NTIA SPECIAL PUBLICATION 01–43

ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND DEVICES AND SELECTED FEDERAL SYSTEMS

Special Publication

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

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EXECUTIVE SUMMARY

Introduction: Ultrawideband Devices

Recent advances in microcircuit and other technologies have allowed the use of very narrow pulses (typically less than a nanosecond) with very wide bandwidths in new applications in both radar and communication devices. These devices, called Ultrawideband (UWB) devices, may have instantaneous bandwidths of 25 percent or more of their center frequency. They are capable of locating nearby objects and can use processing technology to "see through walls" and communicate in multipath propagation environments, which makes them useful in many commercial and government applications. The developers of UWB devices, because of their low output power, low manufacturing cost, and anticipated wide marketability are seeking authorization from the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) to operate UWB systems on an unlicensed basis.

UWB Devices As Unlicensed Devices

The existing rules for unlicensed devices were developed for devices using conventional narrowband technology and do not address UWB devices. Paragraph 15.209 of Volume 47 of the Code of Federal Regulations (47 CFR § 15.209) establishes the rules for the radiated emission limits of devices that can be authorized as unlicensed intentional radiators.[1] Intentional radiating unlicensed devices are not permitted to transmit signals in any of the 64 restricted bands, which occupy a total of 13.283 GHz of the spectrum between 90 kHz and 36.5 GHz, because of potentially harmful effects to critical radio services (47 CFR § 15.205) operating in them. Although UWB device output powers are often low enough to operate under these regulations, their bandwidths are so wide that most emit portions of their signal within the restricted bands. Moreover, operation of many proposed UWB devices under current Part 15 rules is made difficult because they seek to operate with much higher peak powers than the rules permit (47 CFR §15.35(b)). Revision of the current rules is required before UWB devices, as must be the case with any new system or technology, whether licensed or unlicensed, can be accommodated compatibly with existing systems in the electromagnetic environment.

The FCC and NTIA Programs

NTIA and the FCC must work closely with both the UWB community and the operators of conventional radiocommunication equipment they authorize and license to identify under what conditions UWB devices can operate without causing unacceptable interference to authorized and licensed radio services. To this end, the FCC initiated a formal proceeding that has included a *Notice of Inquiry* to gather information from the

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[1] Even if unlicensed devices meet these limits, they are not allowed to cause interference and must accept interference from any station operating in accordance with the tables of frequency allocation (47 CFR §15.5 (c) & (d)).

interested parties on UWB devices and their potential impact on conventional devices and a *Notice of Proposed Rulemaking* to examine proposed rules for the regulation of UWB devices.[2]

NTIA, meanwhile, has conducted a series of measurements and analyses for characterizing and assessing the impact of UWB devices on selected Federal equipment operating between 400 and 6000 MHz, which includes 18 bands and a total of 2502.7 MHz of restricted spectrum.[3] The results include practical methods for characterizing UWB systems and providing the information needed to estimate or measure their potential to interfere with existing radio communications or sensing systems.[4]

NTIA calculated the maximum permissible, average Equivalent Isotropic Radiated Power (EIRP) density in a 1 MHz bandwidth (average EIRP, dBm/MHz (RMS)) that would allow a UWB device to transmit without exceeding the protection criterion determined for each of the systems analyzed after coordination with that system's users.[5] Throughout this report, the average power was calculated from the Root Mean Square (RMS) voltage of the UWB signal. For clarity and simplicity the average power has been written as average (RMS) power and the average spectral density expressed as dBm/MHz (RMS). In addition, NTIA calculated the minimum separation distance at which a UWB device with an average EIRP spectral density of -41.3 dBm/MHz (RMS), which is equivalent to the average field strength specified in Part 15 for devices operating above 1 GHz (a field strength of 500 μV/m at a 3 meter separation distance measured in a 1 MHz bandwidth), will ensure that the protection criteria are met in that receiver. Both the effects of one single UWB emitter on one receiver and of an aggregate of several UWB emitters on one receiver were analyzed. Throughout the assessment, the UWB devices analyzed were presumed to overlap the bands used by the equipment being assessed completely. The analytical results developed were been compared with the measurements made at NTIA's Institute for Telecommunication Sciences (ITS) in Boulder, Colorado and field measurements made at the Federal Aviation Administration facilities at Oklahoma City, Oklahoma.

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[2] See *Revision of Part 15 of the Commission's Rules regarding Ultra-Wideband Transmission Systems, ET Docket No. 98-153, Notice of Proposed Rulemakeing, 65 Fed. Reg. 37332 (June 14, 2000)*.

[3] In addition, because of widespread concern, both the Interagency Government Executive Board, which oversees the development of the Global Positioning System (GPS), and the Federal Aviation Administration (FAA), have funded NTIA to conduct a related series of studies assessing UWB impact on GPS receivers. The measurements involving GPS receivers will be reported separately in a later document. See National Telecommunications and Information Administration, *Notice, Request for Comments on Global Positioning System/Ultrawideband Measurement Plan, 65 Fed. Reg. 49544 (Aug. 14, 2000).*

[4] NTIA and the Institute for Telecommunication Sciences with the support of the National Institute of Science and Technology verified the accuracy of the measurements made using readily available commercial test equipment in three separate ways. The first was by very accurately measuring the temporal (time domain) characteristics of the several devices and comparing the Fourier transformations of the signals in various bandwidths with measurements of the actual spectrums received in those bandwidths. The second was by theoretical analyses of the waveforms and their spectrums. The third way was through numerical simulations of the waveforms.

[5] The protection criteria, which are presented in Appendix A, are based on ITU-R Recommendations, ICAO Standards, and RTCA Minimum Operational Performance Criteria and were provided by the agencies operating the affected systems. NTIA's model is not generally accurate at ranges less than 200 meters due to uncertainties of near field, propagation and antenna gain.

The power levels of the UWB devices are expressed here as RMS spectral power densities, as noted above, rather than the average of the logarithms of the peak power densities measured with the video averaging technique used by the FCC for measuring narrow band Part 15 devices. Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, the RMS detector function better represents the interference effects of UWB signals than averages of the logarithms of the peak detector output of the video filtered response used by the FCC for Part 15 measurements.

Results: Single Emitter

TABLES 1 and 2 provide the results of NTIA's analyses of the effect of single UWB emitters on selected devices. TABLE 1 shows the results for all the systems analyzed, assuming that receiver performance degradation is a function of the UWB signal average power, while TABLE 2 shows the results of the analyses for digitally modulated Earth stations in which receiver performance degradation may be a function of the UWB signal peak power. In TABLE 2 the lower PRF rows are shaded to reflect a possible restriction of the ratio of permissible peak power in a 50 MHz band to the RMS power in a 1 MHz band to less than 30 dB.[6]

To better understand TABLE 1 please look at the results for the Terminal Doppler Weather Radar (TDWR), which shows that a UWB device with an EIRP in the 5600-5650 MHz band of -41.3 dBm/MHz (RMS) could operate out-of-doors without exceeding the TDWR's protection criteria at heights of 2 meters or less with no geographic restriction. Moreover, a UWB device at 2 meters would require an in-band EIRP of -35 dBm/MHz (RMS) or greater to exceed the TDWR's protection criteria. The entry for the Air Route Surveillance Radar (ARSR-4), however, shows that a UWB device at a height of 2 meters with an EIRP of -41.3 dBm/MHz (RMS) in the 1240-1370 MHz band would have to stay about 6 km away to meet the radar's protection criterion or reduce its in-band EIRP to about -61 dBm/MHz (RMS). Please note also that TABLE 1 shows also that if UWB devices were to operate in the same horizontal plane as the TDWR or ARSR-4 antennas (see the columns labeled UWB Ht = 30 m), then the separation distance would have to increase to 6 km for the TDWR and over 15 km for the ARSR-4, or the in-band EIRPs would have to decrease to -63 dBm/MHz (RMS) for the TDWR and -82 dBm/MHz (RMS) for the ARSR-4.

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[6] The 30 dB value was chosen for illustrative purposes and does not suggest an NTIA policy position. This 30 dB value would limit the PRF of UWB non-dithered devices to values greater than 3.5 MHz, and of UWB dithered devices to values greater than 12.5 MHz as shown in Appendix D.

TABLE 1
Summary of Assessment of Effects of UWB Devices on Federal Systems For Average Power Interactions[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters				UWB Height 30 Meters			
			Non-Dithered		Dithered		Non-Dithered		Dithered	
			Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria
Distance Measuring Equipment (DME) Interrogator Airborne Rcvr	960-1215	≤0.1 ≥1	-46 -47	0.08 0.09	-46 -46	0.08 0.08				
DME Ground Transponder Rcvr	1025-1150	≤0.1 ≥1	-63 -64	0.26 0.29	-63 -63	0.26 0.26	-56 -57	0.26 0.29	-56 -56	0.26 0.26
Air Traffic Control Radio Beacon Sys (ATCRBS) Air Transponder Rcvr	1030	≤1 ≥10	-44 -37	0.02 NA	-44 -44	0.02 0.02				
ATCRBS Gnd Interrogator Rcvr	1090	≤1 ≥10	-31 -21	NA NA	-31 -31	NA NA	-45 -36	0.27 NA	-45 -45	0.27 0.27
Air Route Surveil. Radar (ARSR-4)	1240-1370	≤0.1 ≥0.1	-60 -61	5.5 6.1	-60 -60	5.5 5.5	-80 -82	>15 >15	-80 -80	>15 >15
Search & Rescue Sat. (SARSAT) Ground Station Land User Terminal (LUT)	1544-1545	≤0.1 ≥1	-68 -69	2.9 3.1	-68 -68	2.9 2.9	-65 -66	5.5 6.1	-65 -65	5.5 5.5
Airport Surveillance Radar (ASR-9)	2700-2900	≤0.1 ≥1	-44 -46	0.8 1.1	-44 -44	0.8 0.8	-64 -66	1.3 1.5	-65 -65	1.3 1.3
Next Gen Weather Radar (NEXRAD)	2700-2900	≤0.1 ≥1	-39 -42	NA 1.4	-39 -39	NA NA	-73 -76	5.8 7.9	-73 -73	5.8 5.8
Maritime Radars	2900-3100	≤1 ≥10	-56 -50	1.2 0.6	-56 -56	1.2 1.2	-57 -51	1.2 0.6	-57 -57	1.2 1.2
FSS Earth Station (20° Elevation)	3700-4200	≤1 10 ≥100	-36 -26 -20	NA NA NA	-36 -36 -36	NA NA NA	-42 -32 -26	.20 NA NA	-42 -42 -42	.20 .20 .20
FSS Earth Station (5° Elevation)	3700-4200	≤1 10 ≥100	-51 -41 -35	0.60 NA NA	-51 -51 -51	0.60 0.63 0.63	-77 -67 -61	1.0 0.6 0.4	-77 -77 -77	1.0 1.0 1.0
CW Radar Altimeters at minimum altitude	4200-4400	≤0.1 ≥1	25 14	NA NA	25 14	NA NA				
Pulsed Radar Altimeters at Minimum Altitude	4200-4400	≤1 10 ≥10	14 14 14	NA NA NA	14 14 14	NA NA NA				
Microwave Landing System	5030-5091	≤ 0.1 ≥1	-45 -54	0.07 0.16	-45 -45	0.07 0.07				
Terminal Doppler Wx Radar (TDWR)	5600-5650	≤1 ≥10	-35 -35	NA NA	-35 -35	NA NA	-63 -63	6.0 6.0	-63 -63	6.0 6.0

