operating outside of a building.

Table 4-6 summarizes the analysis results for UWB devices that operate with a PRF of 1 MHz. For the narrowly-spaced correlator receiver architecture, when the operational scenario includes either a single UWB device or a small number of UWB devices operating with a PRF of 1 MHz, the interference effect was characterized as being CW-like, pulse-like, or noise-like. This characterization depends on the modulation and gating percentage employed. When the operational scenario considered a single UWB device employing 100% gating and no modulation, the interference effect was characterized as being CW-like. For all other signal permutations, the single entry UWB device interaction interference effect was characterized as being pulse-like. For the single UWB device operational scenario, the interference effect was characterized as being pulse-like and the values of maximum allowable EIRP range from -66.5 to -49 dBW/MHz. When the interference effect was characterized as being CW-like, the computed values of maximum allowable EIRP range from -104.7 to -87.2 dBW, depending on the operational scenario under consideration. In the operational scenarios where multiple UWB device interactions were considered, the interference effect for 1 MHz, 100% gating, was still CW-like. The values of maximum allowable EIRP range from -93.8 to -73.2 dBW. For all other 1 MHz UWB signal permutations, the interference effect was characterized as being noise-like. When the multiple UWB device interaction interference effect was characterized as being noise-like, the computed values of maximum allowable EIRP range from -87.9 to -67.3 dBW/MHz, depending upon the operational scenario under consideration.

In the aviation non-precision approach operational scenario, where the TSO-C129a compliant C/A code receiver architecture was analyzed, the interference effect was characterized as being either CW-like or noise-like. As shown in Table 4-6, the values of computed maximum allowable EIRP are -87 dBW (CW-like) and -88.3 dBW/MHz (noise-like). In the aviation en-route navigation operational scenarios, there were a large number of UWB devices assumed to be present, therefore the interfering signal was characterized as being noise-like. The computed values of maximum allowable EIRP are -75.9 dBW/MHz when all of the UWB devices were assumed to be operating inside of a building and -84.9 dBW/MHz when all of the UWB devices were assumed to operating outside of a building.

Table 4-7 summarizes the analysis results for UWB devices that operate with a PRF of 5 MHz. In the terrestrial and surveying operational scenarios where a single UWB device is operating with a PRF of 5 MHz, the interference effect was characterized as being CW-like, pulse-like, or noise-like. This characterization depends on the type of modulation and gating percentage that was employed. As shown in Table 4-7, the range of the computed values of maximum allowable EIRP for the different interfering signal characterizations were: -107.3 to -89.8 dBW (CW-like), -49.1 to -31.6 dBW/MHz (pulse-like), and -88.3 to -70.8 dBW/MHz (noise-like). In the operational scenarios where a small number of UWB devices with a PRF of 5 MHz were operating, the interference effect was characterized as being either CW-like or noise-like. This characterization depends on the type of modulation and gating percentage that was employed. When the interference effect was characterized as being CW-like, the values of maximum allowable EIRP range from -96.4 to -75.8 dBW, depending on the operational scenario under consideration. When the interference effect was characterized as being noise-like, the values of maximum allowable EIRP range from -87.9 to -67.3 dBW/MHz, depending on the operational scenario under consideration.

In the aviation non-precision approach operational scenarios, where the TSO-C129a compliant C/A code receiver architecture was considered, the interference effect was characterized as being CW-like or noise-like depending on the type of modulation and gating percentage that was employed. As shown in Table 4-7, the values of computed maximum allowable EIRP were -83.6 dBW (CW-like) and -89.3 dBW/MHz (noise-like) In the aviation en-route navigation operational scenarios, there were a large number of UWB devices assumed to be present, therefore the interfering signal was characterized as being noise-like. The computed values of maximum allowable EIRP are -75.9 dBW/MHz when all of the UWB devices were assumed to be operating inside of a building and -84.9 dBW/MHz when all of the UWB devices were assumed to be operating outside of a building.

Table 4-8 summarizes the analysis results for UWB devices that operate with a PRF of 20 MHz. In the terrestrial and surveying operational scenarios where a single UWB device is operating with a PRF of 20 MHz, the interference effect was characterized as being CW-like, pulse-like, or noise-like. This characterization depends on the type of modulation and gating percentage that was employed. As shown in Table 4-8, the range of the computed values of maximum allowable EIRP for the different interfering signal characterizations were: -107.5 to -90 dBW (CW-like), -82.8 to -65.3 dBW/MHz (pulse-like), and -96.1 to -78.6 dBW/MHz (noise-like). In the operational scenarios where a small number of UWB devices with a PRF of 20 MHz are operating, the interference effect was characterized as being either CW-like or noise-like. This characterization depends on the type of modulation and gating percentage that was employed. When the interference effect was characterized as being CW-like, the values of maximum allowable EIRP range from -96.6 dBW to -76 dBW, depending on the operational scenario under consideration. When the interference effect was characterized as being noise-like, the values of maximum allowable EIRP range from -91.2 to -70.6 dBW/MHz, depending on the operational scenario under consideration.

In the aviation non-precision approach operational scenario, where the TSO-C129a compliant C/A code receiver architecture was considered, the interference effect was characterized as being either CW-like or noise-like. As shown in Table 4-8, the values of computed maximum allowable EIRP were -88.1 dBW (CW-like) and -87.3 dBW/MHz (noise-like). In the aviation en-route navigation operational scenarios, there are a large number of UWB devices assumed to be present, and the interference effect was characterized as being noise-like. The computed values of maximum allowable EIRP are -75.9 dBW/MHz when all of the UWB devices were assumed to be operating inside of a building and -84.9 dBW/MHz when all of the UWB devices were assumed to be operating outside of a building.

TABLE 4-5. Summary of Analysis Results (PRF = 100 kHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold (dBW/MHz)	Maximum Allowable EIRP (dBW/MHz)	Comparison with the Current Part 15 Level (dB)
Application	**UWB Single**	**UWB Multiple**	**UWB Indoor**	**UWB Outdoor**	**Gating %**	**Mod.**					
Terrestrial	X			X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-70.8	-0.5
Terrestrial		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-55.2	-16.1
Terrestrial		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-59.9	-11.4
Maritime		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-39.3	-32
Maritime		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-45.7	-25.6
Railway		X	X		20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.9	-17.4
Railway		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-55.4	-15.9
Surveying	X			X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.3	-18
Surveying		X		X	20	OOK	Narrow Correlator	Pulse-Like	-110.2	-53.4	-17.9
Aviation-NPA		X		X	100	None	TSO C-129a	Pulse-Like	-117.9	-58.2	-13.1
Aviation-ER		X	X		Note 1	Note 1	TSO C-129a	Noise-Like	-136	-75.9[2]	4.6
Aviation-ER		X		X	Note 1	Note 1	TSO C-129a	Noise-Like	-136	-84.9[2]	13.6

Notes:
1. In this operational scenario, it is assumed that there is a large enough number of UWB devices such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.
2. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

TABLE 4-6. Summary of Analysis Results (PRF = 1 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	**UWB Single**	**UWB Multiple**	**UWB Indoor**	**UWB Outdoor**	**Gating %**	**Mod.**					
Terrestrial	X			X	100	None	Narrow Correlator	CW-Like	-144.1	–104.7	33.4
Terrestrial	X			X	100	50% Abs.	Narrow Correlator	Pulse-Like	-105.9	-66.5	-4.8
Terrestrial		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-89.1	17.8
Terrestrial		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-83.2	11.9
Terrestrial		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-93.8	22.5
Terrestrial		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-87.9	16.6
Maritime		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-73.2	1.9
Maritime		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-67.3	-4
Maritime		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-79.6	8.3
Maritime		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-73.7	2.4
Railway		X	X		100	None	Narrow Correlator	CW-Like	-144.1	-87.8	16.5
Railway		X	X		20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-80.7	9.4
Railway		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-89.3	18
Railway		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-82.2	10.9
Surveying	X			X	100	None	Narrow Correlator	CW-Like	-144.1	-87.2	15.9
Surveying	X			X	100	50% Abs.	Narrow Correlator	Pulse-Like	-105.9	-49	-22.3
Surveying		X		X	100	None	Narrow Correlator	CW-Like	-144.1	-87.3	16
Surveying		X		X	20 & 100	Multiple	Narrow Correlator	Noise-Like	-132.2	-75.4	4.1
Aviation-NPA		X		X	20	None	TSO C-129a	CW-Like	-146.7	-87	15.7
Aviation-NPA		X		X	100	50% Abs.	TSO C-129a	Noise-Like	-142	-88.3	17
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

TABLE 4-7. Summary of Analysis Results (PRF = 5 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	Gating %	Mod.					
Terrestrial	X			X	100	OOK	Narrow Correlator	CW-Like	-146.7	–107.3	36
Terrestrial	X			X	20	Multiple	Narrow Correlator	Pulse-Like	-88.5	-49.1	-22.2
Terrestrial	X			X	100	50% Abs.	Narrow Correlator	Noise-Like	-127.7	–88.3	17
Terrestrial		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-91.7	20.4
Terrestrial		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-83.2	11.9
Terrestrial		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-96.4	25.1
Terrestrial		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-87.9	16.6
Maritime		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-75.8	4.5
Maritime		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-67.3	-4
Maritime		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-82.2	10.9
Maritime		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-73.7	2.4
Railway		X	X		100	OOK	Narrow Correlator	CW-Like	-146.7	-90.4	19.1
Railway		X	X		20	Multiple	Narrow Correlator	Noise-Like	-132.2	-80.7	9.4
Railway		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-91.9	20.6
Railway		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-82.2	10.9
Surveying	X			X	100	OOK	Narrow Correlator	CW-Like	-146.7	-89.8	18.5
Surveying	X			X	20	Multiple	Narrow Correlator	Pulse-like	-88.5	-31.6	-39.7
Surveying	X			X	100	50% Abs.	Narrow Correlator	Noise-Like	-127.7	-70.8	-0.5
Surveying		X		X	100	OOK	Narrow Correlator	CW-Like	-146.7	-89.9	18.6
Surveying		X		X	20	Multiple	Narrow Correlator	Noise-Like	-132.2	-75.4	4.1
Aviation-NPA		X		X	20	OOK	TSO C-129a	CW-Like	-143.3	-83.6	12.3
Aviation-NPA		X		X	100	2% Rel.	TSO C-129a	Noise-Like	-143	-89.3	18
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

TABLE 4-8. Summary of Analysis Results (PRF = 20 MHz)

Operational Scenario Description					UWB Signal Characteristics		GPS Receiver	Characterization of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	**UWB Single**	**UWB Multiple**	**UWB Indoor**	**UWB Outdoor**	**Gating %**	**Mod.**					
Terrestrial	X			X	20	None	Narrow Correlator	CW-Like	-146.9	–107.5	36.2
Terrestrial	X			X	20	2% Rel.	Narrow Correlator	Pulse-Like	-122.2	-82.8	11.5
Terrestrial	X			X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	–96.1	24.8
Terrestrial		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-91.9	20.6
Terrestrial		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-86.5	15.2
Terrestrial		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-96.6	25.3
Terrestrial		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-91.2	19.9
Maritime		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-76	4.7
Maritime		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-70.6	-0.7
Maritime		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-82.4	11.1
Maritime		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-77	5.7
Railway		X	X		20	None	Narrow Correlator	CW-Like	-146.9	-90.6	19.3
Railway		X	X		100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-84	12.7
Railway		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-92.1	20.8
Railway		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-85.5	14.2
Surveying	X			X	20	None	Narrow Correlator	CW-Like	-146.9	-90	18.7
Surveying	X			X	20	2% Rel.	Narrow Correlator	Pulse-Like	-122.2	-65.3	-6
Surveying	X			X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-78.6	7.3
Surveying		X		X	20	None	Narrow Correlator	CW-Like	-146.9	-90.1	18.8
Surveying		X		X	100	2% Rel.	Narrow Correlator	Noise-Like	-135.5	-78.7	7.4
Aviation-NPA		X		X	20	None	TSO C-129a	CW-Like	-147.8	-88.1	16.8
Aviation-NPA		X		X	100	Multiple	TSO C-129a	Noise-Like	-141	-87.3	18
Aviation-ER		X	X		Note 2	Note 2	TSO C-129a	Noise-Like	-136	-75.9[3]	4.6
Aviation-ER		X		X	Note 2	Note 2	TSO C-129a	Noise-Like	-136	-84.9[3]	13.6

Notes:
1. When the interference effect has been characterized as being pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been characterized as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 active UWB devices per square kilometer.

Certain observations were made based on a review of the last column in Tables 4-5 through 4-8. This column lists the difference between the current Part 15 level of -71.3 dBW/MHz (considered as an average power limit) and the computed maximum allowable EIRP values. As stated earlier, a positive number in the last column indicates that the computed allowable EIRP is less than the current Part 15 level.

An examination of Table 4-5 (PRF = 100 kHz) shows the effect of the C/A code signal process, used by both the narrowly-spaced correlator and the TSO-C129a compliant receivers, as being fairly robust to low-duty cycle pulsed interference. The worst-case comparison to the current Part 15 level is the aviation en-route navigation operational scenario with UWB devices operating outdoors (13.6 dB below the Part 15 level). This is based on a density of active UWB devices of 200/km^2. If one considers the use of 100 kHz PRF is likely to be of interest in only UWB device applications such as ground penetrating radars and through-the-wall imaging radars, the projected density of UWB devices may not be as high as assumed. If, for example, the density of UWB devices operating at 100 kHz is 20/km^2, the maximum allowable EIRP would increase by 10 dB.

Tables 4-6 through 4-8 (UWB waveforms with PRFs of 1, 5, and 20 MHz) show that the maximum allowable EIRP level necessary to satisfy the measured GPS performance criteria must be below the current Part 15 level for most of the operational scenarios considered. Those interactions that involve operational scenario/UWB signal parameter combinations that require an attenuation of 20 dB or more below the Part 15 level were selected for closer examination. This examination indicates that in most of these cases, the interactions involve: 1) UWB waveforms that were deemed CW-like in their interference effect to the GPS receivers, for which the measurements indicate a greater interference susceptibility or 2) operational scenarios in which the UWB transmitter is considered to be operating at a close distance (within several meters) to the GPS receivers. This data suggests that if the spectral line content of the UWB waveforms could be removed from consideration, perhaps through regulation, there still remain interactions involving noise-like UWB waveforms at these PRFs for which the EIRP levels would still have a potential to cause interference at levels 18 to 20 dB below the current Part 15 level.

As shown in Tables 4-5 through 4-8, the results of the analysis indicate that the values of maximum allowable EIRP that are necessary to preclude interference to GPS receivers are highly dependent on the parameters of the UWB signal. This is consistent with the findings from the measurement effort where the performance of the GPS receiver in the presence of a UWB signal was also found to be highly dependent on the UWB signal structure.

Figures 4-2 through 4-5 display computed maximum allowable EIRP levels for those UWB signal permutations that were classified within this study as pulse-like, noise-like, and CW-like with respect to their interference effects on the GPS narrowly-spaced correlator receiver architecture. The values reported in these charts represent the maximum allowable EIRP levels determined from an analysis of each UWB signal permutation in potential interactions with the narrowly-spaced correlator receiver architecture that were defined by all of the operational scenarios considered in the study.

For the operational scenarios considered for single and multiple UWB devices, Figures 4-2 and 4-3 displays the range of maximum allowable EIRP for the UWB signal that were classified in this study as causing pulse-like interference effects in the GPS receiver. Figure 4-4 displays the range of maximum allowable EIRP levels for those UWB signals that were classified in this study as causing noise-like interference effects in the GPS receiver. Figure 4-5 displays the range of maximum allowable EIRP levels for those UWB signals that were classified in this study as being CW-like in their interference effects in the GPS narrowly-spaced correlator receiver. The labels on the y-axis in Figures 4-2 through 4-5 identify the various UWB signal structures in terms of PRF, percent gating, and the type of modulation. For example, a UWB signal structure with a PRF of 100 kHz, 100% gating, and no modulation will have a y-axis label of: 100 kHz, 100%, None.

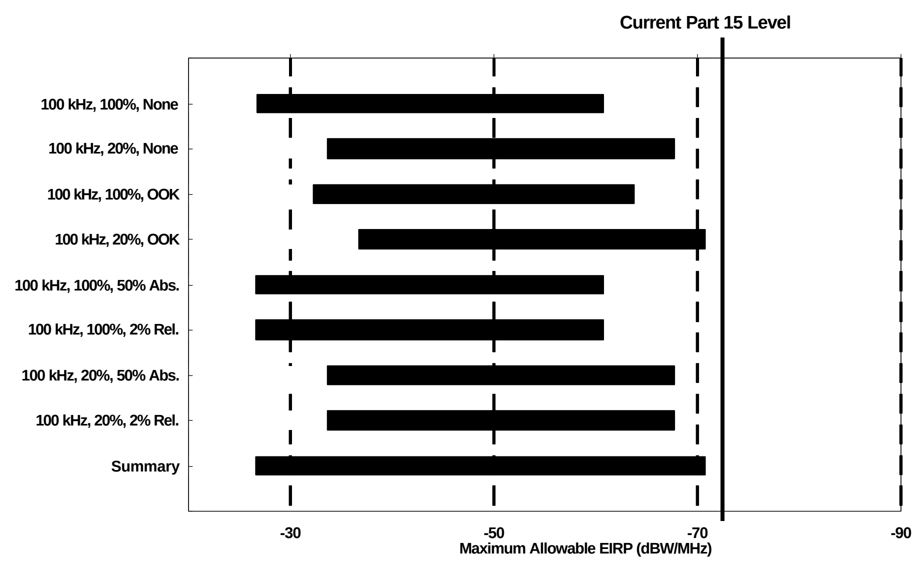


Figure 4-2. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal for the Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Operational Scenario)

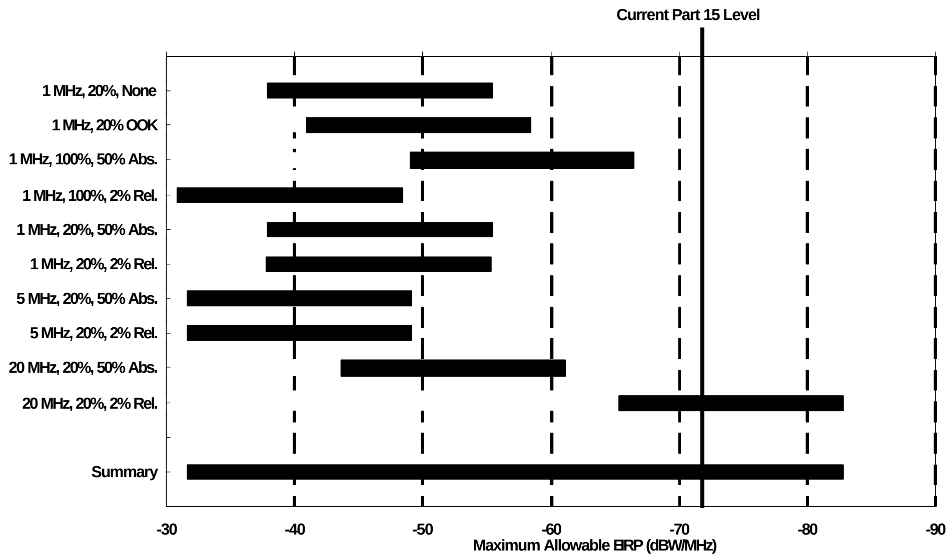


Figure 4-3. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal for the Narrowly- Spaced Correlator Receiver Architecture (Single UWB Device Operational Scenario)

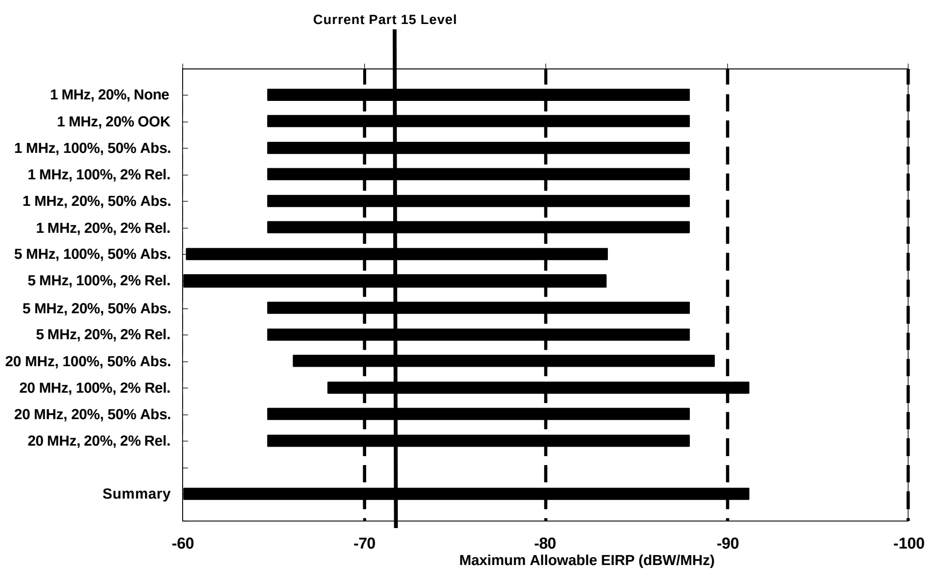


Figure 4-4. Range of Maximum Allowable EIRP for Noise-Like UWB Signals for Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Scenarios)

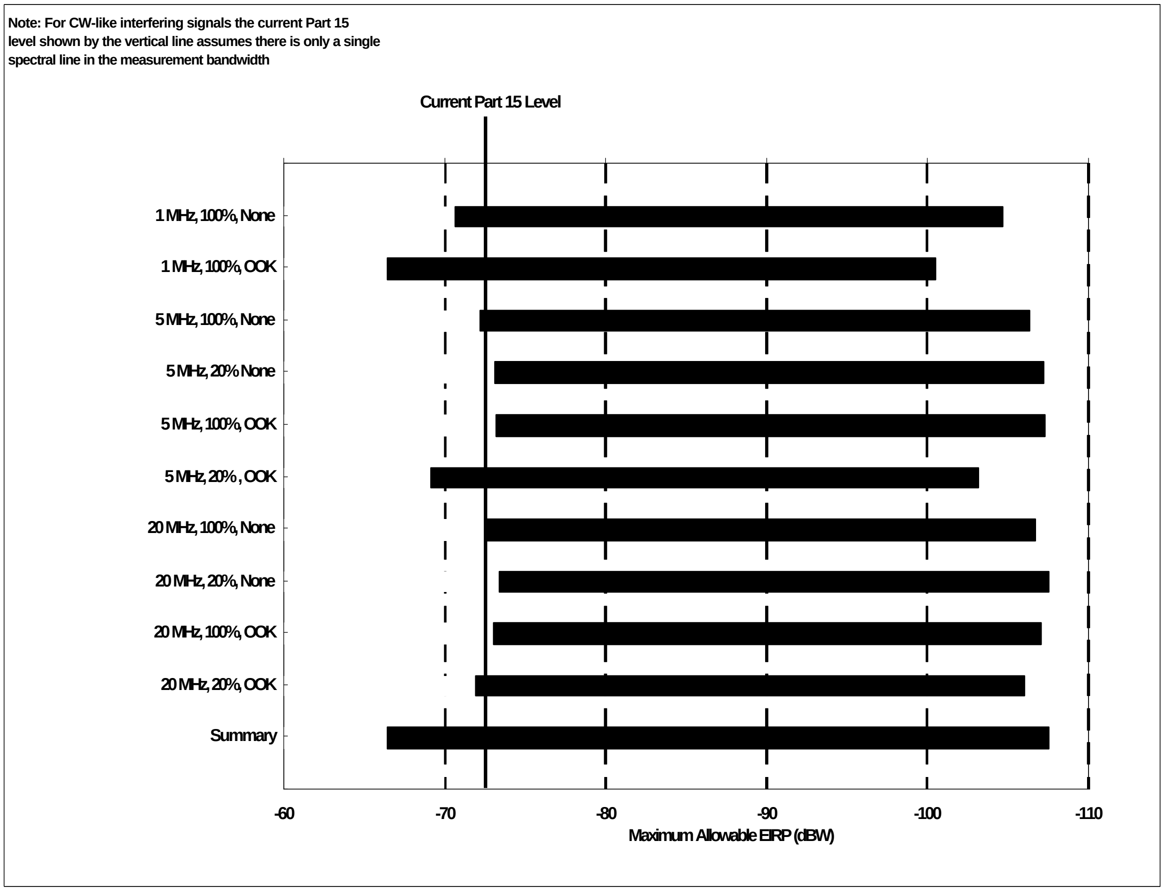


Figure 4-5. Range of Maximum Allowable EIRP for CW-Like UWB Signals for the Narrowly-Spaced Correlator Receiver Architecture (Single and Multiple UWB Device Operational Scenarios)

An examination of Figures 4-2 through 4-5 clearly indicates that the maximum allowable EIRP required to satisfy the measured performance threshold of the narrowly-spaced correlator GPS receiver, across all of the operational scenarios is a function of the UWB signal structure. Figure 4-2 shows the maximum allowable EIRP levels corresponding to those UWB signal permutations with a PRF of 100 kHz. For the UWB signal permutations represented in Figure 4-2, neither a break-lock nor a reacquisition could be measured for UWB power levels up to the maximum power available from the UWB signal generator. For these cases, the maximum UWB signal generator power level was used to compute the maximum allowable EIRP level. Thus the reported maximum allowable EIRP level represents a lower limit for these cases. That is, the actual maximum allowable EIRP level may be higher than the level shown in Figure 4-2 for these 100 kHz PRF UWB waveforms. From Figure 4-2, it can be observed that the maximum allowable EIRP levels necessary to satisfy the measured performance threshold for the narrowly-spaced correlator GPS receiver over all of the operational scenarios considered in this study range from -70.8 to -26.6 dBW/MHz.

In the operational scenarios where single UWB device interactions are considered, several UWB signal permutations employing PRFs of 1 MHz, 5 MHz, and 20 MHz, caused an effect similar to that of low-duty cycle pulsed interference to the narrowly-spaced correlator receiver. Figure 4-3 shows that for these UWB signal permutations, the maximum allowable EIRP levels necessary to satisfy the GPS receiver performance thresholds for the operational scenarios considered within this study range from -82.8 to -31.6 dBW/MHz.

Figure 4-4 shows that the maximum allowable EIRP levels necessary to satisfy the measured performance thresholds over all of the operational scenarios considered in this study range from -91.2 to -60.1 dBW/MHz for those UWB signals employing PRFs of 1 MHz, 5 MHz, and 20 MHz, that are classified as noise-like in their interference effects on the GPS narrowly-spaced correlator receiver.

The data presented in Figure 4-5 shows that the maximum allowable EIRP levels range from -107.5 to -66.4 dBW over all of the operational scenarios considered for those UWB signals that are classified as CW-like in their interference effects on the GPS narrowly-spaced correlator receiver. These maximum allowable EIRP levels are based on the power in a single spectral line and in order to make a comparison to the Part 15 level, it must be assumed that only a single spectral line appears in the measurement bandwidth.

Figures 4-6 through 4-8 present summary plots showing the maximum allowable EIRP calculated for the aviation non-precision approach operational scenario using the TSO-C129a compliant GPS receiver measured as part of this study. The analysis results are presented as a function of the different UWB signal permutations examined. For the TSO-C129a compliant receiver, the interference effects of the UWB signals examined were classified as pulse-like, noise-like, or CW-like.

Figure 4-6 shows that for those UWB signals examined with a PRF of 100 kHz, the calculated maximum allowable EIRP level is above the current Part 15 level. Therefore, based on the results of the analysis, no additional attenuation is necessary.

Figure 4-7 presents the maximum allowable EIRP levels or the PRFs of 1 MHz, 5 MHz, and 20 MHz, when the UWB signal permutations were classified as causing noise-like interference to the TSO-C129a compliant GPS receiver. As shown in Figure 4-7, the maximum allowable EIRP must be as much as 18 dB below the current Part 15 level to satisfy the measured performance threshold of the TSO-C129a compliant GPS receiver in the applicable operational scenarios.

Figure 4-8 shows the maximum allowable EIRP levels for the PRFs of 1 MHz, 5 MHz, and 20 MHz, when the UWB signal permutations were classified as causing CW-like interference effects to the TSO-C129a compliant receiver. As shown in Figure 4-8, for those UWB signal permutations, the maximum allowable EIRP must be as much as 17 dB below the current Part 15 level to satisfy the measured performance threshold of the TSO-C129a compliant receiver in the applicable operational scenarios.

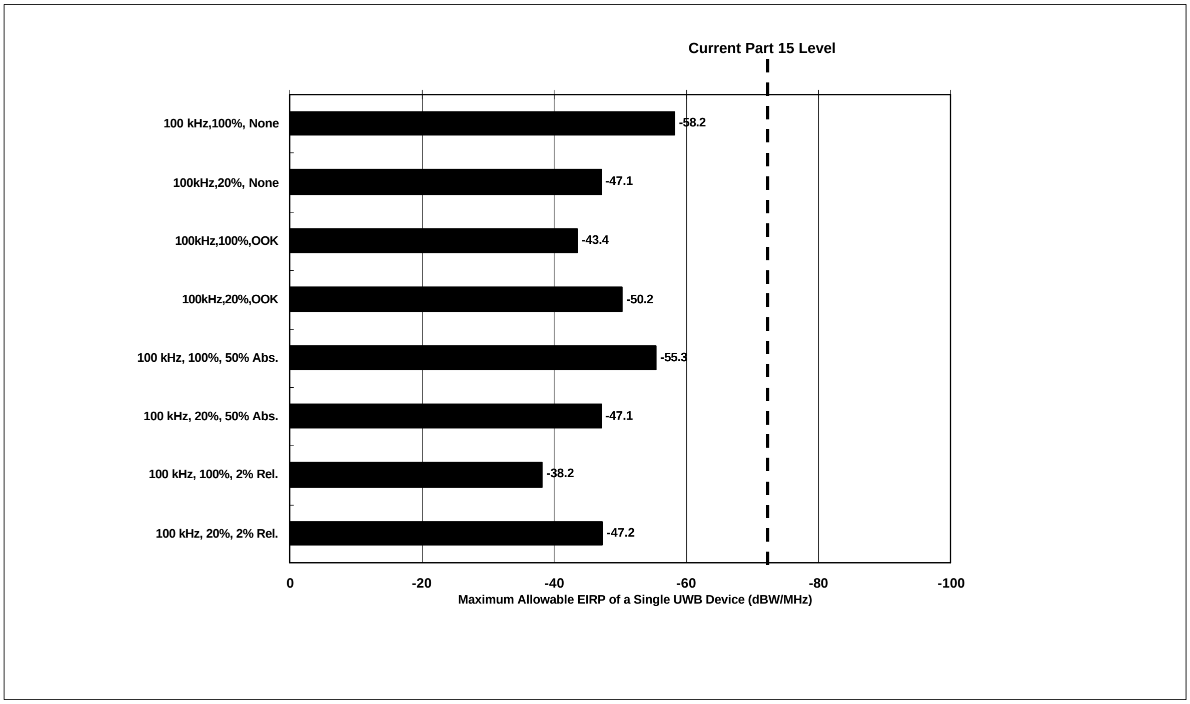


Figure 4-6. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (Pulse-Like UWB Signals)