Note: (1) The calculations were made at UWB PRF Values of, 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz. When the distance values and Maximum EIRP values were the same for a range, they were grouped together to save space in the table. Thus, for the first row, the calculations for PRF values of 0.001, 0.01, and, 0.1 MHz were the same and are shown in the row labeled ≤0.1 MHz, while the calculations for 1, 10, 100, and 500 MHz were the same and are shown in the row labeled ≥1 MHz. (2) The shaded areas represent implausible scenarios where the UWB and aircraft would be at the same altitude (i.e., a collision course). (3) The symbol NA indicates that the maximum calculated EIRP never exceeded -41.3 dBm/MHz (RMS).

TABLE 2 shows that if the receiver performance degradation to digital Earth terminals is related to the peak power rather than the average power, separation distances or additional losses would have to increase to meet the protection criteria established for those receivers.

TABLE 2
Summary of Assessment of Effects of UWB Devices on Federal Systems For Peak Power Interactions with Digitally Modulated Systems[Note]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	UWB Height 2 Meters				UWB Height 30 Meters			
			Non-Dithered		Dithered		Non-Dithered		Dithered	
			Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria	Max. EIRP to Meet Protect. Criteria (dBm/MHz (RMS))	MinSep.(km) for -41.3 dBm/MHz (RMS) EIRP to Meet Protect. Criteria
Search & Rescue Sat. (SARSAT) Ground Station Land User Terminal (LUT)	1544-1545	0.001	-104	>15	-104	>15	-101	>15	-101	>15
		0.01	-94	12.0	-94	12.0	-91	>15	-91	>15
		0.1	-84	7.3	-84	7.3	-81	>15	-81	>15
		1	-74	4.2	-74	4.2	-71	11.3	-71	11.4
		≥10	-69	3.1	-68	2.9	-66	6.1	-65	5.4
FSS Earth Station (20° Elevation)	3700-4200	0.001	-89	6.6	-89	6.6	-95	>15	-95	>15
		0.01	-79	3.9	-79	3.9	-85	>15	-85	>15
		0.1	-69	2.2	-69	2.2	-75	5.3	-75	5.3
		1	-59	1.2	-59	1.2	-65	1.7	-65	1.7
		10	-39	NA	-50	0.5	-45	0.25	-55	0.6
		100	-20	NA	-40	NA	-26	NA	-45	0.25
		500	-20	NA	-36	NA	-26	NA	-42	.20
FSS Earth Station (5° Elevation)	3700-4200	0.001	-104	12.3	-104	13.2	-130	>15	-130	>15
		0.01	-94	8.4	-94	8.4	-120	>15	-120	>15
		0.1	-84	5.1	-84	5.1	-110	>15	-110	>15
		1	-74	3.0	-74	3.0	-100	10.1	-100	10.2
		10	-54	1.0	-64	1.7	-80	1.3	-90	3.3
		100	-35	NA	-54	1.0	-61	0.44	-80	1.3
		500	-35	NA	-51	0.6	-61	0.44	-77	1.0

Note: (1) The calculations were made at UWB PRF Values of, 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz. When the distance values and Maximum EIRP values were the same for a range, they were grouped together to save space in the table. Thus, for the LUT the calculations for 10, 100, and 500 MHz were the same and are shown in the row labeled ≥10 MHz. (2) The shaded areas are for PRF values that would result in peak-to-average power levels greater than 30 dB.

Results: Aggregate Emitters

NTIA examined the implications of possible aggregate interference from UWB devices and developed a number of findings, both general and specific. NTIA developed the UWBRings computer model for this study to calculate effectively aggregate interference levels in a given receiver under a variety of conditions. The model is based upon two fundamental assumptions – that the UWB emitters are uniformly distributed geographically and that the average power received from each emitter adds linearly.

NTIA validated both the aggregate interference assumptions and the methodology through two steps. First, from a limited number of measurements using UWB simulators, NTIA found that the received average (RMS) power from two identical UWB emitters is approximately twice that from a single UWB emitter, in agreement with the linear addition assumption. These results logically extend to an arbitrarily large number of UWB emitters. Second, NTIA examined four other aggregate interference methodologies described in the literature and found that all yielded results quite similar (within 2 dB) to those derived from the NTIA UWBRings model for a variety of hypothetical UWB scenarios. The UWBRings model, however, is unique in its ability to effectively consider various modes of radio propagation and three-dimensional receiver antenna patterns, both being key factors for aggregate studies.

Results of these studies show that received aggregate average (RMS) power from a uniform distribution of identical UWB emitters varies directly with the UWB EIRP, UWB emitter density, and number of active transmitters (transmitter activity factor). These results show that under ideal radio propagation conditions, *i.e.*, with no man-made or natural obstructions, aggregate interference levels from UWB devices can exceed that from a single emitter at densities as low as a few emitters per square kilometer or more than 1000 emitters per square kilometer, depending on the specific receiver.

While some studies of aggregate effects filed in response to the FCC's UWB NPRM used a comparable analytic methodology to that used by NTIA, the studies typically compared the aggregate interference levels to that from a single UWB emitter situated at an unrealistically close distance to the receiving antenna. As a result, conclusions form these studies are misleading.

NTIA also examined additional factors that tend to mitigate aggregate interference as an issue, including higher propagation losses associated with irregular terrain, urban and suburban environments, and building penetration, or antenna directivity. A possible methodology is described for applying these factors.

Interpretation of Results

This report shows that operation of UWB devices is feasible in portions of the spectrum between about 3.1 and 5.650 GHz at heights of about 2 meters with some operating constraints.[7] Operations of UWB devices below 3.1 GHz will be quite challenging and any policy developed will need to consider the results of the analyses of interactions of GPS and UWB systems underway at NTIA and other facilities.

While the study showed that aggregate UWB interference can be a significant factor to receiving systems under ideal propagation conditions, a number of mitigating factors

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[7] UWB operations at greater heights between 3.1 and 5.650 GHz and near low elevation angle 4 GHz FSS earth stations may have to be constrained with respect to such factors as spectral output power, amount of operating time, and quantity of units operating in any area.

must also be taken into account that may reduce or eliminate these aggregate affects. There are also numerous mitigating factors that could relax restrictions on operation of UWB devices below 3.1 GHz. Although these are discussed in the report, the development of suitable policy restrictions and guidance for both aggregate and single emitter interference is beyond the scope of this report and must await the results of the ongoing UWB measurement programs, including those of the GPS.

Schedule for Further Planned NTIA Studies

NTIA anticipates publishing a report of the measurement and assessment of the effects of UWB signals on GPS systems by the end of February 2001. NTIA will continue to work closely with industry, the FCC and Federal government agencies to ensure that interference will not occur.

TABLE OF CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AGL	Above Ground Level
APD	Amplitude Probability Distribution
ARSR	Air Route Surveillance Radar
ASR	Airport Surveillance Radar
ATCRBS	Air Traffic Control Radio Beacon System
BWCF	Bandwidth Correction Factor
CFAR	Constant False Alarm Rate
CFR	Code of Federal Regulations
C/I	Carrier-to-Interference Ratio
CISPR	International Special Committee for Radio Interference
COSPAS	Cosmicheskaya Systyema Poiska Avariynich Sudov
CW	Continuous Wave
dB	Decibel
dBi	Decibels Referenced to an Isotropic Antenna
dBm	Decibel Referenced to a Milliwatt
dBW	Decibels Referenced to a Watt
DME	Distance Measuring Equipment
DCF	Detector Correction Factor
DoD	Department of Defense
EIRP	Equivalent Isotropic Radiated Power
EMC	Electromagnetic Compatibility
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FM	Frequency Modulation
FMCW	Frequency Modulated Continuous Wave
FSS	Fixed Satellite Service
GF	Gating Factor
GHz	Gigahertz (10^9 Hertz)
GMF	Government Master File
GPR	Ground Penetrating Radar
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IF	Intermediate Frequency
I_{MAX}	Maximum Permissible Average or Peak Interference Level, in dBm
I/N	Interference-to-noise Ratio
I+N	Interference plus Noise
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union Radiocommunication Sector
kHz	Kilohertz (10^3 Hertz)
km	Kilometer

^{o}K	Temperature in degrees Kelvin
LUT	Land User Terminal
m	Meter
MHz	Megahertz (10^6 Hertz)
MLS	Microwave Landing System
MTL	Minimum Triggering Level
NEXRAD	Next Generation Weather Radar
NF	Noise Figure
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rule Making
NTIA	National Telecommunications and Information Administration
P_d	Probability of Detection
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density
RF	Radio Frequency
RMS	Root-Mean-Square
RSMS	Radio Spectrum Measurement System
SARSAT	Search and Rescue Satellite
S/I	Signal-to-Interference Ratio
STC	Sensitivity Time Control
TDWR	Terminal Doppler Weather Radar
UWB	Ultrawideband

SECTION 1
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 and use, and providing various departments and agencies with guidance to ensure that their conduct of telecommunication activities is consistent with these policies.[8] Accordingly, NTIA conducts studies and makes recommendations regarding telecommunications 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, studied the feasibility of reallocating spectrum used by the government or relocating government systems, identified existing or potential compatibility problems between systems, provided recommendations for resolving any compatibility conflicts, and recommend changes to promote efficient and effective use of the radio spectrum and to improve spectrum management procedures.

Recent advances in microcircuit and other technologies have resulted in the development of pulsed radar and communications systems with very narrow pulse widths and, consequently, very wide bandwidths. These ultrawideband (UWB) systems have instantaneous bandwidths of at least 25 percent of the center frequency of the device and thereby cannot conform the U.S. frequency allocation table and the associated Federal regulations.[9] UWB systems have shown promise in performing a number of useful telecommunication functions that make them very appealing for both commercial and government applications. These systems have very wide information bandwidths, are capable of accurately locating nearby objects, and can use processing technology with UWB pulses to "see through objects" and communicate using multiple propagation paths. However, the bandwidths of UWB devices are so wide that, although their output powers, in many cases, are low enough to be authorized under the unlicensed device regulations

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[8] National Telecommunications and Information Administration, U.S. Dept. of Commerce, Manual of Regulations and Procedures for Federal Radio Frequency Management, at Chapter 2 (Jan. 2000).

[9] There are several ways of generating very wide signals including spread spectrum and frequency hopping and chirping techniques. The UWB signals for the devices of concern in this study are generated by direct current impulse responses fired into a tuned circuit. This generates a burst of energy of ideally one positive going cycle shaped by the tuned circuit to a specific portion of the spectrum.

of the NTIA and the FCC, some of the systems emit signals in frequency bands in which such transmissions are not permitted because of the potential harmful effects on critical radiocommunication services.

The FCC, in coordination with NTIA, developed rules for unlicensed devices (conventional electronic devices with narrow bandwidths) that did not address the then unknown UWB devices (47 Code of Federal Regulations (CFR) §§ 15.1 et seq.). To obtain information on UWB devices and decide whether accommodating them as unlicensed devices under Part 15, the FCC issued a *Notice of Inquiry (NOI)*.[10] Also, after an initial investigation by NTIA and the FCC, the FCC, in coordination with NTIA, granted limited waivers authorizing the marketing of UWB devices manufactured by three companies. Subsequent to the NOI, the FCC issued a *Notice of Proposed Rule Making (NPRM),* on the revision of Part 15 rules regarding UWB transmission systems.[11]

This report addresses the emissions from UWB devices that occur primarily in the restricted frequency bands,[12] and the possibility of degradation to the performance of critical Federal telecommunication systems except for the Global Positioning System (GPS), which is analyzed in several separate studies. Before NTIA can accept the operation of UWB devices in the restricted frequency bands used by critical Federal radio systems, it must assess the potential impact of UWB devices on these systems, as well as develop solutions to any problems identified. A subsequent NTIA report will address policies and rules pertaining to UWB devices.

UWB operation on an unlicensed basis has been proposed to operate under 47 CFR Part 15 which sets out the regulations under which an intentional, unintentional, or incidental radiator may be operated without an individual license. Part 15 stipulates that unlicenced devices are subject to the condition that no harmful interference is caused to licenced services and that harmful interference to unlicenced devices must be accepted. It is recognized and stated in Part 15.5(c) that “the limits specified in this part will not prevent harmful interference in all circumstances.”

1.2 OBJECTIVE

The objective of this report was to provide an assessment of the compatibility between UWB devices and selected Federal systems.

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[10] *See Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Transmission Systems*, ET Docket No. 98-153, Notice of Inquiry, 63 Fed. Reg. 50184 (Sept. 21, 1998) [hereinafter UWB NOI].

[11] *See* UWB NPRM, *supra* note 2.

[12] “Restricted bands” of operation are listed in 47 CFR §15.205. With certain exceptions, the only emissions radiated from unlicensed devices, that are allowed in these bands are spurious emissions. Spurious emissions per 47 CFR 2.1, are emissions “...which may be reduced without affecting the corresponding transmission of information.”

1.3 APPROACH

In order to accomplish the above objective, NTIA developed, first, a Master Plan to provide a comprehensive approach for obtaining the information required to perform a detailed assessment, and then, a more detailed measurement plan to measure the characteristics of UWB devices and provide the basis for an analytical model used to assess the impact. These plans were provided directly to the Federal agencies and to the public via the Federal Register for comment.[13] The FCC's NPRM on Revision of Part 15 Rules Regarding UWB Transmission Systems was reviewed to make sure that NTIA's effort would address issues for which the FCC sought guidance. NTIA, thus, undertook a comprehensive program consisting of measurements, analytical analysis, and simulations to characterize UWB transmissions and their potential to interact with Federal telecommunication systems. The program included:

A) Establishing a UWB measurement plan to:

1) Develop measurement procedures that use commercial off-the-shelf measurement equipment to accurately portray UWB emission characteristics;
2) Observe the effects of UWB signals in the intermediate frequency (IF) sections of selected receivers, and determine the susceptibility of conventional radio receivers to UWB emissions;
3) Provide a basis for development of a one-on-one interference analysis procedure to determine maximum permitted equivalent isotropic radiated power (EIRP) level or minimum distance separation of UWB devices to ensure compatibility;
4) Perform a limited set of measurements to validate the one-on-one interference analysis (above) between UWB signals and selected Federal radio receivers, particularly radio navigation and safety-of-life systems; and
5) Assess the potential aggregate or cumulative effects of multiple UWB emissions through measurements.

B) Conducting analytical analysis and simulations to:

1) Describe the temporal and spectral characteristics of UWB signals;
2) Characterize an aggregate of UWB signals; and
3) Identify the time waveform and power transfer characteristics of UWB signals in receiver systems as a function of receiver IF bandwidths.

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[13] Ultra Wideband signals for Sensing and Communication: A Plan for Developing Measurement Methods, Characterizing the Signals and Estimating Their Effects on Existing Systems, August 25, 2000, (see NTIA homepage www.ntia.doc.gov/osmhome/uwbtestplan/), and Ultra-Wideband Signals for Sensing, and Communications: A Master Plan for Developing Measurement Methods, Characterizing the Signals and Estimating Their Effects on Existing Systems, ITS Ultra-Wideband Measurement Plan (Master Plan Task 1.2), August 25, 2000, (see NTIA homepage www.ntia.doc.gov/osmhome/uwbtestplan/). These are the final plans incorporating the comments of the Federal government and public sector.

Results of the measurements, analytical analysis and simulations are contained in an NTIA Report.[14]

C) Based on information obtained from “A” and “B” above, the following steps were taken:

1) An analysis procedure and an analytical model were developed to determine the maximum permitted EIRP level and the minimum distance separation which will ensure compatibility between UWB devices and other telecommunications systems. The analytical model was compared to measurements made on two Federal telecommunication systems.
2) An aggregate analytical model was developed to identify the potential cumulative effects of UWB devices.

D) The systems selected for the analysis were chosen primarily due to their crucial role in aviation safety, and with the exception of the Terminal Doppler Weather Radar (TDWR),[15] and maritime radionavigation radars operate in restricted frequency bands. The Federal radiocommunications systems that were chosen for the analysis are listed in TABLE 1-1 along with their allocation bands.

E) The technical characteristics of Federal telecommunication systems listed in TABLE 1-1 needed to conduct an electromagnetic compatibility (EMC) study were identified, and applied to the analytical models described in “C” above. Based on the results of applying the analytical models, maximum permitted EIRP levels and minimum distance separations which will ensure compatibility between UWB devices and other telecommunications systems were identified.

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[14] National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report, The Temporal and Spectral Characteristics of Ultrawideband Signals, Jan. 2001 [hereinafter ITS Report].

[15] Although the TDWR does not operate in a restricted frequency band, the system performs a critical mission of detecting micro bursts, wind shear, near airports to ensure safe landing of aircraft. Unlicensed device operation in this frequency band is still subject to the condition that no harmful interference be caused and that interference to the unlicensed device must be accepted 47 CFR Part 15.5(b). This also applies to maritime radionavigation radars in the 2900-3100 MHz frequency band.

TABLE 1-1
Systems Analyzed in the Single UWB Emitter Analyses

System	Receive Frequency (MHz)	Function
Distance Measuring Equipment (DME) Airborne Interrogator	960-1215	Provides civil and military aircraft pilots with distance from a specific ground beacon (transponder) for navigational purposes.
DME Ground Transponder	1025-1150	Ground transponder component which replies to interrogations from the DME airborne component.
Air Traffic Control Radio Beacon System (ATCRBS) Ground Interrogator	1090	Used in conjunction with the ASR and ARSR radars to provide air traffic controllers with location, altitude and identity of civil and military aircraft.
ATCRBS Airborne Transponder	1030	ATCRBS airborne transponder component of ATCRBS system which replies to the ground interrogator and provides altitude and aircraft identity information in the reply signal.
Air Route Surveillance Radar (ARSR-4)	1240-1400	Used by the Federal Aviation Administration (FAA) and Department of Defense (DoD) to monitor aircraft during enroute flight to distances of beyond 370 km (200 nm).
Search and Rescue Satellite Land User Terminal (SARSAT LUT)	1544-1545	Provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress.
Airport Surveillance Radar (ASR-9)	2700-2900	Monitors location of civil and military aircraft in and around airports to a range of 110 km.
Next Generation Weather Radar (NEXRAD)	2700-3000	Provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information.
Maritime Radionavigation Radar	2900-3100	Maritime radionavigation radars provide a safety service function that assists vessel commanders in safe navigation of waterways. The marine radar provides information on surface craft locations, obstructions, buoy markers, and navigation marks (shore-based racons, radar beacons) to assist in navigation and collision avoidance.
Fixed Satellite Service (FSS) Earth Stations	3700-4200	Used to receive downlink transmissions from geosynchronous satellites for a variety of applications, including voice, data, and video services for Federal agencies.
RF Altimeters	4200-4400	Provides pilots of civil and military aircraft and air traffic controllers with information on the height of an aircraft above ground level (AGL).
Microwave Landing System (MLS)	5030-5091	Used for precision approach and landing of aircraft.
TDWR*	5600-5650	Provides quantitative measurements of gust fronts, wind shear, micro bursts, and other weather hazards for improving the safety of operations at major airports.

* Note: The TDWR does not operate in the restricted frequency bands.

SECTION 2

DISCUSSION OF NPRM REGARDING UWB TRANSMISSION SYSTEMS

2.1 INTRODUCTION

The FCC NPRM discusses rules and regulations for UWB transmission systems that would be incorporated under 47 CFR Part 15.[16] This section discusses FCC proposed Part 15 Rules for emission limits as a basis for conducting an EMC analysis. NTIA has converted the Part 15 Limits, which are stated as field strengths measured at a specific distance, to the transmitting device's EIRP levels. Also, measurement procedures currently used by the FCC in assessing compliance with rules are identified since they are a key to establishing an EMC analysis procedure.