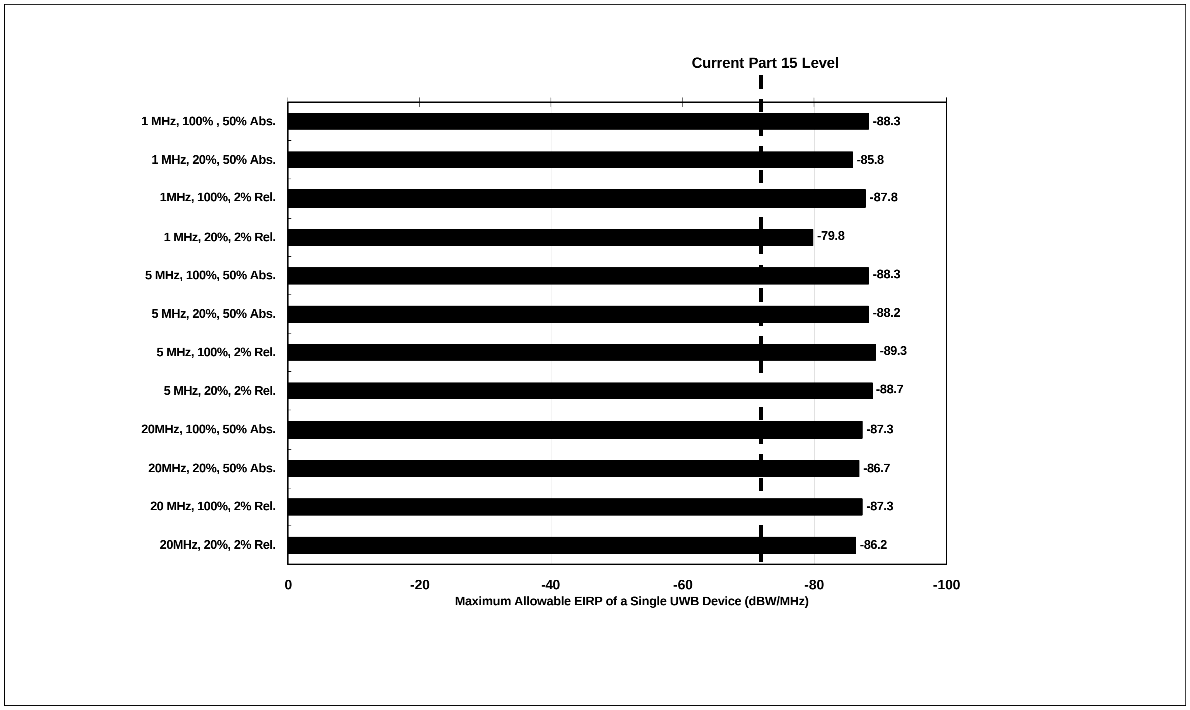


Figure 4-7. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (Noise-Like UWB Signals)

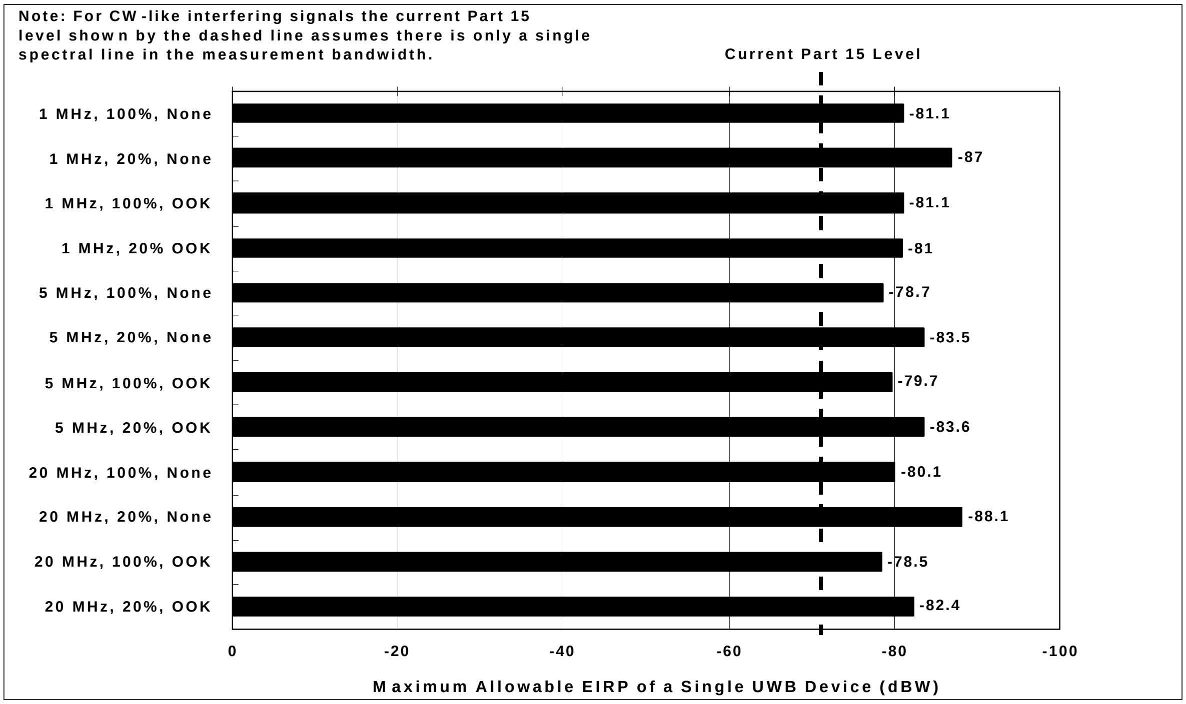


Figure 4-8. Maximum Allowable EIRP as a Function of UWB Signal Structure for the TSO-C129a Compliant C/A Code Receiver Architecture (CW-Like UWB Signals)

Table 4-9 provides a comparison of the range of computed EIRP levels for the C/A code receiver architecture considered in NTIA Report 01-45 and the narrowly-spaced correlator receiver architecture considered in this addendum. Table 4-10 provides a comparison of the computed EIRP levels for the C/A code receiver architecture considered in NTIA Report 01-45 and the TSO-C129a compliant C/A code receiver architecture considered in this addendum. An examination of the computed EIRP levels shown in Tables 4-9 and 4-10 indicates that the ranges of computed EIRP levels are consistent among the different GPS receivers under the conditions of the operational scenarios that were analyzed.

TABLE 4-9. Comparison of EIRP Levels for C/A Code and Narrowly-Spaced Correlator Receiver Architectures

Operational Scenario	Interference Effects	C/A Code	Narrowly-Spaced Correlator
		EIRP Range	EIRP Range
Terrestrial - Single	Pulse-Like	-95.6 to -49.6 dBW/MHz	-82.8 to -48.4 dBW/MHz
Terrestrial - Multiple (Outdoor)	Pulse-Like	-62.3 to -49.7 dBW/MHz	-59.9 to -49.8 dBW/MHz
Terrestrial - Multiple (Indoor)	Pulse-Like	-57.6 to -45 dBW/MHz	-55.2 to -45.1 dBW/MHz
Terrestrial - Single	Noise-Like	-98.6 to -96.6 dBW/MHz	-96.1 to -88.2 dBW/MHz
Terrestrial - Multiple (Outdoor)	Noise-Like	-93.7 to -90.2 dBW/MHz	-91.2 to -83.3 dBW/MHz
Terrestrial - Multiple (Indoor)	Noise-Like	-89 to -85.5 dBW/MHz	-86.5 to -78.6 dBW/MHz
Terrestrial - Single	CW-Like	-106.9 to -104.3 dBW	-107.5 to -100.5 dBW
Terrestrial -Multiple (Outdoor)	CW-Like	-96 to -93.4 dBW	-96.6 to -89.6 dBW
Terrestrial - Multiple (Indoor)	CW-Like	-91.3 to -88.7 dBW	-91.9 to -84.9 dBW
Maritime (Outdoor)	Pulse-Like	-48.1 to -34.8 dBW/MHz	-45.7 to -34.9 dBW/MHz
Maritime (Indoor)	Pulse-Like	-41.7 to -26.5 dBW/MHz	-39.3 to -26.6 dBW/MHz
Maritime (Outdoor)	Noise-Like	-79.5 to -75.3 dBW/MHz	-77 to -68.4 dBW/MHz
Maritime (Indoor)	Noise-Like	-73.1 to -67 dBW/MHz	-70.6 to -60.1 dBW/MHz
Maritime (Outdoor)	CW-Like	-81.8 to -78.5 dBW	-82.4 to -74.7 dBW
Maritime (Indoor)	CW-Like	-75.4 to -70.2 dBW	-76 to -66.4 dBW
Railway (Outdoor)	Pulse-Like	-57.8 to -45.2 dBW/MHz	-55.4 to -45.3 dBW/MHz
Railway (Indoor)	Pulse-Like	-56.3 to -43.7 dBW/MHz	-53.9 to -43.8 dBW/MHz
Railway (Outdoor)	Noise-Like	-88 to -84.5 dBW/MHz	-85.5 to -77.6 dBW/MHz
Railway (Indoor)	Noise-Like	-86.5 to -83 dBW/MHz	-84 to -76.1 dBW/MHz
Railway (Outdoor)	CW-Like	-91.5 to -88.9 dBW	-92.1 to -85.1 dBW
Railway (Indoor)	CW-Like	-90 to -87.4 dBW	-90.6 to -83.6 dBW

TABLE 4-10. Comparison of EIRP Levels for C/A Code and TSO-C129a Complaint C/A Code Receiver Architectures

Operational Scenario	Interference Effects	C/A Code EIRP Range	TSO-C129a Compliant EIRP Range
Aviation - Non-Precision Approach	Pulse-Like	-52.9 to -40.3 dBW/MHz	-58.2 to -38.2 dBW/MHz
Aviation - Non-Precision Approach	Noise-Like	-84.3 to -80.8 dBW/MHz	-89.3 to -79.8 dBW/MHz
Aviation - Non-Precision Approach	CW-Like	-86.6 to -84 dBW	-88.1 to -78.5 dBW
Aviation - En-route (Outdoor)	Noise-Like	-85.6 dBW/MHz	-84.9 dBW/MHz
Aviation - En-route (Indoor)	Noise-Like	-76.6 dBW/MHz	-75.9 dBW/MHz

An analysis was also performed to determine the distance separations that would preclude interference to the different GPS receiver architectures, if the UWB device is operating at the current Part 15 level of -71.3 dBW/MHz. The measured UWB interference thresholds for both single-entry and multiple-entry UWB device interactions were considered.

Table 4-11 presents an overview of the distance separation analysis results for the C/A code, semi-codeless, and narrowly-spaced correlator receiver architectures for single-entry UWB device interactions. Table 4-12 presents an overview of the analysis results for the TSO-C129a compliant receiver. Table 4-13 presents an overview of the distance separation analysis results for the C/A code receiver architecture for multiple-entry UWB device interactions.

TABLE 4-11. Overview of Single-Entry Analysis Results for the C/A Code, Semi-Codeless, and Narrowly-Space Correlator Receiver Architectures

UWB PRF (MHz)	Distance Separation (m)*								
	Gr = 3 dBi			Gr = 0 dBi			Gr = -4.5 dBi		
	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator	C/A Code	Semi-Codeless	Narrowly-Spaced Correlator
0.1	5	92	4	3.5	65	3	2	39	2
1	178	412	186	126	292	132	75	174	79
5	219	412	251	155	292	178	92	174	106
20	240	347	257	170	246	182	101	146	108

*Note: G_r is is the GPS antenna receive antenna gain

TABLE 4-12. Overview of Distance Separation Analysis Results for TSO-C129a Compliant GPS Receiver

UWB PRF (MHz)	Distance Separation (m)
0.1	9
1	251
5	170
20	285

TABLE 4-13. Calculated Distance Separations to Preclude Interference from Multiple-Entry UWB Device Interactions Based on the Current Part 15 Emission Limit (C/A Code Receiver Architecture)

UWB Parameters				Distance Separation (m)*		
PRF (MHz)	Gating Percent	Modulation	Number of UWB Signal Generators	Gr = 3 dBi	Gr = 0 dBi	Gr = -4.5 dBi
10	100	Dithering 2% Rel.	6	213	151	90
10	20	Dithering 2% Rel.	6	180	127	76
10 3 3	100 100 20	None None Dithering 2% Rel.	2 1 3	351	248	148
3 3	20 20	None Dithering 2% Rel.	4 2	174	123	73
1	100	Dithering 2% Rel.	1	41	29	17
1	100	Dithering 2% Rel.	2	104	73	44
1	100	Dithering 2% Rel.	3	127	90	54
1	100	Dithering 2% Rel.	4	147	104	62
1	100	Dithering 2% Rel.	5	184	130	78
1	100	Dithering 2% Rel.	6	180	127	76

*Note: G_r is is the GPS antenna receive antenna gain

4.4 CONCLUSIONS

This addendum was prepared to report on the results of the susceptibility measurements on the two GPS receivers that were not completed in time to be included in the initial NTIA report (NTIA Report 01-45). This addendum also provides the results of the analyses applying this measured data to determine maximum EIRP levels that would protect these GPS receivers within the applications represented by the operational scenarios examined. The measurements reported in this addendum are limited to single-entry interference cases. The aggregate and other ancillary measurements reported in NTIA Report 01-45 were not repeated as a part of this addendum. There were no noteworthy differences in either the receiver susceptibility measurements or the analysis results between the initial report and this addendum.

In addition to reporting the interference susceptibility data from the remaining two receivers tested in the overall NTIA measurement effort, this addendum report presents a comparison among the data sets collected within the NTIA measurement program as well as a comparison of the NTIA data with comparable data sets measured in the other UWB-to-GPS measurement efforts conducted by SU and ARL:UT. In performing this comparison, a definite consistency in the total data set that has been made a part of the public record has been noted. This consistency within the measured data has also been noted by other parties to this proceeding.

The data sets acquired from three of the receivers tested in the NTIA measurement program were compared to one another and found to be consistent with respect to the interference susceptibility levels measured and the interference effects that were observed. In addition, the NTIA measured data was compared to similar data sets collected for the GPS receivers examined in the measurement efforts performed by SU and ARL:UT. This comparison also indicates a significant consistency between the measured susceptibility data and the observed interference effects among the GPS receivers considered in the various test programs. Finally, an NTIA comparison between the measured GPS susceptibility data and the existing interference protection criteria developed within RTCA and the ITU-R also indicates a consistency between the measured interference thresholds and the existing GPS interference criteria

This strong consistency across the data sets, coupled with emergence of consistent trends in the interference effects observed by all of the measurement parties, suggests that a meaningful record of GPS receiver susceptibility data has been compiled in this proceeding.

The previous NTIA report noted a relationship between the interference susceptibility of a GPS receiver, particularly the C/A-code receiver, and the characteristics of the interfering UWB signal (e.g., PRF, dithering, gating, etc). This same relationship is also noted in the results of the additional measurements reported in this addendum; however, another parameter effecting the interference potential to a GPS receiver from UWB emissions was noted - the pre-correlator bandwidth of the GPS receiver. In the supplemental measurement effort, the susceptibility to UWB emissions was examined for two additional GPS receivers. Both of these receivers process the GPS C/A-code signal transmitted on L1 (the narrowly-spaced correlator receiver also has an L2 capability, but it was disabled for these tests). The narrowly-spaced correlator GPS receiver utilizes an architecture that makes use of multiple correlators, spaced less than one chip apart, to mitigate multipath effects at the receiver. This GPS receiver architecture uses a precorrelator bandwidth of approximately 16 MHz. The second GPS receiver measured in the supplemental effort is an existing aviation-grade (TSO-C129a-compliant) receiver. This receiver is unique in that it provides a Receiver Autonomous Integrity Monitoring (RAIM) capability. The precorrelator bandwidth of this receiver is approximately 2 MHz. The C/A-code receiver for which the measured interference susceptibility data was reported in NTIA Report 01-45, employed a precorrelator bandwidth of approximately 10 MHz. When comparing the susceptibility data collected for each of these receivers, a relationship between the interference effect and the receiver bandwidth was observed. For example, some of the UWB signal permutations (particularly among the 1 MHz PRF signals) that produced pulse-like interference effects in the wider band GPS receivers (the 10 MHz C/A-code receiver and the 16 MHz narrowly-spaced correlator receiver), excited a response characteristic of the more disruptive noise-like or CW-like interference effects in the narrower bandwidth receiver (i.e., the 2 MHz aviation receiver).