2.2 PROPOSED UWB DEVICE EMISSION LIMITS

2.2.1 Average and Quasi-Peak Power Limits

The FCC sought comments on the sufficiency of the existing Part 15 general emission limits to protect other users, especially radio operations within the restricted frequency bands from harmful interference or whether different limits should be applied to UWB systems.[17]

Section15.209 of the FCC's rules establishes general requirements for radiated emission limits for intentional radiators, which are reproduced below in TABLE 2-1. Conformance to the field strength limits is assessed using an International Special Committee for Radio Interference (CISPR) quasi-peak detector except for the frequency bands 9-90 kHz, 110-490 kHz and above 1000 MHz. In these three bands, an average detector is used.[18] Also, included in TABLE 2-1 is the measurement reference bandwidth and the EIRP calculated using the equation in note (b) of the table.

Regarding measurements using an average detector, the FCC's measurement procedure in an average logarithm detector process is not equivalent to an root-mean-square (RMS) detector process. Measurements have shown that the average logarithm is largely insensitive to energy contained in low-duty-cycle, high amplitude signals. This results in Part 15 measurement values that can be substantially lower

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16 *See* UWB NPRM, *supra* note 2, at ¶ 1.

17 *Id.* at ¶ 34.

18 The FCC measurement method calls for video filtering in which a 1 MHz bandwidth filter is used in conjunction with a video filter with a bandwidth not less than 10 Hz .

(10-15 dB) than the RMS power in a UWB signal.[19] Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, NTIA measurements and analysis indicates that the RMS detector function better quantifies the potential interference affects of UWB signals than the current average-logarithmic detector function used for Part 15 compliance.[20]

TABLE 2-1
Section 15.209 Radiated Emission Limits

Frequency (MHz)	Field Strength[a] (μV/m)	Measurement Distance (m)	Reference Measurement Bandwidth (kHz)	EIRP[b] (dBm)
0.009–0.015	2400/F(kHz)	300	0.30	$11.8 - 20\log_{10}F(kHz)$
0.015–0.490	2400/F(kHz)	300	10	$11.8 - 20\log_{10}F(kHz)$
0.490–1.705	24000/F(kHz)	30	10	$12.3 - 20\log_{10}F(kHz)$
1.705–30.0	30	30	10	-45.7
30–88	100[c]	3	100	-55.3
88–216	150[c]	3	100	-51.7
216–960	200[c]	3	100	-49.2
960-1000	500	3	100	-41.3
above 1000	500	3	1000	-41.3

a) Below 1000 MHz, the field strength emission limits specified are based on measurements employing a CISPR quasi-peak detector, except for the frequency bands: 9-90 kHz, 110-490 kHz, and above 1000 MHz. Emission limits in these three frequency bands are based on measurements employing an average-logarithmic detector.

b) The field strength emission limits were converted to an EIRP level in dBm using the following equation.

$$EIRP(dBm) = E_o(dB\mu V/m) + 20\log_{10}D(m) - 104.8$$

c) Except for perimeter protection systems and biomedical telemetry systems, fundamental emissions from intentional radiators operating under Section 15.209 shall not be located in the frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz, or 470-806 MHz, except as specified in 15.231 & 15.241.

The FCC also seeks comments on proposals that emissions from UWB devices, other than ground penetrating radars and possibly through wall imaging systems, operating below approximately 2 GHz be at least 12 dB below the general emission limits of 47 CFR

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[19] *See* ITS Report, *supra* note 14, at §8.4 (Items 5, 6, and 7).

[20] *Id.* at §6.4.6 and A.2.2.

Section 15.209. Comments are requested on whether additional attenuation below 2 GHz is possible or necessary and whether the proposed reduction in the emission levels should apply to all emissions below 2 GHz or only to emissions below 2 GHz that fall within the restricted frequency bands shown in 47 CFR Section 15.205. The FCC also seeks comments on any changes to the technical standards or operational parameters of UWB transmitters that could be employed to facilitate the operation of these products below 2 GHz.[21]

2.2.2 Peak Power Limits

Section15.35 of the FCC rules states that when average radiated emission measurements are specified in the regulations, the radio frequency emissions, measured using instrumentation with a peak detector function, can be no more than 20 dB above the maximum permitted average limit. The FCC has applied this 20 dB limit to the total peak power in the transmitted waveform. Thus, the peak power limit is measured in a bandwidth sufficient to capture the total peak power, and **not** measured in a 1 MHz reference bandwidth.

The FCC states in the NPRM that a limit on peak emissions is necessary to reduce the potential for UWB emitters to cause harmful interference to radio operations above 1 GHz.[22] Two methods of measurement to assess conformity are also presented for comment: 1) the peak level of the emission when measured over a bandwidth of 50 MHz which the FCC states is comparable to the widest victim receiver likely to be encountered; 2) the absolute peak output of the emission over its entire bandwidth.[23] For the peak signal strength measured over the 50 MHz bandwidth, the FCC seeks comments on proposals to apply a 20 dB limit above the maximum permitted average emission level.[24] For the absolute peak limit for the emission over its entire bandwidth, the FCC seeks comments on proposals that it be variable based on the amount of the -10 dB bandwidth of the UWB emission exceeds 50 MHz.[25] Appendix D of this report addresses peak power of UWB signals in a 50 MHz bandwidth.

2.3 SIGNAL GATING

The FCC's NPRM does not address gating of the UWB signal. Gating is the turning on and off of the UWB signal for some period of time. The gating percent is defined as the percent of the time the signal is on. For example, a UWB signal that has a 25 percent gated signal would have the signal on for 25 percent of the period and off for 75 percent

21 *See* UWB NPRM, *supra* note 2, at ¶ 39.

22 *Id.* at ¶ 42.

23 *Id.*

24 *Id.* at ¶ 43.

25 *Id.*

of the period. NTIA conducted measurements on several UWB devices which implemented gating of the transmitted waveform. There are several questions concerning procedures for establishing emission limits for UWB devices implementing gating. For example, will the average (RMS) power be measured only when the signal is on, or will the average (RMS) power be measured over the entire period?

2.4 SUMMARY OF PROPOSED EMISSION LIMITS

Although the FCC states that the general emission limits for intentional radiators contained in 47 CFR § 15.209 appears to be appropriate for UWB operations, they sought comments on the sufficiency of the existing Part 15 general emission limits to protect other users, especially radio operations within the restricted frequency bands from harmful interference or whether different limits should be applied to UWB systems. Also, the FCC states that a limit on peak emissions is necessary to reduce the potential for UWB emitters to cause harmful interference to radio operations above 1 GHz; however, at this time no peak power limit or measurement procedure for UWB devices has been adopted. The FCC did not propose any change to the measurement reference bandwidths for average (RMS) power (see TABLE 2-1).

SECTION 3

ELECTROMAGNETIC COMPATIBILITY ANALYSIS PROCEDURE

3.1 INTRODUCTION

This section discusses the analysis procedures used to determine the maximum permitted EIRP level and minimum distance separation which will ensure compatibility between UWB devices and other telecommunications systems. A description of the EMC analytical model (which uses a commercially available spreadsheet) used to assess compatibility is provided. Also, the analysis results are compared with measured data taken on two telecommunication systems.

3.2 GENERAL EMC ANALYSIS APPROACH

Considering the FCC is seeking information on appropriate emission limits for UWB devices, the EMC analysis must be focused on determining the permitted EIRP of UWB devices which will ensure compatibility. In establishing a permitted EIRP level, it is necessary to establish a reference measurement bandwidth and a spectrum analyzer detector function. The measurement reference bandwidth is required to convert the UWB signal power level at the receiver input to the UWB signal power level at the victim receiver IF output. The identification of a detector function is also key to ensuring that the establishment of any standards will be based on a particular spectrum analyzer detector function.

Based on the UWB NPRM (see Section 2) and the NTIA measurements of UWB device characteristics, the following EMC analysis approach was taken.

1. The analysis was based on a spectrum analyzer RMS detector function for average power.[26] This average (RMS) level is **not** equivalent to the Part 15 log-average level. See ITS Report.[27]

2. The measurement reference bandwidth, B_{ref}, for establishing the EIRP limit was based on the information in TABLE 2-1 of Section 2 (e.g., for systems operating above 1000 MHz, the measurement reference bandwidth is 1 MHz).

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[26] Throughout this report average power is based on the Root-Mean-Square (RMS) voltage of the UWB signal. For clarity, average power will be written as average (RMS) power, and the EIRP average power spectral density will be expressed as EIRP dBm/MHz RMS.

[27] *See* ITS Report, *supra* note 14, at § 8.4 (Items 5, 6, and 7), and A.2.2.

3. A Bandwidth Correction Factor (BWCF) was developed to correct for the average and peak power level of the UWB signal at the victim receiver IF output. The BWCF was normalized to the average (RMS) power level in the measurement reference bandwidth, B_{ref}.

4. The analysis did not limit the peak to average (RMS) power ratio (e.g., 20 dB in a 50 MHz bandwidth) since a peak to average (RMS) power ratio limit for UWB devices has not been established. The FCC has proposed a peak power limit of 20 dB in a 50 MHz bandwidth.[28] Appendix D of this report address peak power of UWB signals in a 50 MHz bandwidth.

5. The analysis assumes that for gated transmissions the average (RMS) power was measured over one or more gated periods. That is, it was not averaged over only the period when the pulse train is on.

6. The required distance separation was based on an EIRP limit of UWB devices equal to -41.3 dBm/MHz (RMS). The systems that were studied operate above 1000 MHz. Therefore, the EIRP limit was based on the emission limit given in TABLE 2-1 of Section 2 for the frequency range above 1000 MHz.

3.3 ESTABLISHMENT OF UWB DEVICE EMISSION LIMITS

The maximum permitted EIRP level was determined using the following equation:

$$EIRP_{MAX} = + I_{MAX} - BWCF_{A/P} - G_R(\theta) + L_P + L_R + DCF + GF \qquad (3\text{-}1)$$

where:

$EIRP_{MAX}$ = the maximum permitted EIRP of the UWB device, in dBm/B_{ref} (RMS).

I_{MAX} = the maximum permissible average or peak interference level at the receiver input, in dBm.