Appendix A
Results of Maximum Allowable EIRP Scenario Based Analysis

Operational Scenario: Terrestrial GPS Receiver and Single UWB Device

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-92.8	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-104.7	BL
5 MHz	100%	None	-145.7	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-106.3	BL
20 MHz	100%	None	-146.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-106.7	BL
5 MHz	20%	None	-146.6	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-107.2	BL
20 MHz	20%	None	-146.9	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-107.5	BL
1 MHz	100%	OOK	-139.9	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-100.5	BL
5 MHz	100%	OOK	-146.7	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-107.3	BL
20 MHz	100%	OOK	-146.5	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-107.1	BL
5 MHz	20%	OOK	-142.6	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-103.2	BL
20 MHz	20%	OOK	-145.4	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-106.0	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-60.8	DNBL
100 kHz	20%	None	-107.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-67.7	DNBL
1 MHz	20%	None	-94.8	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-55.4	DNBL
100 kHz	100%	OOK	-103.2	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-63.8	DNBL
100 kHz	20%	OOK	-110.2	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-70.8	DNBL
1 MHz	20%	OOK	-97.8	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-58.4	DNBL
100 kHz	100%	50% Abs.	-100.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-60.7	DNBL
1 MHz	100%	50% Abs.	-105.9	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-66.5	BL
5 MHz	100%	50% Abs.	-127.7	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-88.3	BL
20 MHz	100%	50% Abs.	-133.6	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-94.2	BL
100 kHz	100%	2% Rel.	-100.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-60.7	DNBL
1 MHz	100%	2% Rel.	-87.8	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-48.4	DNBL
5 MHz	100%	2% Rel.	-127.6	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-88.2	BL
20 MHz	100%	2% Rel.	-135.5	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-96.1	BL
100 kHz	20%	50% Abs.	-107.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-67.7	DNBL
1 MHz	20%	50% Abs.	-94.8	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-55.4	DNBL
5 MHz	20%	50% Abs.	-88.5	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-49.1	DNBL
20 MHz	20%	50% Abs.	-100.5	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-61.1	BL
100 kHz	20%	2% Rel.	-107.1	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-67.7	DNBL
1 MHz	20%	2% Rel.	-94.7	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-55.3	DNBL
5 MHz	20%	2% Rel.	-88.5	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-49.1	DNBL
20 MHz	20%	2% Rel.	-122.2	3	3	2	0	0	2	42.4	0	0	3	0	0	0	-82.8	BL

BL - Break Lock

DNBL - Did not break-lock at the maximum UWB generator signal power

Operational Scenario: Terrestrial GPS Receiver and Multiple UWB Device (Outdoor Operation)
GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-93.8	BL
5 MHz	100%	None	-145.7	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-95.4	BL
20 MHz	100%	None	-146.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-95.8	BL
5 MHz	20%	None	-146.6	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-96.3	BL
20 MHz	20%	None	-146.9	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-96.6	BL
1 MHz	100%	OOK	-139.9	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-89.6	BL
5 MHz	100%	OOK	-146.7	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-96.4	BL
20 MHz	100%	OOK	-146.5	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-96.2	BL
5 MHz	20%	OOK	-142.6	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-92.3	BL
20 MHz	20%	OOK	-145.4	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-95.1	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-49.9	DNBL
100 kHz	20%	None	-107.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-56.8	DNBL
1 MHz	20%	None	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
100 kHz	100%	OOK	-103.2	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-52.9	DNBL
100 kHz	20%	OOK	-110.2	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-59.9	DNBL
1 MHz	20%	OOK	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
100 kHz	100%	50% Abs.	-100.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-49.8	DNBL
1 MHz	100%	50% Abs.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
5 MHz	100%	50% Abs.	-127.7	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-83.4	BL
20 MHz	100%	50% Abs.	-133.6	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-89.3	BL
100 kHz	100%	2% Rel.	-100.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-49.8	DNBL
1 MHz	100%	2% Rel.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
5 MHz	100%	2% Rel.	-127.6	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-83.3	BL
20 MHz	100%	2% Rel.	-135.5	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-91.2	BL
100 kHz	20%	50% Abs.	-107.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-56.8	DNBL
1 MHz	20%	50% Abs.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
5 MHz	20%	50% Abs.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
20 MHz	20%	50% Abs.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
100 kHz	20%	2% Rel.	-107.1	3	3	10	0	0	10	56.4	0	3	3	0	0	0	-56.8	DNBL
1 MHz	20%	2% Rel.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
5 MHz	20%	2% Rel.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL
20 MHz	20%	2% Rel.	-132.2	3	3	10	0	0	10	56.4	6	3	3	0	0	0	-87.9	NBL

BL - Break Lock

DNBL Did not break lock at the maximum UWB signal generator power level
NBL - Broadband Noise Break Lock

Operational Scenario: Terrestrial GPS Receiver and Multiple UWB Device (Indoor Operation)
GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-89.1	BL
5 MHz	100%	None	-145.7	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-90.7	BL
20 MHz	100%	None	-146.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-91.1	BL
5 MHz	20%	None	-146.6	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-91.6	BL
20 MHz	20%	None	-146.9	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-91.9	BL
1 MHz	100%	OOK	-139.9	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-84.9	BL
5 MHz	100%	OOK	-146.7	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-91.7	BL
20 MHz	100%	OOK	-146.5	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-91.5	BL
5 MHz	20%	OOK	-142.6	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-87.6	BL
20 MHz	20%	OOK	-145.4	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-90.4	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-45.2	DNBL
100 kHz	20%	None	-107.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-52.1	DNBL
1 MHz	20%	None	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
100 kHz	100%	OOK	-103.2	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-48.2	DNBL
100 kHz	20%	OOK	-110.2	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-55.2	DNBL
1 MHz	20%	OOK	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
100 kHz	100%	50% Abs.	-100.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-45.1	DNBL
1 MHz	100%	50% Abs.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
5 MHz	100%	50% Abs.	-127.7	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-78.7	BL
20 MHz	100%	50% Abs.	-133.6	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-84.6	BL
100 kHz	100%	2% Rel.	-100.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-45.1	DNBL
1 MHz	100%	2% Rel.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
5 MHz	100%	2% Rel.	-127.6	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-78.6	BL
20 MHz	100%	2% Rel.	-135.5	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-86.5	BL
100 kHz	20%	50% Abs.	-107.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-52.1	DNBL
1 MHz	20%	50% Abs.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
5 MHz	20%	50% Abs.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
20 MHz	20%	50% Abs.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
100 kHz	20%	2% Rel.	-107.1	3	10	5	54.5	3	8.6	55.0	0	3	3	0	9	0	-52.1	DNBL
1 MHz	20%	2% Rel.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL
5 MHz	20%	2% Rel.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL

20 MHz	20%	2% Rel.	-132.2	3	10	5	54.5	3	8.6	55.0	6	3	3	0	9	0	-83.2	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Navigation in Constricted Waterways GPS Receiver and Multiple UWB Device (Indoor Operation) (I)

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
Broadband Noise			-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-73.2	BL
5 MHz	100%	None	-145.7	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-74.8	BL
20 MHz	100%	None	-146.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-75.2	BL
5 MHz	20%	None	-146.6	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-75.7	BL
20 MHz	20%	None	-146.9	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-76.0	BL
1 MHz	100%	OOK	-139.9	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-69.0	BL
5 MHz	100%	OOK	-146.7	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-75.8	BL
20 MHz	100%	OOK	-146.5	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-75.6	BL
5 MHz	20%	OOK	-142.6	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-71.7	BL
20 MHz	20%	OOK	-145.4	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-74.5	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-29.3	DNBL
100 kHz	20%	None	-107.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-36.2	DNBL
1 MHz	20%	None	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
100 kHz	100%	OOK	-103.2	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-32.3	DNBL
100 kHz	20%	OOK	-110.2	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-39.3	DNBL
1 MHz	20%	OOK	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
100 kHz	100%	50% Abs.	-100.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-29.2	DNBL
1 MHz	100%	50% Abs.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
5 MHz	100%	50% Abs.	-127.7	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-62.8	BL
20 MHz	100%	50% Abs.	-133.6	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-68.7	BL
100 kHz	100%	2% Rel.	-100.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-29.2	DNBL
1 MHz	100%	2% Rel.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
5 MHz	100%	2% Rel.	-127.6	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-62.7	BL
20 MHz	100%	2% Rel.	-135.5	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-70.6	BL
100 kHz	20%	50% Abs.	-107.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-36.2	DNBL
1 MHz	20%	50% Abs.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
5 MHz	20%	50% Abs.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
20 MHz	20%	50% Abs.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
100 kHz	20%	2% Rel.	-107.1	13.5	10	37.5	-5.3	0	37.7	67.9	0	3	3	0	9	0	-36.2	DNBL

1 MHz	20%	2% Rel.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
5 MHz	20%	2% Rel.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL
20 MHz	20%	2% Rel.	-132.2	13.5	10	37.5	-5.3	0	37.7	67.9	6	3	3	0	9	0	-67.3	NBL

BL -Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break-Lock

Operational Scenario: Navigation in Constricted Waterways GPS Receiver and Multiple UWB Device (Outdoor Operation) (I)

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-78.9	BL
5 MHz	100%	None	-145.7	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-80.5	BL
20 MHz	100%	None	-146.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-80.9	BL
5 MHz	20%	None	-146.6	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-81.4	BL
20 MHz	20%	None	-146.9	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-81.7	BL
1 MHz	100%	OOK	-139.9	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-74.7	BL
5 MHz	100%	OOK	-146.7	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-81.5	BL
20 MHz	100%	OOK	-146.5	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-81.3	BL
5 MHz	20%	OOK	-142.6	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-77.4	BL
20 MHz	20%	OOK	-145.4	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-80.2	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-35.0	DNBL
100 kHz	20%	None	-107.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-41.9	DNBL
1 MHz	20%	None	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
100 kHz	100%	OOK	-103.2	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-38.0	DNBL
100 kHz	20%	OOK	-110.2	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-45.0	DNBL
1 MHz	20%	OOK	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
100 kHz	100%	50% Abs.	-100.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-34.9	DNBL
1 MHz	100%	50% Abs.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
5 MHz	100%	50% Abs.	-127.7	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-68.5	BL
20 MHz	100%	50% Abs.	-133.6	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-74.4	BL
100 kHz	100%	2% Rel.	-100.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-34.9	DNBL
1 MHz	100%	2% Rel.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
5 MHz	100%	2% Rel.	-127.6	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-68.4	BL
20 MHz	100%	2% Rel.	-135.5	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-76.3	BL
100 kHz	20%	50% Abs.	-107.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-41.9	DNBL
1 MHz	20%	50% Abs.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
5 MHz	20%	50% Abs.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
20 MHz	20%	50% Abs.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
100 kHz	20%	2% Rel.	-107.1	13.5	3	37.5	-15.6	-3	38.9	68.2	0	3	3	0	0	0	-41.9	DNBL
1 MHz	20%	2% Rel.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL

5 MHz	20%	2% Rel.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL
20 MHz	20%	2% Rel.	-132.2	13.5	3	37.5	-15.6	-3	38.9	68.2	6	3	3	0	0	0	-73.0	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Navigation in Constricted Waterways GPS Receiver and Multiple UWB Device (Indoor Operation) (II)
GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-70.6	BL
5 MHz	100%	None	-145.7	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-72.2	BL
20 MHz	100%	None	-146.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-72.6	BL
5 MHz	20%	None	-146.6	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-73.1	BL
20 MHz	20%	None	-146.9	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-73.4	BL
1 MHz	100%	OOK	-139.9	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-66.4	BL
5 MHz	100%	OOK	-146.7	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-73.2	BL
20 MHz	100%	OOK	-146.5	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-73.0	BL
5 MHz	20%	OOK	-142.6	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-69.1	BL
20 MHz	20%	OOK	-145.4	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-71.9	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-26.7	DNBL
100 kHz	20%	None	-107.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-33.6	DNBL
1 MHz	20%	None	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
100 kHz	100%	OOK	-103.2	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-29.7	DNBL
100 kHz	20%	OOK	-110.2	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-36.7	DNBL
1 MHz	20%	OOK	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
100 kHz	100%	50% Abs.	-100.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-26.6	DNBL
1 MHz	100%	50% Abs.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
5 MHz	100%	50% Abs.	-127.7	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-60.2	BL
20 MHz	100%	50% Abs.	-133.6	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-66.1	BL
100 kHz	100%	2% Rel.	-100.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-26.6	DNBL
1 MHz	100%	2% Rel.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
5 MHz	100%	2% Rel.	-127.6	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-60.1	BL
20 MHz	100%	2% Rel.	-135.5	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-68.0	BL
100 kHz	20%	50% Abs.	-107.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-33.6	DNBL
1 MHz	20%	50% Abs.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
5 MHz	20%	50% Abs.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL

20 MHz	20%	50% Abs.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
100 kHz	20%	2% Rel.	-107.1	7.5	10	51	2.8	0	51.1	70.5	0	3	3	0	9	0	-33.6	DNBL
1 MHz	20%	2% Rel.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
5 MHz	20%	2% Rel.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL
20 MHz	20%	2% Rel.	-132.2	7.5	10	51	2.8	0	51.1	70.5	6	3	3	0	9	0	-64.7	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Navigation in Constricted Waterways GPS Receiver and Multiple UWB Device (Outdoor Operation) (II)

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-79.6	BL
5 MHz	100%	None	-145.7	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-81.2	BL
20 MHz	100%	None	-146.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-81.6	BL
5 MHz	20%	None	-146.6	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-82.1	BL
20 MHz	20%	None	-146.9	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-82.4	BL
1 MHz	100%	OOK	-139.9	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-75.4	BL
5 MHz	100%	OOK	-146.7	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-82.2	BL
20 MHz	100%	OOK	-146.5	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-82.0	BL
5 MHz	20%	OOK	-142.6	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-78.1	BL
20 MHz	20%	OOK	-145.4	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-80.9	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-35.7	DNBL
100 kHz	20%	None	-107.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-42.6	DNBL
1 MHz	20%	None	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
100 kHz	100%	OOK	-103.2	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-38.7	DNBL
100 kHz	20%	OOK	-110.2	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-45.7	DNBL
1 MHz	20%	OOK	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
100 kHz	100%	50% Abs.	-100.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-35.6	DNBL
1 MHz	100%	50% Abs.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
5 MHz	100%	50% Abs.	-127.7	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-69.2	BL
20 MHz	100%	50% Abs.	-133.6	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-75.1	BL
100 kHz	100%	2% Rel.	-100.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-35.6	DNBL
1 MHz	100%	2% Rel.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
5 MHz	100%	2% Rel.	-127.6	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-69.1	BL
20 MHz	100%	2% Rel.	-135.5	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-77.0	BL
100 kHz	20%	50% Abs.	-107.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-42.6	DNBL

1 MHz	20%	50% Abs.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
5 MHz	20%	50% Abs.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
20 MHz	20%	50% Abs.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
100 kHz	20%	2% Rel.	-107.1	7.5	3	51	-5.0	0	51.2	70.5	0	3	3	0	0	0	-42.6	DNBL
1 MHz	20%	2% Rel.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
5 MHz	20%	2% Rel.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL
20 MHz	20%	2% Rel.	-132.2	7.5	3	51	-5.0	0	51.2	70.5	6	3	3	0	0	0	-73.7	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL- Broadband Noise Break Lock

Operational Scenario: Railway GPS Receiver and Multiple UWB Device (Outdoor Operation)
GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-89.3	BL
5 MHz	100%	None	-145.7	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-90.9	BL
20 MHz	100%	None	-146.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-91.3	BL
5 MHz	20%	None	-146.6	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-91.8	BL
20 MHz	20%	None	-146.9	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-92.1	BL
1 MHz	100%	OOK	-139.9	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-85.1	**BL**
5 MHz	100%	OOK	-146.7	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-91.9	BL
20 MHz	100%	OOK	-146.5	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-91.7	BL
5 MHz	20%	OOK	-142.6	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-87.8	BL
20 MHz	20%	OOK	-145.4	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-90.6	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-45.4	DNBL
100 kHz	20%	None	-107.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-52.3	DNBL
1 MHz	20%	None	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
100 kHz	100%	OOK	-103.2	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-48.4	DNBL
100 kHz	20%	OOK	-110.2	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-55.4	DNBL
1 MHz	20%	OOK	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
100 kHz	100%	50% Abs.	-100.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-45.3	DNBL
1 MHz	100%	50% Abs.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
5 MHz	100%	50% Abs.	-127.7	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-77.7	BL
20 MHz	100%	50% Abs.	-133.6	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-83.6	BL
100 kHz	100%	2% Rel.	-100.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-45.3	DNBL
1 MHz	100%	2% Rel.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
5 MHz	100%	2% Rel.	-127.6	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-77.6	BL
20 MHz	100%	2% Rel.	-135.5	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-85.5	BL
100 kHz	20%	50% Abs.	-107.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-52.3	DNBL

1 MHz	20%	50% Abs.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
5 MHz	20%	50% Abs.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
20 MHz	20%	50% Abs.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
100 kHz	20%	2% Rel.	-107.1	10	3	7	-45	-4.5	9.9	56.3	0	3	3	0	0	0	-52.3	DNBL
1 MHz	20%	2% Rel.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
5 MHz	20%	2% Rel.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL
20 MHz	20%	2% Rel.	-132.2	10	3	7	-45	-4.5	9.9	56.3	4.8	3	3	0	0	0	-82.2	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Railway GPS Receiver and Multiple UWB Device (Indoor Operation)

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-87.8	BL
5 MHz	100%	None	-145.7	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-89.4	BL
20 MHz	100%	None	-146.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-89.8	BL
5 MHz	20%	None	-146.6	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-90.3	BL
20 MHz	20%	None	-146.9	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-90.6	BL
1 MHz	100%	OOK	-139.9	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-83.6	BL
5 MHz	100%	OOK	-146.7	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-90.4	BL
20 MHz	100%	OOK	-146.5	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-90.2	BL
5 MHz	20%	OOK	-142.6	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-86.3	BL
20 MHz	20%	OOK	-145.4	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-89.1	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-43.9	DNBL
100 kHz	20%	None	-107.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-50.8	DNBL
1 MHz	20%	None	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
100 kHz	100%	OOK	-103.2	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-46.9	DNBL
100 kHz	20%	OOK	-110.2	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-53.9	DNBL
1 MHz	20%	OOK	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
100 kHz	100%	50% Abs.	-100.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-43.8	DNBL
1 MHz	100%	50% Abs.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
5 MHz	100%	50% Abs.	-127.7	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-76.2	BL
20 MHz	100%	50% Abs.	-133.6	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-82.1	BL
100 kHz	100%	2% Rel.	-100.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-43.8	DNBL
1 MHz	100%	2% Rel.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
5 MHz	100%	2% Rel.	-127.6	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-76.1	BL
20 MHz	100%	2% Rel.	-135.5	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-84.0	BL

100 kHz	20%	50% Abs.	-107.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-50.8	DNBL
1 MHz	20%	50% Abs.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
5 MHz	20%	50% Abs.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
20 MHz	20%	50% Abs.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
100 kHz	20%	2% Rel.	-107.1	10	10	7	0.0	0	7.0	53.3	0	3	3	0	9	0	-50.8	DNBL
1 MHz	20%	2% Rel.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
5 MHz	20%	2% Rel.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL
20 MHz	20%	2% Rel.	-132.2	10	10	7	0.0	0	7.0	53.3	4.8	3	3	0	9	0	-80.7	NBL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Surveying GPS Receiver and Single UWB Device

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep (m)	Theta (deg)	Gr (dBic)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-132.2	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-75.3	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-144.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-87.2	BL
5 MHz	100%	None	-145.7	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-88.8	BL
20 MHz	100%	None	-146.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-89.2	BL
5 MHz	20%	None	-146.6	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-89.7	BL
20 MHz	20%	None	-146.9	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-90.0	BL
1 MHz	100%	OOK	-139.9	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-83.0	BL
5 MHz	100%	OOK	-146.7	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-89.8	BL
20 MHz	100%	OOK	-146.5	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-89.6	BL
5 MHz	20%	OOK	-142.6	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-85.7	BL
20 MHz	20%	OOK	-145.4	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-88.5	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Hsep (m)**	**Theta (deg)**	**Gr (dBic)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-100.2	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-43.3	DNBL
100 kHz	20%	None	-107.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-50.2	DNBL
1 MHz	20%	None	-94.8	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-37.9	DNBL
100 kHz	100%	OOK	-103.2	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-46.3	DNBL
100 kHz	20%	OOK	-110.2	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-53.3	DNBL
1 MHz	20%	OOK	-97.8	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-40.9	DNBL
100 kHz	100%	50% Abs.	-100.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-43.2	DNBL
1 MHz	100%	50% Abs.	-105.9	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-49.0	BL
5 MHz	100%	50% Abs.	-127.7	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-70.8	BL
20 MHz	100%	50% Abs.	-133.6	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-76.7	BL
100 kHz	100%	2% Rel.	-100.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-43.2	DNBL
1 MHz	100%	2% Rel.	-87.8	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-30.9	DNBL
5 MHz	100%	2% Rel.	-127.6	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-70.7	BL

20 MHz	100%	2% Rel.	-135.5	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-78.6	BL
100 kHz	20%	50% Abs.	-107.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-50.2	DNBL
1 MHz	20%	50% Abs.	-94.8	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-37.9	DNBL
5 MHz	20%	50% Abs.	-88.5	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-31.6	DNBL
20 MHz	20%	50% Abs.	-100.5	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-43.6	BL
100 kHz	20%	2% Rel.	-107.1	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-50.2	DNBL
1 MHz	20%	2% Rel.	-94.7	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-37.8	DNBL
5 MHz	20%	2% Rel.	-88.5	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-31.6	DNBL
20 MHz	20%	2% Rel.	-122.2	3	10	30	13.1	3	30.0	65.9	0	3	3	0	0	0	-65.3	BL

BL - Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Surveying GPS Receiver and Multiple UWB Devices

GPS Receiver Architecture: Narrowly Spaced Correlator

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Hsep #1 (m)	Theta #1 (deg)	Gr #1 (dBic)	Dmin #1 (m)	Lp #1 (dB)	Hsep #2 (m)	Theta #2 (deg)	Gr #2 (dBic)	Dmin #2 (m)	Lp #2 (dB)	Hsep #3 (m)	Theta #3 (deg)	Gr #3 (dBic)	Dmin #3 (m)	Lp #3 (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP	GPS Receiver Criteria (dBW/MHz)
Broadband Noise			-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Vsep #1 (m)**	**Theta #1 (deg)**	**Gr #1 (dBic)**	**Dmin #1 (m)**	**Lp #1 (dB)**	**Vsep #2 (m)**	**Theta #2 (deg)**	**Gr #2 (dBic)**	**Dmin #2 (m)**	**Lp #2 (dB)**	**Vsep #3 (m)**	**Theta #3 (deg)**	**Gr #3 (dBic)**	**Dmin #3 (m)**	**Lp #3 (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**		**UWB EIRP (dBW/MHz)**
1 MHz	100%	None	-144.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-87.3	BL
5 MHz	100%	None	-145.7	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-88.9	BL
20 MHz	100%	None	-146.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-89.3	BL
5 MHz	20%	None	-146.6	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-89.8	BL
20 MHz	20%	None	-146.9	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-90.1	BL
1 MHz	100%	OOK	-139.9	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-83.1	BL
5 MHz	100%	OOK	-146.7	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-89.9	BL
20 MHz	100%	OOK	-146.5	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-89.7	BL
5 MHz	20%	OOK	-142.6	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-85.8	BL
20 MHz	20%	OOK	-145.4	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-88.6	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Vsep #1 (m)**	**Theta #1 (deg)**	**Gr #1 (dBic)**	**Dmin #1 (m)**	**Lp #1 (dB)**	**Vsep #2 (m)**	**Theta #2 (deg)**	**Gr #2 (dBic)**	**Dmin #2 (m)**	**Lp #2 (dB)**	**Vsep #3 (m)**	**Theta #3 (deg)**	**Gr #3 (dBic)**	**Dmin #3 (m)**	**Lp #3 (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP**	**GPS Receiver Criteria (dBW/MHz)**
100 kHz	100%	None	-100.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-43.4	DNBL
100 kHz	20%	None	-107.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-50.3	DNBL
1 MHz	20%	None	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
100 kHz	100%	OOK	-103.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-46.4	DNBL
100 kHz	20%	OOK	-110.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-53.4	DNBL
1 MHz	20%	OOK	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
100 kHz	100%	50% Abs.	-100.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-43.3	DNBL
1 MHz	100%	50% Abs.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
5 MHz	100%	50% Abs.	-127.7	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-70.9	BL
20 MHz	100%	50% Abs.	-133.6	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-76.8	BL
100 kHz	100%	2% Rel.	-100.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-43.3	DNBL

1 MHz	100%	2% Rel.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
5 MHz	100%	2% Rel.	-127.6	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-70.8	BL
20 MHz	100%	2% Rel.	-135.5	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-78.7	BL
100 kHz	20%	50% Abs.	-107.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-50.3	DNBL
1 MHz	20%	50% Abs.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
5 MHz	20%	50% Abs.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
20 MHz	20%	50% Abs.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
100 kHz	20%	2% Rel.	-107.1	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-50.3	DNBL
1 MHz	20%	2% Rel.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
5 MHz	20%	2% Rel.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL
20 MHz	20%	2% Rel.	-132.2	3	10	30	13.1	3	30.0	65.9	300.0	1.3	0	300.0	85.9	750	0.5	0	750	93.8	3.00	3	0	0	0	-75.4	NBL

BL Break Lock

DNBL - Did not break lock at the maximum UWB generator signal power

NBL - Broadband Noise Break Lock

Operational Scenario: Aviation GPS Receiver Non-Precision Approach and Multiple UWB Devices

GPS Receiver Architecture: C/A Code (TSO-C129a Compliant)

			Imax (dBW/MHz)	Hgps (m)	Huwb (m)	Gr (dBi)	Dmin (m)	Lp (dB)	Lmult (dB)	Lallot (dB)	Lman (dB)	Laf (dB)	Lba (dB)	Lsm (dB)	UWB EIRP (dBW/MHz)	GPS Receiver Criteria
Broadband Noise			-136	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-82.3	RQT
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW)**	**Hgps (m)**	**Huwb (m)**	**Gr (dBi)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW)**	
1 MHz	100%	None	-140.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-81.1	BL
5 MHz	100%	None	-138.4	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-78.7	BL
20 MHz	100%	None	-139.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-80.1	BL
1 MHz	20%	None	-146.7	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-87.0	BL
5 MHz	20%	None	-143.2	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-83.5	BL
20 MHz	20%	None	-147.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-88.1	BL
1 MHz	100%	OOK	-140.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-81.1	BL
5 MHz	100%	OOK	-139.4	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-79.7	BL
20 MHz	100%	OOK	-138.2	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-78.5	BL
1 MHz	20%	OOK	-140.7	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-81.0	BL
5 MHz	20%	OOK	-143.3	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-83.6	BL
20 MHz	20%	OOK	-142.1	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-82.4	BL
UWB PRF	**UWB Gating**	**UWB Modulation**	**Imax (dBW/MHz)**	**Hgps (m)**	**Huwb (m)**	**Gr (dBi)**	**Dmin (m)**	**Lp (dB)**	**Lmult (dB)**	**Lallot (dB)**	**Lman (dB)**	**Laf (dB)**	**Lba (dB)**	**Lsm (dB)**	**UWB EIRP (dBW/MHz)**	**GPS Receiver Criteria**
100 kHz	100%	None	-117.9	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-58.2	BL
100 kHz	20%	None	-106.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-47.1	DNBL
100 kHz	100%	OOK	-103.1	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-43.4	DNBL
100 kHz	20%	OOK	-109.9	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-50.2	DNBL
100 kHz	100%	50% Abs.	-115	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-55.3	DNBL
1 MHz	100%	50% Abs.	-142	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-88.3	RQT
5 MHz	100%	50% Abs.	-142	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-88.3	RQT
20 MHz	100%	50% Abs.	-141	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-87.3	RQT

100 kHz	100%	2% Rel.	-97.9	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-38.2	BL
1 MHz	100%	2% Rel.	-141.5	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-87.8	RQT
5 MHz	100%	2% Rel.	-143	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-89.3	RQT
20 MHz	100%	2% Rel.	-141	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-87.3	RQT
100 kHz	20%	50% Abs.	-106.8	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-47.1	DNBL
1 MHz	20%	50% Abs.	-139.5	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-85.8	RQT
5 MHz	20%	50% Abs.	-141.9	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-88.2	RQT
20 MHz	20%	50% Abs.	-140.4	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-86.7	RQT
100 kHz	20%	2% Abs.	-106.9	41.4	3	-10	41.4	68.7	0	10	3	0	0	6	-47.2	DNBL
1 MHz	20%	2% Rel.	-133.5	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-79.8	BL
5 MHz	20%	2% Rel.	-142.4	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-88.7	RQT
20 MHz	20%	2% Rel.	-139.9	41.4	3	-10	41.4	68.7	6	10	3	0	0	6	-86.2	RQT

BL - Break Lock

RQT - Reacquisition Time

DNBL - Did not break lock at the maximum UWB generator signal power

Transmitter

uV/m/MHz @ R(m)

500 | 3 | (•) field st

-41.278 | | ( ) EIRP

FREQ 1575.42

RIN 0 | (•) maxvis

ROUT 20 | ( ) ROUT

Path Loss: Free Space | Continental Tempera | Okumura

Tirem & ITM: Flat

Average Groun | 10%,50%,5

Receive Antenna: bw(deg) 515.74, Gain(dBi) -10 (•); bw(deg) 180, Gain(dBi) -0.8569 ( )

Const | OMNI | (•) V ( ) H

Beamwidth horizontal(deg | vertical(deg | backlobe | elev(deg) | [ ] backlobe

General: Calculate | [x] Iagg+Isingle

Mode: EIRP[I/N] | Parameterize: Altitude

Criteria(dB) -2.0228 | MxSnglEirp -68.952 | @R(km) 0

h(km) | tranht(m) 3

NF(dB) 10 | N(dBm/MHz) -103.98

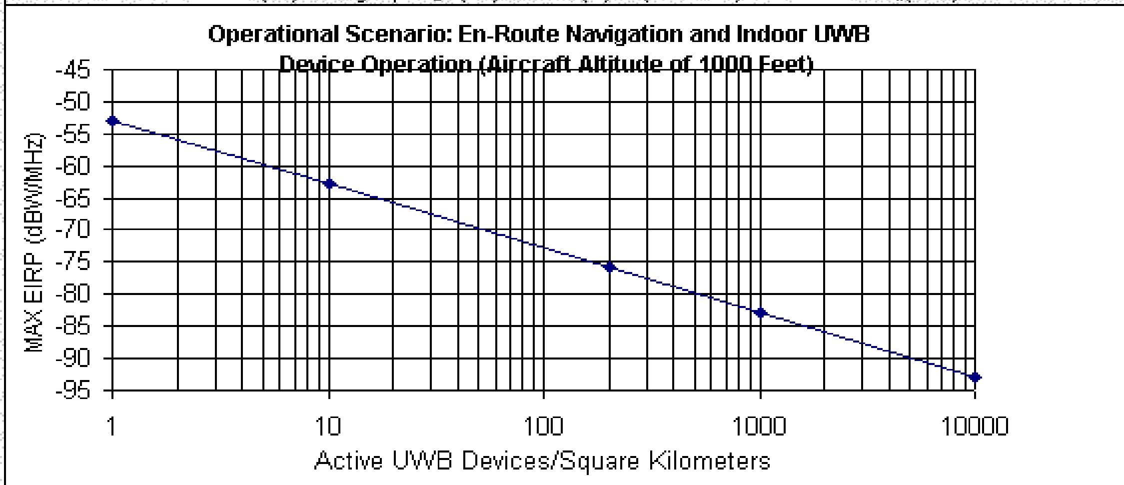
System Losses -8 dB

Smin(dBm) | B_{if}(MHz) 0.15

Iother(dBm/MHz) | [ ] I other

Ring Spacing: 10 meter | [ ] Make trace file?