$BWCF_{A/P}$ = the receiver BWCF to correct for the power of the UWB signal at the victim receiver IF bandwidth (B_{IF}) output relative to the Part 15 measurement reference bandwidth, B_{ref} (see TABLE 2-1, Section 2). The BWCF is normalized to the average (RMS) power level in a 1 MHz bandwidth, and provides a correction for the UWB signal average (RMS) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output, in dB.

[28] *See* UWB NPRM, *supra* note 2, at ¶ 42.

$G_R(\theta)$ = the victim receiver elevation pattern antenna gain in the direction of the UWB device, in dBi.

L_P = the propagation loss between transmitting and receiving antennas, in dB.

L_R = the insertion loss (loss between the receiver antenna and receiver input), in dB.

DCF = a detector correction factor (DCF) to correct for the type of detector used in the Part 15 measurement procedure, quasi-peak or average detector (see TABLE 2-1 Section 2, Note "a").

GF = a gating factor (GF) to correct for the increase in peak power when the UWB device transmissions are gated.

3.4 MAXIMUM PERMISSIBLE INTERFERENCE LEVEL

The initial step in determining the maximum permitted EIRP level and required minimum separation distance to ensure compatibility is to establish a maximum permissible interference level, I_{MAX}, which requires the identification of a protection criterion for each system. Generally the protection criteria are specified in terms of an average or peak interference-to-noise ratio (I/N) or signal/carrier-to-average or peak interference ratio (S/I or C/I). Appendix A contains the protection criteria for the radiocommunication systems considered in this study.

$$I_{MAX} = I/N + N, \text{ or} \quad (3\text{-}2)$$

$$I_{MAX} = S - S/I \quad (3\text{-}3)$$

where: I/N = the maximum permissible average or peak interference-to-noise ratio at the receiver IF output (detector input) necessary to maintain acceptable performance criteria, in dB.

N = the receiver inherent noise level at the receiver IF output referred to the receiver input, in dBm.

S/I = minimum signal-to-average or peak Interference ratio at the receiver IF output (detector input) necessary to maintain acceptable performance criteria, in dB. Sometimes a carrier-to-interference ratio (C/I) is used.

S = desired signal level at the receiver input, in dBm. Sometimes a carrier level (C) is used.

For a known receiver IF bandwidth and receiver noise figure (NF) or system noise temperature, the receiver inherent noise level is given by:

$$N = -114 \text{ dBm} + 10\log B_{IF}(\text{MHz}) + NF \quad (3\text{-}4a)$$

$$N = -144 \text{ dBm} + 10\log B_{IF}(\text{kHz}) + NF \quad (3\text{-}4b)$$

or

$$N = KT_sB_{IF} = -198.6 \text{ dBm/}^oK/Hz + 10\log T_s(^oK) + 10\log B_{IF}(\text{Hz}) \quad (3\text{-}4c)$$

where: B_{IF} = the receiver IF bandwidth (see equations for units)
NF = the receiver NF, in dB
K = Boltzmann's constant, 1.38×10^{-23}, in Watts/^{o}K/Hz
T_s = the system noise temperature, in degrees Kelvin

3.5 BANDWIDTH CORRECTION FACTOR (BWCF)

The following is a discussion of the procedure for calculating the BWCF for various UWB modulation types and ranges of victim receiver IF bandwidths (B_{IF}) relative to the Part 15 measurement reference bandwidth (B_{ref}) given in TABLE 2-1 for various frequency bands. The equations are based on measurements and simulations contained in the ITS report.[29] The BWCF equations are normalized to the average (RMS) power level in a 1 MHz bandwidth, and provide a correction for the UWB signal average (RMS) power level ($BWCF_A$) or peak power level ($BWCF_P$) at the victim receiver IF output, in dB. The equations do not include any additional peak power factor for gated UWB signals. Also, the equations assume that the UWB device emissions are uniform across the receiver IF bandwidth. That is, the receiver IF bandwidth is less than 1/T, where T is the pulse width of the UWB device.

Part 15 limits above 1000 MHz are specified as an average power limit of 500 μv/m at 3 meters (Part 15.209) which equates to -41.3 dBm/MHz EIRP.[30] The total peak power (measured in a bandwidth to capture the total peak power) is limited to 20 dB above the maximum permitted average power (Part 15.35b). To assess the compatibility of UWB systems with other telecommunication systems, both average and peak power levels at the receiver IF output (detector input) of the telecommunication systems is required. Therefore, a BWCF must be determined to correct for the difference in power as measured in the Part 15.209 reference bandwidth (B_{ref}) and the receiver IF bandwidth (B_{IF}) of the victim radiocommunication system. Since the victim receiver performance degradation may be a function of the UWB signal average power level or peak power level at the receiver IF output, a correction factor for the UWB signal average (RMS) power level ($BWCF_A$) and peak power level ($BWCF_P$) at the victim receiver IF output are provided.

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[29] *See* ITS Report, *supra* note 14, at Section 8, Appendix B, and Appendix D.

[30] The FCC average power level is a log-average power level based on their measurement procedure. The BWCF is normalized to the average (RMS) power level.

The UWB signal time waveform and power level at the victim receiver IF output is a function of the type of modulation used in the UWB device and the victim receiver's IF bandwidth. The major UWB modulation parameters affecting the UWB time waveform and power level at the receiver IF output are the pulse repetition frequency (PRF), the pulse width (T), and the use of time dithering and/or gating of the UWB device.

Dithering, as referred to in this report, is the intentional variation in the interpulse period. One method of dithering a signal is to use the random amplitude of a white-noise source which results in a smearing of the spectral lines, which gives a more noise-like spectra. Another method is to control the pulse-to-pulse timing using a pseudo-random code. However, the code length has an influence on whether the signal exhibits characteristics closer to a random noise-like signal.

Note: The limiting conditions associated with each of the Equations 3-5 through 3-14, must be met to ensure applicability of the equations.

3.5.1 UWB Non-Dithered Pulse Trains

UWB systems not using time dithering will produce spectral lines in the frequency domain with a separation equal to the PRF. For $B_{IF} \leq PRF$, the time waveform at the victim receiver IF output will be continuous in nature (continuous wave, CW-like), if centered on a spectral line) and its amplitude is dependent on the power in the spectral line of the UWB device, and the tuned frequency and IF selectivity characteristics of the victim receiver. For a CW-like signal, the average and peak power level are equal. For $B_{IF} > 1.7\ PRF$, the time waveform at the victim receiver IF output will be pulse-like with the amplitude and pulse width being dependent on the receiver IF bandwidth.

3.5.1.1 Average (RMS) Power BWCF Transfer Properties for Non-Dithered UWB Signals

For $B_{IF} \leq PRF$, the average (RMS) power $BWCF_A$ can be expressed as:

$$BWCF_A = 0, \quad \text{for } B_{IF} \leq PRF \text{ and } B_{Ref} < PRF \tag{3-5}$$

$$BWCF_A = 10\log(PRF/B_{Ref}), \quad \text{for } B_{IF} \leq PRF \text{ and } B_{Ref} \geq PRF \tag{3-6}$$

For $B_{IF} > PRF$, the average (RMS) power of the UWB signal at the receiver will vary as a 10log trend for $PRF \leq B_{IF} < 1/T$.

$$BWCF_A = 10\log_{10}(B_{IF}/PRF), \quad \text{for } PRF \leq B_{IF} < 1/T \text{ and } B_{Ref} < PRF \tag{3-7}$$

$BWCF_A = 10\log_{10}(B_{IF}/B_{Ref})$,   for $PRF \le B_{IF} < 1/T$ and $B_{Ref} \ge PRF$ (3-8)

For $B_{IF} \ge 1/T$, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

3.5.1.2 Peak Power BWCF Transfer Properties for Non-Dithered UWB Signals

For $B_{IF} \le 0.45\ PRF$, the peak power $BWCF_P$ can be expressed as:

$BWCF_P = 0$, for $B_{IF} \le 0.45\ PRF$ and $B_{Ref} < PRF$ (3-9)

$BWCF_P = 10\log(PRF/B_{Ref})$,   for $B_{IF} \le 0.45\ PRF$ and $B_{Ref} \ge PRF$ (3-10)

For $B_{IF} > 0.45\ PRF$, the peak power of the UWB signal at the receiver will vary as a 20log bandwidth trend for $0.45\ PRF \le B_{IF} < 1/T$.

$BWCF_P = 20\log_{10}[B_{IF}/(0.45 \times PRF)]$,   for $0.45\ PRF \le B_{IF} < 1/T$ and $B_{Ref} < PRF$ (3-11)

$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2\times B_{Ref} \times PRF)]$,   for $0.45\ PRF < B_{IF} < 1/T$ and $B_{Ref} \ge PRF$ (3-12)

For $B_{IF} \ge 1/T$, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

Figures 3-1 and 3-2 show representative BWCF curves for 0.1 MHz and 10 MHz PRF non-dithered UWB signals.

3.5.2 UWB Dithered Pulse Trains

The receiver IF output response to a time dithered UWB signal may appear noise-like or pulse-like, and depends on the ratio of the UWB signal PRF to the victim receiver IF bandwidth (B_{IF}). The degree to which the receiver output response appears noise-like depends on two factors: 1) the percentage dither of the inter-pulse period, and 2) the randomness of the dither process. The receiver BWCF transfer properties given below are based on 50 percent dithering with a random algorithm. That is, the pulse delay will vary randomly between 0 percent and 50 percent of the interpulse period with a uniform distribution.