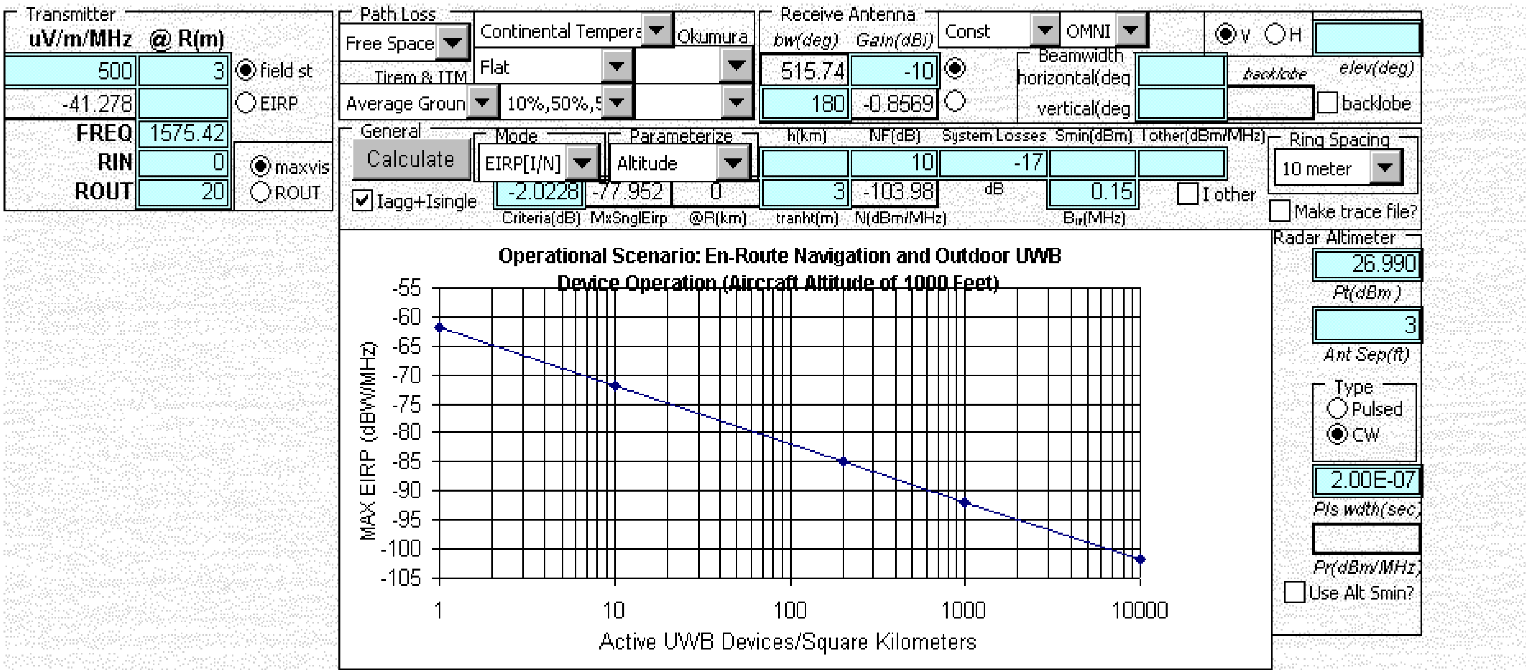
Radar Altimeter: Pt(dBm) 26.990 | Ant Sep(ft) 3 | Type: ( ) Pulsed (•) CW | Pls wdth(sec) 2.00E-07 | Pr(dBm/MHz) | [ ] Use Alt Smin?



		0.03	0.1	0.1	0.3048
( )	1	-69.082	-59.162	-59.162	-52.851
( )	10	-70.1	-63.296	-63.296	-62.851
( )	200	-76.769	-76.307	-76.307	-75.861
( )	1000	-83.758	-83.296	-83.296	-82.851
(•)	10000	-93.758	-93.296	-93.296	-92.851
		(•)	( )	( )	( )

-106 Imax(dBm)

-2.0228



	0.03	0.1	0.1	0.3048
1	-78.082	-68.162	-68.162	-61.851
10	-79.1	-72.296	-72.296	-71.851
200	-85.769	-85.307	-85.307	-84.861
1000	-92.758	-92.296	-92.296	-91.851
10000	-102.76	-102.3	-102.3	-101.85

-106 Imax(dBm)

-2.0228

Appendix B
Results of Distance Separation Analysis

C/A Code Receiver Architecture (3 dBi Antenna gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Category of Interfering Signal	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP (Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-112.6	-71.3	3	63.95	27.55	3	3	4.96
100 kHz	None	20%	Pulse-Like	-106.5	-71.3	3	63.95	27.55	3	3	2.46
100 kHz	OOK	100%	Pulse-Like	-102.6	-71.3	3	63.95	27.55	3	3	1.57
100 kHz	OOK	20%	Pulse-Like	-109.4	-71.3	3	63.95	27.55	3	3	3.43
100 kHz	50% Abs.	100%	Pulse-Like	-100	-71.3	3	63.95	27.55	3	3	1.16
100 kHz	50% Abs.	20%	Pulse-Like	-107	-71.3	3	63.95	27.55	3	3	2.60
100 kHz	2% Rel.	100%	Pulse-Like	-100	-71.3	3	63.95	27.55	3	3	1.16
100 kHz	2% Rel.	20%	Pulse-Like	-107	-71.3	3	63.95	27.55	3	3	2.60
1 MHz	None	100%	CW-Like	-143.7	-71.3	3	63.95	27.55	3	3	177.87
1 MHz	None	20%	Pulse-Like	-97.6	-71.3	3	63.95	27.55	3	3	0.88
1 MHz	OOK	100%	Pulse-Like	-121.2	-71.3	3	63.95	27.55	3	3	13.34
1 MHz	OOK	20%	Pulse-Like	-101.1	-71.3	3	63.95	27.55	3	3	1.32
1 MHz	50% Abs.	100%	Pulse-Like	-113	-71.3	3	63.95	27.55	3	3	5.19
1 MHz	50% Abs.	20%	Pulse-Like	-97.5	-71.3	3	63.95	27.55	3	3	0.87
1 MHz	2% Rel.	100%	Pulse-Like	-131	-71.3	3	63.95	27.55	3	3	41.22
1 MHz	2% Rel.	20%	Pulse-Like	-97	-71.3	3	63.95	27.55	3	3	0.82
5 MHz	None	100%	CW-Like	-145.5	-71.3	3	63.95	27.55	3	3	218.83
5 MHz	None	20%	CW-Like	-145.2	-71.3	3	63.95	27.55	3	3	211.40
5 MHz	OOK	100%	CW-Like	-144.5	-71.3	3	63.95	27.55	3	3	195.03
5 MHz	OOK	20%	CW-Like	-144.2	-71.3	3	63.95	27.55	3	3	188.41
5 MHz	50% Abs.	100%	Noise-Like	-137	-71.3	3	63.95	27.55	3	3	82.24
5 MHz	50% Abs.	20%	Pulse-Like	-105	-71.3	3	63.95	27.55	3	3	2.07
5 MHz	2% Rel.	100%	Noise-Like	-136.5	-71.3	3	63.95	27.55	3	3	77.64
5 MHz	2% Rel.	20%	Pulse-Like	-89	-71.3	3	63.95	27.55	3	3	0.33
20 MHz	None	100%	CW-Like	-145	-71.3	3	63.95	27.55	3	3	206.59
20 MHz	None	20%	CW-Like	-145.8	-71.3	3	63.95	27.55	3	3	226.52
20 MHz	OOK	100%	CW-Like	-144.5	-71.3	3	63.95	27.55	3	3	195.03
20 MHz	OOK	20%	CW-Like	-146.3	-71.3	3	63.95	27.55	3	3	239.94
20 MHz	50% Abs.	100%	Noise-Like	-138	-71.3	3	63.95	27.55	3	3	92.28
20 MHz	50% Abs.	20%	Pulse-Like	-135	-71.3	3	63.95	27.55	3	3	65.33
20 MHz	2% Rel.	100%	Noise-Like	-136	-71.3	3	63.95	27.55	3	3	73.30
20 MHz	2% Rel.	20%	Pulse-Like	-133	-71.3	3	63.95	27.55	3	3	51.89

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

C/A Code Receiver Architecture (0 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP (Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-112.6	-71.3	0	63.95	27.55	3	3	3.51
100 kHz	None	20%	Pulse-Like	-106.5	-71.3	0	63.95	27.55	3	3	1.74
100 kHz	OOK	100%	Pulse-Like	-102.6	-71.3	0	63.95	27.55	3	3	1.11
100 kHz	OOK	20%	Pulse-Like	-109.4	-71.3	0	63.95	27.55	3	3	2.43
100 kHz	50% Abs.	100%	Pulse-Like	-100	-71.3	0	63.95	27.55	3	3	0.82
100 kHz	50% Abs.	20%	Pulse-Like	-107	-71.3	0	63.95	27.55	3	3	1.84
100 kHz	2% Rel.	100%	Pulse-Like	-100	-71.3	0	63.95	27.55	3	3	0.82
100 kHz	2% Rel.	20%	Pulse-Like	-107	-71.3	0	63.95	27.55	3	3	1.84
1 MHz	None	100%	CW-Like	-143.7	-71.3	0	63.95	27.55	3	3	125.92
1 MHz	None	20%	Pulse-Like	-97.6	-71.3	0	63.95	27.55	3	3	0.62
1 MHz	OOK	100%	Pulse-Like	-121.2	-71.3	0	63.95	27.55	3	3	9.44
1 MHz	OOK	20%	Pulse-Like	-101.1	-71.3	0	63.95	27.55	3	3	0.93
1 MHz	50% Abs.	100%	Pulse-Like	-113	-71.3	0	63.95	27.55	3	3	3.67
1 MHz	50% Abs.	20%	Pulse-Like	-97.5	-71.3	0	63.95	27.55	3	3	0.62
1 MHz	2% Rel.	100%	Pulse-Like	-131	-71.3	0	63.95	27.55	3	3	29.18
1 MHz	2% Rel.	20%	Pulse-Like	-97	-71.3	0	63.95	27.55	3	3	0.58
5 MHz	None	100%	CW-Like	-145.5	-71.3	0	63.95	27.55	3	3	154.92
5 MHz	None	20%	CW-Like	-145.2	-71.3	0	63.95	27.55	3	3	149.66
5 MHz	OOK	100%	CW-Like	-144.5	-71.3	0	63.95	27.55	3	3	138.07
5 MHz	OOK	20%	CW-Like	-144.2	-71.3	0	63.95	27.55	3	3	133.38
5 MHz	50% Abs.	100%	Noise-Like	-137	-71.3	0	63.95	27.55	3	3	58.22
5 MHz	50% Abs.	20%	Pulse-Like	-105	-71.3	0	63.95	27.55	3	3	1.46
5 MHz	2% Rel.	100%	Noise-Like	-136.5	-71.3	0	63.95	27.55	3	3	54.97
5 MHz	2% Rel.	20%	Pulse-Like	-89	-71.3	0	63.95	27.55	3	3	0.23
20 MHz	None	100%	CW-Like	-145	-71.3	0	63.95	27.55	3	3	146.25
20 MHz	None	20%	CW-Like	-145.8	-71.3	0	63.95	27.55	3	3	160.36
20 MHz	OOK	100%	CW-Like	-144.5	-71.3	0	63.95	27.55	3	3	138.07
20 MHz	OOK	20%	CW-Like	-146.3	-71.3	0	63.95	27.55	3	3	169.86
20 MHz	50% Abs.	100%	Noise-Like	-138	-71.3	0	63.95	27.55	3	3	65.33
20 MHz	50% Abs.	20%	Pulse-Like	-135	-71.3	0	63.95	27.55	3	3	46.25
20 MHz	2% Rel.	100%	Noise-Like	-136	-71.3	0	63.95	27.55	3	3	51.89
20 MHz	2% Rel.	20%	Pulse-Like	-133	-71.3	0	63.95	27.55	3	3	36.74

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

C/A Code Receiver Architecture (-4.5 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-112.6	-71.3	-4.5	63.95	27.55	3	3	2.09
100 kHz	None	20%	Pulse-Like	-106.5	-71.3	-4.5	63.95	27.55	3	3	1.04
100 kHz	OOK	100%	Pulse-Like	-102.6	-71.3	-4.5	63.95	27.55	3	3	0.66
100 kHz	OOK	20%	Pulse-Like	-109.4	-71.3	-4.5	63.95	27.55	3	3	1.45
100 kHz	50% Abs.	100%	Pulse-Like	-100	-71.3	-4.5	63.95	27.55	3	3	0.49
100 kHz	50% Abs.	20%	Pulse-Like	-107	-71.3	-4.5	63.95	27.55	3	3	1.10
100 kHz	2% Rel.	100%	Pulse-Like	-100	-71.3	-4.5	63.95	27.55	3	3	0.49
100 kHz	2% Rel.	20%	Pulse-Like	-107	-71.3	-4.5	63.95	27.55	3	3	1.10
1 MHz	None	100%	CW-Like	-143.7	-71.3	-4.5	63.95	27.55	3	3	75.01
1 MHz	None	20%	Pulse-Like	-97.6	-71.3	-4.5	63.95	27.55	3	3	0.37
1 MHz	OOK	100%	Pulse-Like	-121.2	-71.3	-4.5	63.95	27.55	3	3	5.62
1 MHz	OOK	20%	Pulse-Like	-101.1	-71.3	-4.5	63.95	27.55	3	3	0.56
1 MHz	50% Abs.	100%	Pulse-Like	-113	-71.3	-4.5	63.95	27.55	3	3	2.19
1 MHz	50% Abs.	20%	Pulse-Like	-97.5	-71.3	-4.5	63.95	27.55	3	3	0.37
1 MHz	2% Rel.	100%	Pulse-Like	-131	-71.3	-4.5	63.95	27.55	3	3	17.38
1 MHz	2% Rel.	20%	Pulse-Like	-97	-71.3	-4.5	63.95	27.55	3	3	0.35
5 MHz	None	100%	CW-Like	-145.5	-71.3	-4.5	63.95	27.55	3	3	92.28
5 MHz	None	20%	CW-Like	-145.2	-71.3	-4.5	63.95	27.55	3	3	89.15
5 MHz	OOK	100%	CW-Like	-144.5	-71.3	-4.5	63.95	27.55	3	3	82.24
5 MHz	OOK	20%	CW-Like	-144.2	-71.3	-4.5	63.95	27.55	3	3	79.45
5 MHz	50% Abs.	100%	Noise-Like	-137	-71.3	-4.5	63.95	27.55	3	3	34.68
5 MHz	50% Abs.	20%	Pulse-Like	-105	-71.3	-4.5	63.95	27.55	3	3	0.87
5 MHz	2% Rel.	100%	Noise-Like	-136.5	-71.3	-4.5	63.95	27.55	3	3	32.74
5 MHz	2% Rel.	20%	Pulse-Like	-89	-71.3	-4.5	63.95	27.55	3	3	0.14
20 MHz	None	100%	CW-Like	-145	-71.3	-4.5	63.95	27.55	3	3	87.12
20 MHz	None	20%	CW-Like	-145.8	-71.3	-4.5	63.95	27.55	3	3	95.52
20 MHz	OOK	100%	CW-Like	-144.5	-71.3	-4.5	63.95	27.55	3	3	82.24
20 MHz	OOK	20%	CW-Like	-146.3	-71.3	-4.5	63.95	27.55	3	3	101.18
20 MHz	50% Abs.	100%	Noise-Like	-138	-71.3	-4.5	63.95	27.55	3	3	38.91
20 MHz	50% Abs.	20%	Pulse-Like	-135	-71.3	-4.5	63.95	27.55	3	3	27.55
20 MHz	2% Rel.	100%	Noise-Like	-136	-71.3	-4.5	63.95	27.55	3	3	30.91
20 MHz	2% Rel.	20%	Pulse-Like	-133	-71.3	-4.5	63.95	27.55	3	3	21.88

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Semi-Codeless Receiver Architecture (3 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz)	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-118	-71.3	3	63.95	27.55	3	3	9.23
100 kHz	None	20%	Pulse-Like	-116.5	-71.3	3	63.95	27.55	3	3	7.76
100 kHz	OOK	100%	Pulse-Like	-112	-71.3	3	63.95	27.55	3	3	4.62
100 kHz	OOK	20%	Pulse-Like	-118.5	-71.3	3	63.95	27.55	3	3	9.77
100 kHz	50% Abs.	100%	Pulse-Like	-121	-71.3	3	63.95	27.55	3	3	13.03
100 kHz	50% Abs.	20%	Pulse-Like	-116	-71.3	3	63.95	27.55	3	3	7.33
100 kHz	2% Rel.	100%	Pulse-Like	-119	-71.3	3	63.95	27.55	3	3	10.35
100 kHz	2% Rel.	20%	Pulse-Like	-138	-71.3	3	63.95	27.55	3	3	92.28
1 MHz	50% Abs.	100%	Pulse-Like	-151	-71.3	3	63.95	27.55	3	3	412.20
1 MHz	50% Abs.	20%	Pulse-Like	-132	-71.3	3	63.95	27.55	3	3	46.25
1 MHz	2% Rel.	100%	Pulse-Like	-149	-71.3	3	63.95	27.55	3	3	327.42
1 MHz	2% Rel.	20%	Pulse-Like	-134	-71.3	3	63.95	27.55	3	3	58.22
5 MHz	50% Abs.	100%	Noise-Like	-151	-71.3	3	63.95	27.55	3	3	412.20
5 MHz	50% Abs.	20%	Pulse-Like	-151	-71.3	3	63.95	27.55	3	3	412.20
5 MHz	2% Rel.	100%	Noise-Like	-149	-71.3	3	63.95	27.55	3	3	327.42
5 MHz	2% Rel.	20%	Pulse-Like	-142.5	-71.3	3	63.95	27.55	3	3	154.92
20 MHz	None	100%	Noise-Like	-145	-71.3	3	63.95	27.55	3	3	206.59
20 MHz	None	20%	Noise-Like	-148	-71.3	3	63.95	27.55	3	3	291.81
20 MHz	OOK	100%	Noise-Like	-137	-71.3	3	63.95	27.55	3	3	82.24
20 MHz	OOK	20%	Noise-Like	-146	-71.3	3	63.95	27.55	3	3	231.79
20 MHz	50% Abs.	100%	Noise-Like	-149.5	-71.3	3	63.95	27.55	3	3	346.82
20 MHz	50% Abs.	20%	Pulse-Like	-148	-71.3	3	63.95	27.55	3	3	291.81
20 MHz	2% Rel.	100%	Noise-Like	-149.5	-71.3	3	63.95	27.55	3	3	346.82
20 MHz	2% Rel.	20%	Pulse-Like	-143.5	-71.3	3	63.95	27.55	3	3	173.82

Semi-Codeless Receiver Architecture (0 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz)	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-118	-71.3	0	63.95	27.55	3	3	6.53
100 kHz	None	20%	Pulse-Like	-116.5	-71.3	0	63.95	27.55	3	3	5.50
100 kHz	OOK	100%	Pulse-Like	-112	-71.3	0	63.95	27.55	3	3	3.27
100 kHz	OOK	20%	Pulse-Like	-118.5	-71.3	0	63.95	27.55	3	3	6.92
100 kHz	50% Abs.	100%	Pulse-Like	-121	-71.3	0	63.95	27.55	3	3	9.23
100 kHz	50% Abs.	20%	Pulse-Like	-116	-71.3	0	63.95	27.55	3	3	5.19
100 kHz	2% Rel.	100%	Pulse-Like	-119	-71.3	0	63.95	27.55	3	3	7.33
100 kHz	2% Rel.	20%	Pulse-Like	-138	-71.3	0	63.95	27.55	3	3	65.33
1 MHz	50% Abs.	100%	Pulse-Like	-151	-71.3	0	63.95	27.55	3	3	291.81
1 MHz	50% Abs.	20%	Pulse-Like	-132	-71.3	0	63.95	27.55	3	3	32.74
1 MHz	2% Rel.	100%	Pulse-Like	-149	-71.3	0	63.95	27.55	3	3	231.79
1 MHz	2% Rel.	20%	Pulse-Like	-134	-71.3	0	63.95	27.55	3	3	41.22
5 MHz	50% Abs.	100%	Noise-Like	-151	-71.3	0	63.95	27.55	3	3	291.81
5 MHz	50% Abs.	20%	Pulse-Like	-151	-71.3	0	63.95	27.55	3	3	291.81
5 MHz	2% Rel.	100%	Noise-Like	-149	-71.3	0	63.95	27.55	3	3	231.79
5 MHz	2% Rel.	20%	Pulse-Like	-142.5	-71.3	0	63.95	27.55	3	3	109.67
20 MHz	None	100%	Noise-Like	-145	-71.3	0	63.95	27.55	3	3	146.25
20 MHz	None	20%	Noise-Like	-148	-71.3	0	63.95	27.55	3	3	206.59
20 MHz	OOK	100%	Noise-Like	-137	-71.3	0	63.95	27.55	3	3	58.22
20 MHz	OOK	20%	Noise-Like	-146	-71.3	0	63.95	27.55	3	3	164.10
20 MHz	50% Abs.	100%	Noise-Like	-149.5	-71.3	0	63.95	27.55	3	3	245.53
20 MHz	50% Abs.	20%	Pulse-Like	-148	-71.3	0	63.95	27.55	3	3	206.59
20 MHz	2% Rel.	100%	Noise-Like	-149.5	-71.3	0	63.95	27.55	3	3	245.53
20 MHz	2% Rel.	20%	Pulse-Like	-143.5	-71.3	0	63.95	27.55	3	3	123.06

Semi-Codeless Receiver Architecture (-4.5 dBic Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz)	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-118	-71.3	-4.5	63.95	27.55	3	3	3.89
100 kHz	None	20%	Pulse-Like	-116.5	-71.3	-4.5	63.95	27.55	3	3	3.27
100 kHz	OOK	100%	Pulse-Like	-112	-71.3	-4.5	63.95	27.55	3	3	1.95
100 kHz	OOK	20%	Pulse-Like	-118.5	-71.3	-4.5	63.95	27.55	3	3	4.12
100 kHz	50% Abs.	100%	Pulse-Like	-121	-71.3	-4.5	63.95	27.55	3	3	5.50
100 kHz	50% Abs.	20%	Pulse-Like	-116	-71.3	-4.5	63.95	27.55	3	3	3.09
100 kHz	2% Rel.	100%	Pulse-Like	-119	-71.3	-4.5	63.95	27.55	3	3	4.37
100 kHz	2% Rel.	20%	Pulse-Like	-138	-71.3	-4.5	63.95	27.55	3	3	38.91
1 MHz	50% Abs.	100%	Pulse-Like	-151	-71.3	-4.5	63.95	27.55	3	3	173.82
1 MHz	50% Abs.	20%	Pulse-Like	-132	-71.3	-4.5	63.95	27.55	3	3	19.50
1 MHz	2% Rel.	100%	Pulse-Like	-149	-71.3	-4.5	63.95	27.55	3	3	138.07
1 MHz	2% Rel.	20%	Pulse-Like	-134	-71.3	-4.5	63.95	27.55	3	3	24.55
5 MHz	50% Abs.	100%	Noise-Like	-151	-71.3	-4.5	63.95	27.55	3	3	173.82
5 MHz	50% Abs.	20%	Pulse-Like	-151	-71.3	-4.5	63.95	27.55	3	3	173.82
5 MHz	2% Rel.	100%	Noise-Like	-149	-71.3	-4.5	63.95	27.55	3	3	138.07
5 MHz	2% Rel.	20%	Pulse-Like	-142.5	-71.3	-4.5	63.95	27.55	3	3	65.33
20 MHz	None	100%	Noise-Like	-145	-71.3	-4.5	63.95	27.55	3	3	87.12
20 MHz	None	20%	Noise-Like	-148	-71.3	-4.5	63.95	27.55	3	3	123.06
20 MHz	OOK	100%	Noise-Like	-137	-71.3	-4.5	63.95	27.55	3	3	34.68
20 MHz	OOK	20%	Noise-Like	-146	-71.3	-4.5	63.95	27.55	3	3	97.75
20 MHz	50% Abs.	100%	Noise-Like	-149.5	-71.3	-4.5	63.95	27.55	3	3	146.25
20 MHz	50% Abs.	20%	Pulse-Like	-148	-71.3	-4.5	63.95	27.55	3	3	123.06
20 MHz	2% Rel.	100%	Noise-Like	-149.5	-71.3	-4.5	63.95	27.55	3	3	146.25
20 MHz	2% Rel.	20%	Pulse-Like	-143.5	-71.3	-4.5	63.95	27.55	3	3	73.30

Narrowly Spaced Correlator Receiver Architecture (3 dBi Antenna gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Category of Interfering Signal	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-100.2	-71.3	3	63.95	27.55	3	3	1.19
100 kHz	None	20%	Pulse-Like	-107.1	-71.3	3	63.95	27.55	3	3	2.63
100 kHz	OOK	100%	Pulse-Like	-103.2	-71.3	3	63.95	27.55	3	3	1.68
100 kHz	OOK	20%	Pulse-Like	-110.2	-71.3	3	63.95	27.55	3	3	3.76
100 kHz	50% Abs.	100%	Pulse-Like	-100.1	-71.3	3	63.95	27.55	3	3	1.18
100 kHz	50% Abs.	20%	Pulse-Like	-107.1	-71.3	3	63.95	27.55	3	3	2.63
100 kHz	2% Rel.	100%	Pulse-Like	-100.1	-71.3	3	63.95	27.55	3	3	1.18
100 kHz	2% Rel.	20%	Pulse-Like	-107.1	-71.3	3	63.95	27.55	3	3	2.63
1 MHz	None	100%	CW-Like	-144.1	-71.3	3	63.95	27.55	3	3	186.25
1 MHz	None	20%	Pulse-Like	-94.8	-71.3	3	63.95	27.55	3	3	0.64
1 MHz	OOK	100%	CW-Like	-139.9	-71.3	3	63.95	27.55	3	3	114.84
1 MHz	OOK	20%	Pulse-Like	-97.8	-71.3	3	63.95	27.55	3	3	0.90
1 MHz	50% Abs.	100%	Pulse-Like	-105.9	-71.3	3	63.95	27.55	3	3	2.29
1 MHz	50% Abs.	20%	Pulse-Like	-94.8	-71.3	3	63.95	27.55	3	3	0.64
1 MHz	2% Rel.	100%	Pulse-Like	-87.8	-71.3	3	63.95	27.55	3	3	0.29
1 MHz	2% Rel.	20%	Pulse-Like	-94.7	-71.3	3	63.95	27.55	3	3	0.63
5 MHz	None	100%	CW-Like	-145.7	-71.3	3	63.95	27.55	3	3	223.93
5 MHz	None	20%	CW-Like	-146.6	-71.3	3	63.95	27.55	3	3	248.37
5 MHz	OOK	100%	CW-Like	-146.7	-71.3	3	63.95	27.55	3	3	251.25
5 MHz	OOK	20%	CW-Like	-142.6	-71.3	3	63.95	27.55	3	3	156.71
5 MHz	50% Abs.	100%	Noise-Like	-127.7	-71.3	3	63.95	27.55	3	3	28.19
5 MHz	50% Abs.	20%	Pulse-Like	-88.5	-71.3	3	63.95	27.55	3	3	0.31
5 MHz	2% Rel.	100%	Noise-Like	-127.6	-71.3	3	63.95	27.55	3	3	27.87
5 MHz	2% Rel.	20%	Pulse-Like	-88.5	-71.3	3	63.95	27.55	3	3	0.31
20 MHz	None	100%	CW-Like	-146.1	-71.3	3	63.95	27.55	3	3	234.48
20 MHz	None	20%	CW-Like	-146.9	-71.3	3	63.95	27.55	3	3	257.10
20 MHz	OOK	100%	CW-Like	-146.5	-71.3	3	63.95	27.55	3	3	245.53
20 MHz	OOK	20%	CW-Like	-145.4	-71.3	3	63.95	27.55	3	3	216.32
20 MHz	50% Abs.	100%	Noise-Like	-133.6	-71.3	3	63.95	27.55	3	3	55.60
20 MHz	50% Abs.	20%	Pulse-Like	-100.5	-71.3	3	63.95	27.55	3	3	1.23
20 MHz	2% Rel.	100%	Noise-Like	-135.5	-71.3	3	63.95	27.55	3	3	69.20
20 MHz	2% Rel.	20%	Pulse-Like	-122.2	-71.3	3	63.95	27.55	3	3	14.97