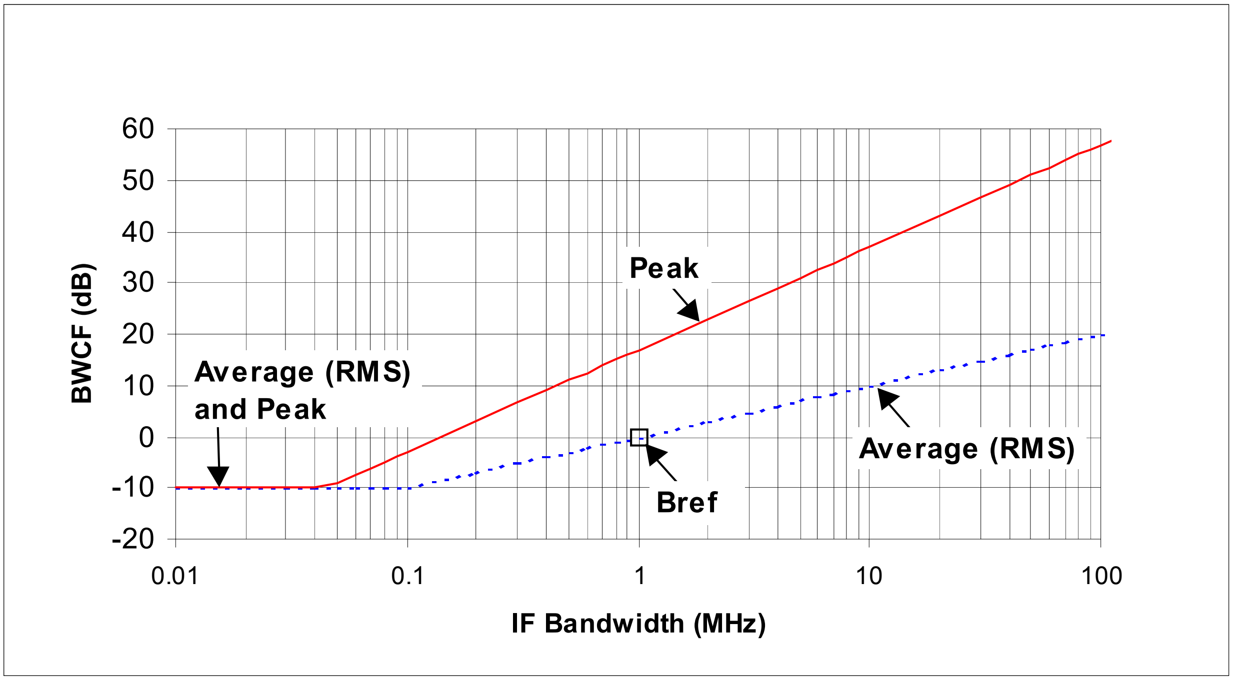

Figure 3-1. BWCF for 0.1 MHz PRF Non-dithered UWB Signal.

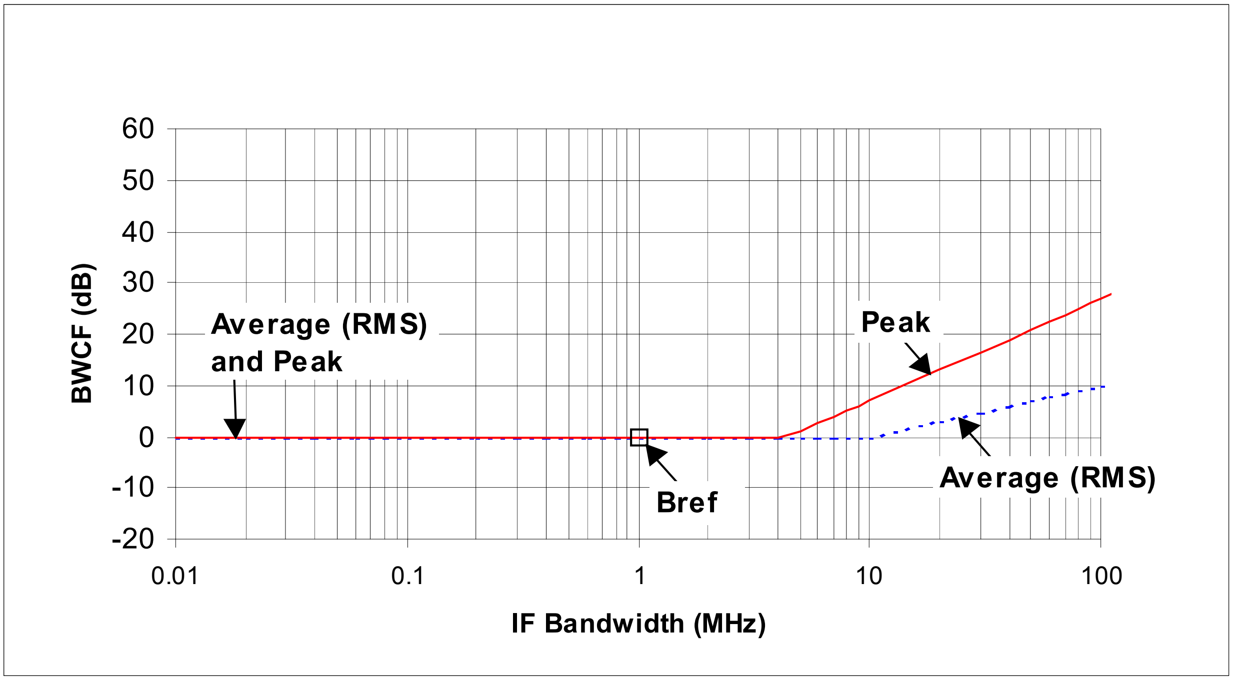

Figure 3-2. BWCF for 10 MHz PRF Non-dithered UWB Signal.

In general, for dithered UWB signals, the receiver IF output response appears noise-like for $B_{IF} \leq 0.2$ PRF and pulse-like for B_{IF} **>** 1.7 PRF. Thus, there is a transition region, 0.2 PRF < B_{IF} < 1.7 PRF, where the receiver response transitions from noise-like to pulse-like. When the UWB signal appears noise-like at the receiver IF output, the average (RMS) power of the noise-like signal should be used in assessing receiver performance degradation. However, when the UWB signal appears pulse-like at the receiver IF output, either average or peak power should be used in assessing receiver performance degradation based on receiver desired signal processing. Therefore, both average and peak UWB signal receiver transfer properties for BWCF are provided below.

3.5.2.1 Average (RMS) Power BWCF Transfer Properties for Dithered UWB Signals

For $B_{IF} \leq$ 0.2 PRF, the time waveform at the victim receiver IF output will be more noise-like with the amplitude being dependent on the IF bandwidth of the victim receiver. For noise-like signals at the receiver IF output, the average (RMS) power will change with a 10log bandwidth trend. As the UWB signal transitions to become pulse-like at the receiver IF output, 0.2 PRF < B_{IF} < 1.7 PRF, and then becomes pulse-like, $B_{IF} \geq$ 1.7 PRF, the average (RMS) power of the UWB signal will also continue to change with a 10log bandwidth trend. Therefore, for a 50 percent time dithered UWB signal, the average (RMS) power BWCF can be expressed as:

$$BWCF_A = 10\log_{10}(B_{IF}/B_{Ref}), \quad \text{for any value of } B_{IF} \text{ and } B_{Ref} \qquad (3\text{-}13)$$

For $B_{IF} \geq$ 1/T, the receiver IF output pulse width is equal to the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

3.5.2.2 Peak Power BWCF Transfer Properties for Dithered UWB Signals

For B_{IF} < 0.2 PRF, as mentioned previously, the UWB signal time waveform at the victim receiver IF output will be noise-like and only average (RMS) power should be used to assess receiver performance degradation. Therefore, Equation 3-13 should be used; however, the receiver IF bandwidth (B_{IF}) **must** be less than 0.2 PRF of the UWB signal.

For $B_{IF} \geq$ 0.2 PRF, as the signal transitions to become pulse-like it may be appropriate to use peak power of the UWB signal at the receiver IF output to assess receiver performance degradation. The peak amplitude of the UWB signal increases as a 20log bandwidth trend, and the pulse width at the receiver IF output will be approximately equal to the impulse response of the IF filter ($1/B_{IF}$). The peak power BWCF is given by:

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2\times B_{Ref}\times PRF)], \quad \text{for } 0.2\ PRF < B_{IF} < 1/T \text{ and } B_{Ref} = \text{any value} \qquad (3\text{-}14)$$

For $B_{IF} \geq 1/T$, the receiver IF output pulse width is equal to or greater than the UWB transmitter pulse width. The BWCF does not increase above the level $B_{IF} = 1/T$.

Figures 3-3 and 3-4 show representative BWCF curves for 0.1 MHz and 10 MHz PRF time dithered UWB signals.

3.6 DETECTOR CORRECTION FACTOR (DCF)

A DCF is needed when the UWB signal is dithered and the receiver response at the IF output is noise-like, and the Part 15 measurement procedure requires quasi-peak detection (see TABLE 2-1, Note "a"). For noise-like responses at the receiver IF output, the receiver degradation should be based on the average (RMS) power of the noise-like signal, and not the quasi-peak level of the noise-like signal. Based on measurements, there is approximately an 8 dB difference between the quasi-peak level and the average level of a noise-like signal. Therefore, for receiver systems operating below 1000 MHz, where quasi-peak detection is required, the DCF should equal -8 dB.

3.7 GATING FACTOR (GF)

Some UWB devices turn the pulse train off for a period of time which is referred to as gating. The percentage of time the pulse train is on is referred to as the gating percent. That is. 25 percent gating means that the signal is on for one-quarter of a period of time, and off for three-quarters of the period. The average (RMS) power level of the UWB signal will depend on the period of time over which the signal is measured. For example, if the average (RMS) power level is measured over the entire gating period, the average (RMS) power level will be lower than if the average (RMS) power level is measured only during the time the pulse train is gated on. If the average (RMS) power level is measured over the gating period, this could result in a higher peak to average (RMS) power ratio if the UWB signal power level was increased to maintain a specified emission average (RMS) power limit. To correct for this increase in peak-to-average (RMS) power ratio, the following correction should be made when peak power is used in assessing performance degradation:

$$GF = 10\log_{10} GP/100 \quad (3\text{-}15)$$

where: GP = the percentage of time the signal is transmitted (gated on)

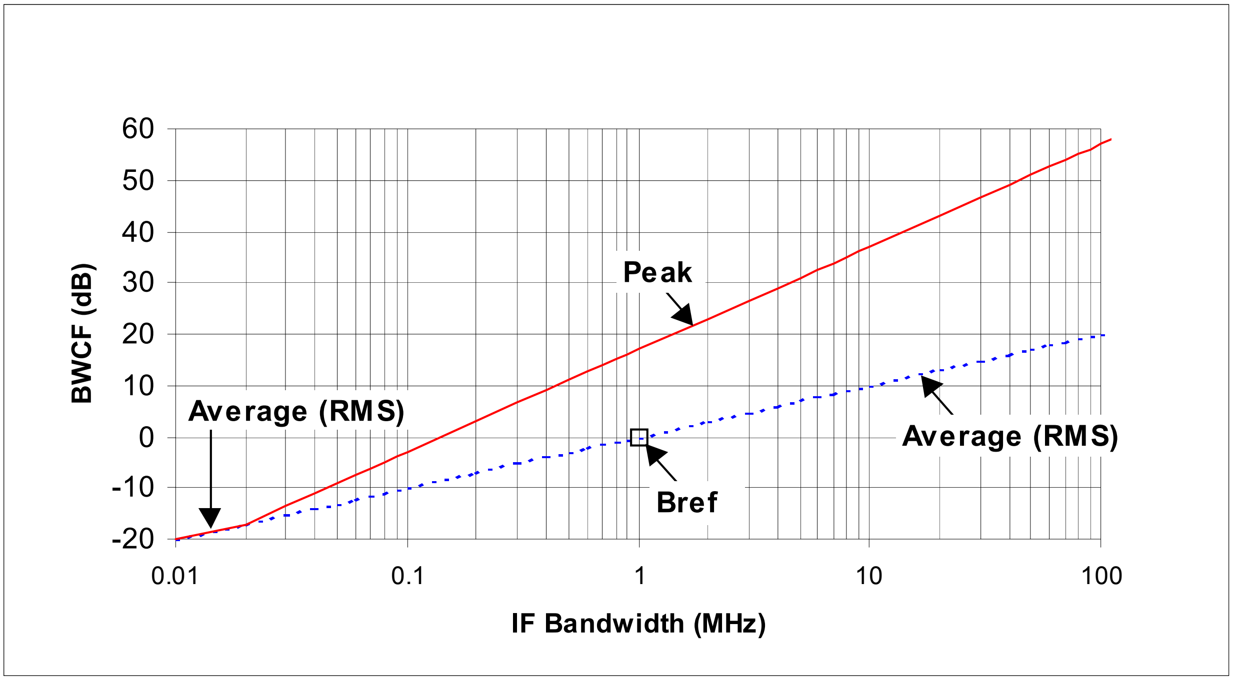

Figure 3-3. BWCF for 0.1 MHz PRF Dithered UWB Signal.

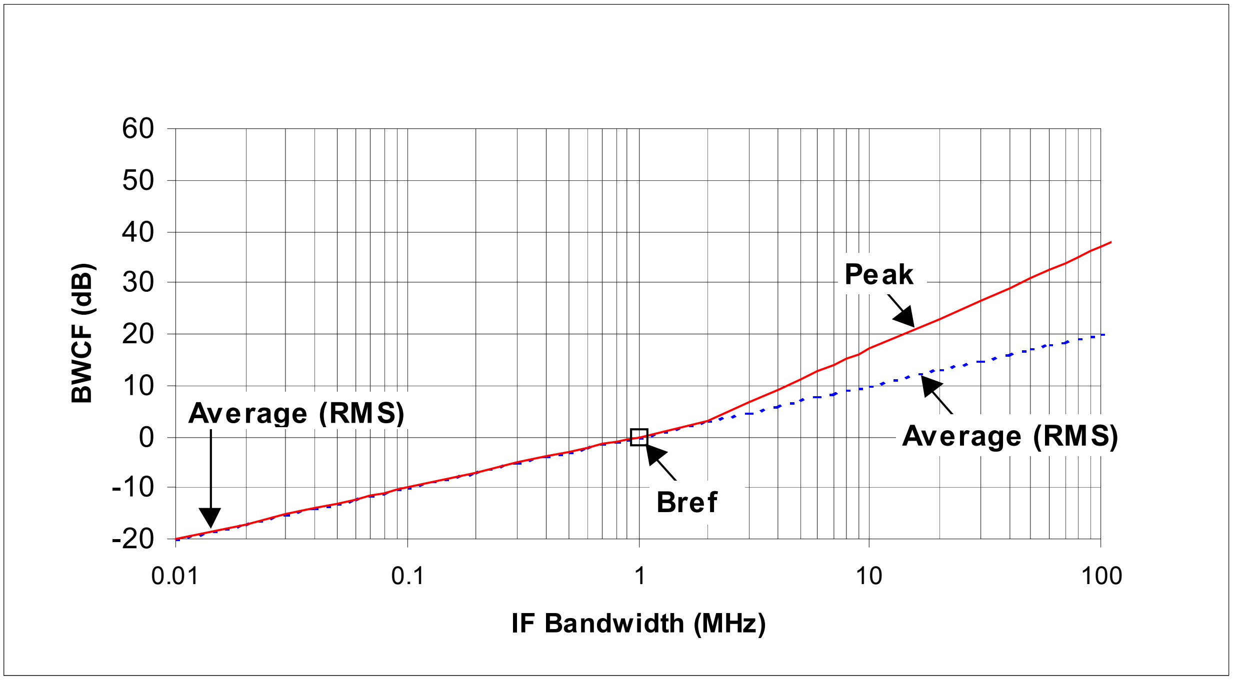

Figure 3-4. BWCF for 10 MHz Dithered UWB Signal.

3.8 SYSTEM CHARACTERISTICS

Representative system characteristics for the Federal telecommunication systems and UWB devices related to the parameters in Equations 3-1 through 3-15 were identified. The following representative UWB characteristics were chosen to conduct the EMC analysis.

PRF = Pulse repetition frequency, in pulses per second, nominal range is 1 kHz to 500 MHz.
Dither = 0% (non-dither) or 50%
Gating = 0% or 50%
Antenna type = Omni (0 dBi gain)
Antenna height = 2 and 30 meters

The Federal telecommunication system characteristics used in the EMC analysis are contained in Appendix A.

3.9 DESCRIPTION OF EMC ANALYTICAL MODEL

A series of spreadsheets were developed for each system to implement Equations 3-1 through 3-15 and the associated routines necessary to compute the propagation loss and antenna vertical off-axis gains. The ITS Irregular Terrain Model (ITM)[31] of radio propagation which is based on electromagnetic theory and on statistical[32] analysis of both terrain features and radio measurements was used to predict the median attenuation as a function of distance and the variability of the signal in time and space. The antenna patterns were coded such that the gain could be determined as a function the relative heights of the system of interest and the UWB source and the distance between them. This approach provides a more accurate estimation of the received power level from the UWB device than using the main beam gain of the receivers and freespace loss.

For the purpose of this analysis, Equation 3-1 has been modified to exclude the DCF and GF terms because, in the case of the DCF, only systems above 1 GHz are analyzed, and,in the case of the GF, all runs were made for 100 percent gating (0 dB GF for peak interference protection criteria).

This analysis procedure answers two questions by using Equation 3-16: 1) what is the maximum EIRP level allowable for a UWB device, assuming only a relatively small

[31] National Telecommunications and Information Administration, U.S. Dept. of Commerce, A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode, NTIA Report 82-100, at 5-1 (April 1982), [hereinafter ITM Report].

[32] The time, location, and confidence levels used in the analysis were 10%, 50%, and 50% respectively and the terrain delta height factor was set to zero.

separation distance, and 2) what distance separation is necessary if a UWB device were to radiate at the proposed EIRP level of -41.3 dBm/MHz RMS? Both questions may be simultaneously answered for a given set of parameters by using the techniques used in the spreadsheet.

$$EIRP_{MAX} = + I_{MAX} - BWCF_{A/P} - G_R(\theta) + L_P + L_R \qquad (3\text{-}16)$$

In Equation 3-16, both the propagation term, L_P, and the antenna gain, $G_R(\theta)$, are functions of the distance between the transmitter and receiver, while the other terms (I_{MAX}, $BWCF_{A/P}$, and L_R) are not a function of the separation distance. Given fixed antenna heights for both the transmitter and receiver, $G_R(\theta)$ is a function of distance, and the relative difference between the antenna heights. The angle theta (θ) is computed from the arctan($|h_r-h_t|$/distance). Appendix A contains the antenna elevation gain patterns as a function of theta for each of the systems analyzed, and the protection criteria used in using Equations 3-2 and 3-3 to calculate the maximum permissible interference level, $I_{MAX.}$

After equations that were not functions of distance (i.e., I_{MAX}, BWCF) were solved, Equation 3-16 was solved for $EIRP_{MAX}$ at 10 meter increments in the distance range from 200 meters out to a distance of 15 kilometers more or less as the individual situation required. The distance between antennas, the off-axis angle between antennas, off-axis gain, propagation loss, and computed EIRP were then saved to a table in the sreadsheet for later reference and plotting. TABLE 3-1 is a portion of one of the tables that was saved in the analysis of the ARSR-4. The data from TABLE 3-1 is plotted in Figure 3-5. After the table was created, the PRF of the UWB device (which affects the BWCF) was changed and the calculations of $EIRP_{MAX}$ were performed again and saved in a table. The process was repeated for the PRFs of 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz saving the tables for each PRF. These calculations were again repeated for the two cases of dithered and non-dithered UWB sources which again affects the BWCF. The above processes are then repeated again for a different UWB antenna height which affects the off-axis antenna gain, thereby, influencing the $EIRP_{Max}$. The computations are reiterated for 7 PRFs, for each of two UWB cases (dithered and non-dithered) and for antenna heights of 2 and 30 meters. TABLE 3-2 is a summary of the maximum permitted EIRP (with minimal distance constraints) and distance constraints (based on the level of -41.3 dBm/MHz RMS) of 14 cases (7 PRFs dithered, and 7 PRFs non-dithered) for a UWB antenna height of 2 meters. The program computes and saves similar tables for a 30 meter antenna height.