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Narrowly Spaced Correlator Receiver Architecture (0 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-100.2	-71.3	0	63.95	27.55	3	3	0.84
100 kHz	None	20%	Pulse-Like	-107.1	-71.3	0	63.95	27.55	3	3	1.86
100 kHz	OOK	100%	Pulse-Like	-103.2	-71.3	0	63.95	27.55	3	3	1.19
100 kHz	OOK	20%	Pulse-Like	-110.2	-71.3	0	63.95	27.55	3	3	2.66
100 kHz	50% Abs.	100%	Pulse-Like	-100.1	-71.3	0	63.95	27.55	3	3	0.83
100 kHz	50% Abs.	20%	Pulse-Like	-107.1	-71.3	0	63.95	27.55	3	3	1.86
100 kHz	2% Rel.	100%	Pulse-Like	-100.1	-71.3	0	63.95	27.55	3	3	0.83
100 kHz	2% Rel.	20%	Pulse-Like	-107.1	-71.3	0	63.95	27.55	3	3	1.86
1 MHz	None	100%	CW-Like	-144.1	-71.3	0	63.95	27.55	3	3	131.86
1 MHz	None	20%	Pulse-Like	-94.8	-71.3	0	63.95	27.55	3	3	0.45
1 MHz	OOK	100%	CW-Like	-139.9	-71.3	0	63.95	27.55	3	3	81.30
1 MHz	OOK	20%	Pulse-Like	-97.8	-71.3	0	63.95	27.55	3	3	0.64
1 MHz	50% Abs.	100%	Pulse-Like	-105.9	-71.3	0	63.95	27.55	3	3	1.62
1 MHz	50% Abs.	20%	Pulse-Like	-94.8	-71.3	0	63.95	27.55	3	3	0.45
1 MHz	2% Rel.	100%	Pulse-Like	-87.8	-71.3	0	63.95	27.55	3	3	0.20
1 MHz	2% Rel.	20%	Pulse-Like	-94.7	-71.3	0	63.95	27.55	3	3	0.45
5 MHz	None	100%	CW-Like	-145.7	-71.3	0	63.95	27.55	3	3	158.53
5 MHz	None	20%	CW-Like	-146.6	-71.3	0	63.95	27.55	3	3	175.83
5 MHz	OOK	100%	CW-Like	-146.7	-71.3	0	63.95	27.55	3	3	177.87
5 MHz	OOK	20%	CW-Like	-142.6	-71.3	0	63.95	27.55	3	3	110.94
5 MHz	50% Abs.	100%	Noise-Like	-127.7	-71.3	0	63.95	27.55	3	3	19.96
5 MHz	50% Abs.	20%	Pulse-Like	-88.5	-71.3	0	63.95	27.55	3	3	0.22
5 MHz	2% Rel.	100%	Noise-Like	-127.6	-71.3	0	63.95	27.55	3	3	19.73
5 MHz	2% Rel.	20%	Pulse-Like	-88.5	-71.3	0	63.95	27.55	3	3	0.22
20 MHz	None	100%	CW-Like	-146.1	-71.3	0	63.95	27.55	3	3	166.00
20 MHz	None	20%	CW-Like	-146.9	-71.3	0	63.95	27.55	3	3	182.01
20 MHz	OOK	100%	CW-Like	-146.5	-71.3	0	63.95	27.55	3	3	173.82
20 MHz	OOK	20%	CW-Like	-145.4	-71.3	0	63.95	27.55	3	3	153.15
20 MHz	50% Abs.	100%	Noise-Like	-133.6	-71.3	0	63.95	27.55	3	3	39.36
20 MHz	50% Abs.	20%	Pulse-Like	-100.5	-71.3	0	63.95	27.55	3	3	0.87
20 MHz	2% Rel.	100%	Noise-Like	-135.5	-71.3	0	63.95	27.55	3	3	48.99
20 MHz	2% Rel.	20%	Pulse-Like	-122.2	-71.3	0	63.95	27.55	3	3	10.60

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Narrowly Spaced Correlator Receiver Architecture (-4.5 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-100.2	-71.3	-4.5	63.95	27.55	3	3	0.50
100 kHz	None	20%	Pulse-Like	-107.1	-71.3	-4.5	63.95	27.55	3	3	1.11
100 kHz	OOK	100%	Pulse-Like	-103.2	-71.3	-4.5	63.95	27.55	3	3	0.71
100 kHz	OOK	20%	Pulse-Like	-110.2	-71.3	-4.5	63.95	27.55	3	3	1.59
100 kHz	50% Abs.	100%	Pulse-Like	-100.1	-71.3	-4.5	63.95	27.55	3	3	0.50
100 kHz	50% Abs.	20%	Pulse-Like	-107.1	-71.3	-4.5	63.95	27.55	3	3	1.11
100 kHz	2% Rel.	100%	Pulse-Like	-100.1	-71.3	-4.5	63.95	27.55	3	3	0.50
100 kHz	2% Rel.	20%	Pulse-Like	-107.1	-71.3	-4.5	63.95	27.55	3	3	1.11
1 MHz	None	100%	CW-Like	-144.1	-71.3	-4.5	63.95	27.55	3	3	78.54
1 MHz	None	20%	Pulse-Like	-94.8	-71.3	-4.5	63.95	27.55	3	3	0.27
1 MHz	OOK	100%	CW-Like	-139.9	-71.3	-4.5	63.95	27.55	3	3	48.43
1 MHz	OOK	20%	Pulse-Like	-97.8	-71.3	-4.5	63.95	27.55	3	3	0.38
1 MHz	50% Abs.	100%	Pulse-Like	-105.9	-71.3	-4.5	63.95	27.55	3	3	0.97
1 MHz	50% Abs.	20%	Pulse-Like	-94.8	-71.3	-4.5	63.95	27.55	3	3	0.27
1 MHz	2% Rel.	100%	Pulse-Like	-87.8	-71.3	-4.5	63.95	27.55	3	3	0.12
1 MHz	2% Rel.	20%	Pulse-Like	-94.7	-71.3	-4.5	63.95	27.55	3	3	0.27
5 MHz	None	100%	CW-Like	-145.7	-71.3	-4.5	63.95	27.55	3	3	94.43
5 MHz	None	20%	CW-Like	-146.6	-71.3	-4.5	63.95	27.55	3	3	104.74
5 MHz	OOK	100%	CW-Like	-146.7	-71.3	-4.5	63.95	27.55	3	3	105.95
5 MHz	OOK	20%	CW-Like	-142.6	-71.3	-4.5	63.95	27.55	3	3	66.09
5 MHz	50% Abs.	100%	Noise-Like	-127.7	-71.3	-4.5	63.95	27.55	3	3	11.89
5 MHz	50% Abs.	20%	Pulse-Like	-88.5	-71.3	-4.5	63.95	27.55	3	3	0.13
5 MHz	2% Rel.	100%	Noise-Like	-127.6	-71.3	-4.5	63.95	27.55	3	3	11.75
5 MHz	2% Rel.	20%	Pulse-Like	-88.5	-71.3	-4.5	63.95	27.55	3	3	0.13
20 MHz	None	100%	CW-Like	-146.1	-71.3	-4.5	63.95	27.55	3	3	98.88
20 MHz	None	20%	CW-Like	-146.9	-71.3	-4.5	63.95	27.55	3	3	108.42
20 MHz	OOK	100%	CW-Like	-146.5	-71.3	-4.5	63.95	27.55	3	3	103.54
20 MHz	OOK	20%	CW-Like	-145.4	-71.3	-4.5	63.95	27.55	3	3	91.22
20 MHz	50% Abs.	100%	Noise-Like	-133.6	-71.3	-4.5	63.95	27.55	3	3	23.45
20 MHz	50% Abs.	20%	Pulse-Like	-100.5	-71.3	-4.5	63.95	27.55	3	3	0.52
20 MHz	2% Rel.	100%	Noise-Like	-135.5	-71.3	-4.5	63.95	27.55	3	3	29.18
20 MHz	2% Rel.	20%	Pulse-Like	-122.2	-71.3	-4.5	63.95	27.55	3	3	6.31

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

TSO-C129a Compliant C/A Code Receiver Architecture (-10 dBi Antenna Gain)

UWB PRF	UWB Modulation	UWB Gating Percentage	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Lman (dB)	Lallot (dB)	Lsafety (dB)	Required Distance Separation (m)
100 kHz	None	100%	Pulse-Like	-117.9	-71.3	-10	63.95	27.55	3	10	6	9.12
100 kHz	None	20%	Pulse-Like	-106.8	-71.3	-10	63.95	27.55	3	10	6	2.54
100 kHz	OOK	100%	Pulse-Like	-103.1	-71.3	-10	63.95	27.55	3	10	6	1.66
100 kHz	OOK	20%	Pulse-Like	-109.9	-71.3	-10	63.95	27.55	3	10	6	3.63
100 kHz	50% Abs.	100%	Pulse-Like	-115	-71.3	-10	63.95	27.55	3	10	6	6.53
100 kHz	50% Abs.	20%	Pulse-Like	-106.8	-71.3	-10	63.95	27.55	3	10	6	2.54
100 kHz	2% Rel.	100%	Pulse-Like	-97.9	-71.3	-10	63.95	27.55	3	10	6	0.91
100 kHz	2% Rel.	20%	Pulse-Like	-106.9	-71.3	-10	63.95	27.55	3	10	6	2.57
1 MHz	None	100%	CW-Like	-140.8	-71.3	-10	63.95	27.55	3	10	6	127.38
1 MHz	None	20%	CW-Like	-146.7	-71.3	-10	63.95	27.55	3	10	6	251.25
1 MHz	OOK	100%	CW-Like	-140.8	-71.3	-10	63.95	27.55	3	10	6	127.38
1 MHz	OOK	20%	CW-Like	-140.7	-71.3	-10	63.95	27.55	3	10	6	125.92
1 MHz	50% Abs.	100%	Noise-Like	-142	-71.3	-10	63.95	27.55	3	10	6	146.25
1 MHz	50% Abs.	20%	Noise-Like	-139.5	-71.3	-10	63.95	27.55	3	10	6	109.67
1 MHz	2% Rel.	100%	Noise-Like	-141.5	-71.3	-10	63.95	27.55	3	10	6	138.07
1 MHz	2% Rel.	20%	Noise-Like	-133.5	-71.3	-10	63.95	27.55	3	10	6	54.97
5 MHz	None	100%	CW-Like	-138.4	-71.3	-10	63.95	27.55	3	10	6	96.63
5 MHz	None	20%	CW-Like	-143.2	-71.3	-10	63.95	27.55	3	10	6	167.92
5 MHz	OOK	100%	CW-Like	-139.4	-71.3	-10	63.95	27.55	3	10	6	108.42
5 MHz	OOK	20%	CW-Like	-143.3	-71.3	-10	63.95	27.55	3	10	6	169.86
5 MHz	50% Abs.	100%	Noise-Like	-142	-71.3	-10	63.95	27.55	3	10	6	146.25
5 MHz	50% Abs.	20%	Noise-Like	-141.9	-71.3	-10	63.95	27.55	3	10	6	144.58
5 MHz	2% Rel.	100%	Noise-Like	-143	-71.3	-10	63.95	27.55	3	10	6	164.10
5 MHz	2% Rel.	20%	Noise-Like	-142.4	-71.3	-10	63.95	27.55	3	10	6	153.15
20 MHz	None	100%	CW-Like	-139.8	-71.3	-10	63.95	27.55	3	10	6	113.53
20 MHz	None	20%	CW-Like	-147.8	-71.3	-10	63.95	27.55	3	10	6	285.17
20 MHz	OOK	100%	CW-Like	-138.2	-71.3	-10	63.95	27.55	3	10	6	94.43
20 MHz	OOK	20%	CW-Like	-142.1	-71.3	-10	63.95	27.55	3	10	6	147.95
20 MHz	50% Abs.	100%	Noise-Like	-141	-71.3	-10	63.95	27.55	3	10	6	130.35
20 MHz	50% Abs.	20%	Noise-Like	-140.4	-71.3	-10	63.95	27.55	3	10	6	121.65

20 MHz	2% Rel.	100%	Noise-Like	-141	-71.3	-10	63.95	27.55	3	10	6	130.35
20 MHz	2% Rel.	20%	Noise-Like	-139.9	-71.3	-10	63.95	27.55	3	10	6	114.84

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Aggergate C/A Code Receiver Architecture (3 dBi Antenna Gain)

Measurement Case	Interfering Signal Effect	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Number of UWB Devices	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
I	Noise-Like	-137.5	-71.3	3	63.95	27.55	6	3	3	213.39
II	Noise-Like	-136	-71.3	3	63.95	27.55	6	3	3	179.55
III	CW-Like	-149.6	-71.3	3	63.95	27.55	1	3	3	350.84
IV	CW-Like	-143.5	-71.3	3	63.95	27.55	1	3	3	173.82
V (One UWB Signal Generator)	Pulse-Like	-131	-71.3	3	63.95	27.55	1	3	3	41.22
V (Two UWB Signal Generators)	Pulse-Like	-136	-71.3	3	63.95	27.55	2	3	3	103.66
V (Three UWB Signal Generators)	Noise-Like	-136	-71.3	3	63.95	27.55	3	3	3	126.96
V (Four UWB Signal Generators)	Noise-Like	-136	-71.3	3	63.95	27.55	4	3	3	146.60
V (Five UWB Signal Generators)	Noise-Like	-137	-71.3	3	63.95	27.55	5	3	3	183.90
V (Six UWB Signal Generators)	Noise-Like	-136	-71.3	3	63.95	27.55	6	3	3	179.55

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Aggregate C/A Code Receiver Architecture (0 dBi Antenna Gain)

Measurement Case	Category of Interfering Signal	UWB Interference Threshold (dBW/MHz or dBW)	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Number of UWB Devices	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
I	Noise-Like	-137.5	-71.3	0	63.95	27.55	6	3	3	151.07
II	Noise-Like	-136	-71.3	0	63.95	27.55	6	3	3	127.11
III	CW-Like	-149.6	-71.3	0	63.95	27.55	1	3	3	248.37
IV	CW-Like	-143.5	-71.3	0	63.95	27.55	1	3	3	123.06
V (One UWB Signal Generator)	Pulse-Like	-131	-71.3	0	63.95	27.55	1	3	3	29.18
V (Two UWB Signal Generators)	Pulse-Like	-136	-71.3	0	63.95	27.55	2	3	3	73.39
V (Three UWB Signal Generators)	Noise-Like	-136	-71.3	0	63.95	27.55	3	3	3	89.88
V (Four UWB Signal Generators)	Noise-Like	-136	-71.3	0	63.95	27.55	4	3	3	103.78
V (Five UWB Signal Generators)	Noise-Like	-137	-71.3	0	63.95	27.55	5	3	3	130.19
V (Six UWB Signal Generators)	Noise-Like	-136	-71.3	0	63.95	27.55	6	3	3	127.11

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.

Aggergate C/A Code Receiver Architecture (-4.5 dBi Antenna Gain)

Measurement Case	Category of Interfering Signal	UWB Interference Threshold (dBW/MHz or dBW)[a,b]	EIRP(Part 15 Limit) (dBW/MHz)	Gr (dBi)	20 Log F (dB)	Propagation Constant	Number of UWB Devices	Lman (dB)	Lallot (dB)	Required Distance Separation (m)
I	Noise-Like	-137.5	-71.3	-4.5	63.95	27.55	6	3	3	89.99
II	Noise-Like	-136	-71.3	-4.5	63.95	27.55	6	3	3	75.71
III	CW-Like	-149.6	-71.3	-4.5	63.95	27.55	1	3	3	147.95
IV	CW-Like	-143.5	-71.3	-4.5	63.95	27.55	1	3	3	73.30
V (One UWB Signal Generator)	Pulse-Like	-131	-71.3	-4.5	63.95	27.55	1	3	3	17.38
V (Two UWB Signal Generators)	Pulse-Like	-136	-71.3	-4.5	63.95	27.55	2	3	3	43.71
V (Three UWB Signal Generators)	Noise-Like	-136	-71.3	-4.5	63.95	27.55	3	3	3	53.54
V (Four UWB Signal Generators)	Noise-Like	-136	-71.3	-4.5	63.95	27.55	4	3	3	61.82
V (Five UWB Signal Generators)	Noise-Like	-137	-71.3	-4.5	63.95	27.55	5	3	3	77.55
V (Six UWB Signal Generators)	Noise-Like	-136	-71.3	-4.5	63.95	27.55	6	3	3	75.71

Note: a) UWB signals characterized as causing noise-like and pulse-like interference will have units of dBW/MHz. UWB signals characterized as causing CW-like interference will have units of dBW.

b) For UWB signals that have been characterized as causing CW-like interference, the current Part 15 level assumes there is only a single spectral line in the measurement bandwidth.