TABLE 3-1
EIRP Calculation Results for 10 MHz PRF, non-dithered, and 2 meter UWB Antenna Height

Distance (meters)	theta (deg)	Antenna gain	ITM Propagation Loss (dB)	EIRP (dBm)
200	5.58	2.4	80.4	-42.4
210	5.32	2.7	80.8	-42.2
220	5.08	2.9	81.2	-42.1
230	4.86	3.3	81.6	-42.1
240	4.66	3.7	82.0	-42.1
250	4.47	4.1	82.3	-42.1
260	4.30	4.4	82.7	-42.1
270	4.14	4.7	83.0	-42.1
280	3.99	5.0	83.3	-42.1
290	3.86	5.6	83.6	-42.3
300	3.73	6.1	83.9	-42.6
310	3.61	6.6	84.2	-42.8
320	3.50	7.0	84.5	-42.9
330	3.39	7.9	84.8	-43.5
340	3.29	8.6	85.0	-44.0
350	3.20	9.4	85.3	-44.5
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...
14970	0.07	38.04	135.52	-22.92
14980	0.07	38.04	135.53	-22.91
14990	0.07	38.04	135.55	-22.89
15000	0.07	38.04	135.56	-22.88

Ultimately, the spreadsheet determines from TABLE 3-1 and records in TABLE 3-2, the maximum permitted EIRP and minimum separation distance which are illustrated in Figure 3-5. The lowest point of the curve on the graph is the highest, or maximum allowable, EIRP from a UWB device, that does not exceed the interference criteria of the receiver of interest for a given PRF. It can be seen from Figure 3-5 that, in this instance, this level is approximately -60 dBm. The figure also shows that if the EIRP level is equal to -41.3 dBm/MHz EIRP, the UWB device must maintain a separation distance of approximately 5.5 km in order not to exceed the interference threshold of the receiver. One very important assumption in this example is the UWB antenna height. In this example, the UWB antenna height is assumed to be 2 meters and the receiving antenna is at a height of 22 meters (22 meters is the mean of actual measured antenna heights of all ARSR-4s in the United States). This factor is the reason that as the distance between the antennas is decreased to distances of less than one kilometer, the allowable EIRP increases (the line curves upwards). This is because the UWB is not in the receiving antenna's main beam. That is, the gain of the receiver is much less underneath the antenna than in front of the antenna.

Figure 3-6 graphs the same scenario as in Figure 3-5 except the UWB antenna is assumed to be at a height of 30 meters, as if it were mounted on a building or tower. As may be observed from Figure 3-6, increasing the UWB antenna height increases the antenna coupling (i.e., puts the UWB source in the main beam of the receiver antenna) and hence, increases the minimum required separation distance to approximately 15 km from 5.5 km, and conversely, reduces the maximum allowable EIRP to over -80 dBm/MHz RMS from -60 dBm/MHz RMS.

Also of note in both figures is the fact that the distance and EIRP levels are not recorded for distances of less than 200 meters. For this receiver's high gain antenna in this example, distances of less than 200 meters are not included because of uncertainty in the antenna gain characteristics.

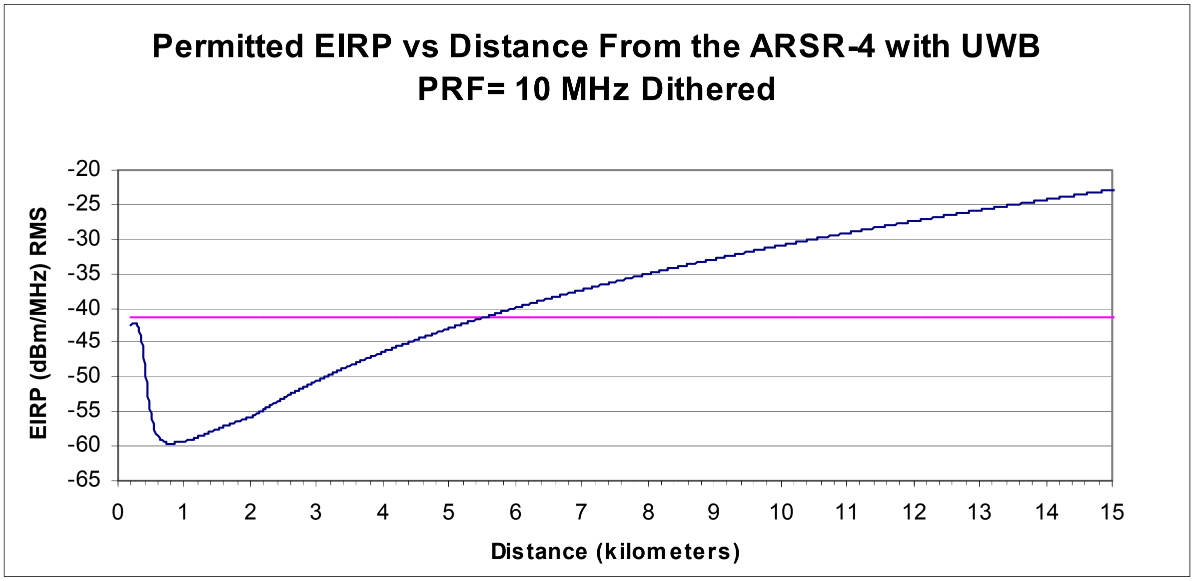

Figure 3-5. Maximum EIRP vs. Distance for 2 Meter UWB Antenna Height.

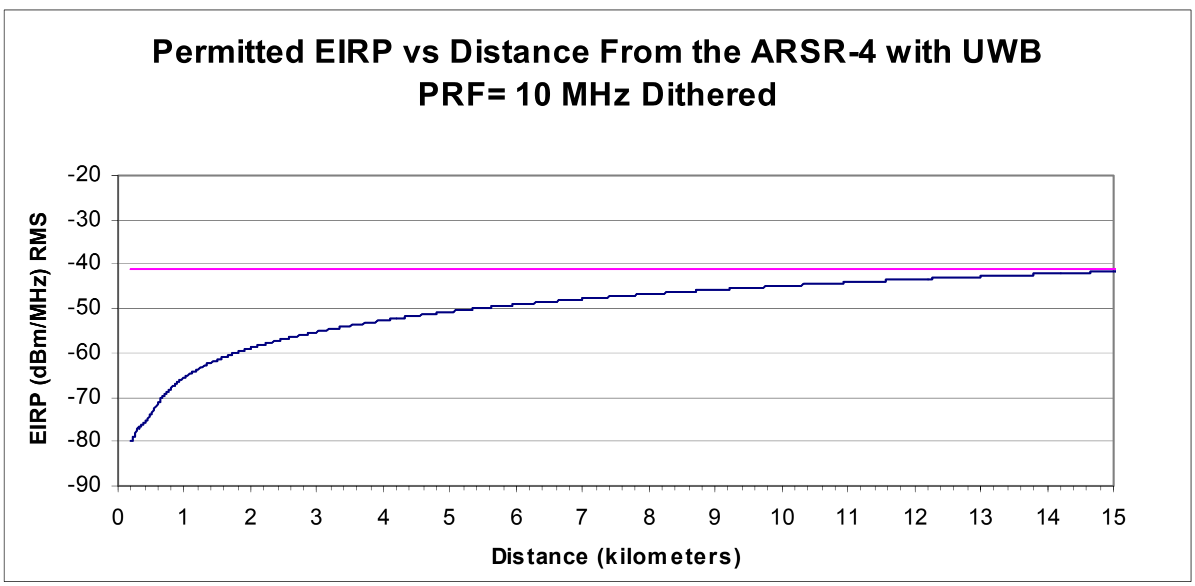

Figure 3-6. Maximum EIRP vs. Distance for UWB Antenna Height of 30 Meters.

TABLE 3-2
Two Meter UWB Antenna Height Summary

Mode	PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
Non-Dithered	0.001	-1.6	-59.6	-18.3	5.54
	0.01	-1.6	-59.6	-18.3	5.54
	0.1	-1.6	-59.6	-18.3	5.54
	1	0.0	-61.2	-19.9	6.11
	10	0.0	-61.2	-19.9	6.11
	100	0.0	-61.2	-19.9	6.11
	500	0.0	-61.2	-19.9	6.11
Dithered	0.001	-1.6	-59.6	-18.3	5.54
	0.01	-1.6	-59.6	-18.3	5.54
	0.1	-1.6	-59.6	-18.3	5.54
	1	-1.6	-59.6	-18.3	5.54
	10	-1.6	-59.6	-18.3	5.54
	100	-1.6	-59.6	-18.3	5.54
	500	-1.6	-59.6	-18.3	5.54

3.10 COMPARISON OF EMC ANALYTICAL MODEL AND MEASUREMENTS

Measurements were made on two telecommunication systems, an ARSR-4 and an ASR-8, for the purpose of assessing the adequacy of the EMC analysis procedure and the analytical model discussed in Section 3.9. A discussion of the measurements made in Oklahoma City, Oklahoma, are contained in Appendix C. Measurements were initially made with the UWB signal coupled directly into the receiver front-end to observe the receiver response to the UWB signal which were followed by radiated measurements made at several distances from the receiver. Measurements were made using a UWB PRF of 10 MHz with the signal being non-dithered and dithered. The general measurement approach was to set up the UWB signal source with a level which produced an EIRP equivalent to the Part 15 limit using the FCC measurement procedure. That is, an EIRP of -41.3 dBm/MHz log-average. For each measurement site, the increase or absence of an increase in the receiver inherent noise level caused by the UWB signal was observed at the receive IF output. That is, an (I+N)/N ratio at the receiver IF output was measured and converted to an equivalent I/N ratio. An UWB EIRP level which would not exceed the receiver I/N protection criteria was then determined.

Measurements were made at three sites on the ARSR-4. The parameters used in the analytical model are given below, and are based on the characteristics of the radar on which measurements were made and the UWB source set-up.

ARSR-4 Parameters:

Operating Frequency: 1241 MHz
IF Bandwidth: 0.69 MHz
Receiver NF: 3.6 dB
Receiver Losses: 0 dB

Antenna Gain: 41.0 dB
Antenna Tilt Angle: 2 degrees
Antenna Height: 26 meters
Protection Criteria: I/N = -10 dB, average

UWB Parameters:

PRF: 10 MHz dithered
Antenna Height: 4 meters

TABLE 3-3 shows a comparison of the analytical model results with the measured data taken on the ARSR-4 for the 10 MHz dithered UWB signal. Figure 3-7 shows the predicted and measured maximum permitted EIRP as a function of distance for the ARSR-4 for a 10 MHz dithered UWB signal. For the three measurement sites, the average difference between the predicted and measured EIRP was -1.9 dB.

Measurements were made at two sites on the ASR-8. The parameters used in the analytical model are given below, and are based on the characteristics of the radar on which measurements were made and the UWB source set-up.

ASR-8 Parameters:

Operating Frequency: 2770 MHz
IF Bandwidth: 0.9 MHz
Receiver NF: 4.0 dB
Receiver Losses: 2.0 dB

Antenna Gain: 33.5 dB
Antenna Tilt Angle: 1.5 degrees
Antenna Height: 15 meters
Protection Criteria: I/N = 10 dB, average

UWB Parameters:

PRF: 10 MHz non-dithered and dithered
Antenna Height: 4 meters

TABLE 3-3
Comparison of Measurements with Analytical Model for ARSR-4 and 10 MHz Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	1.26	-58.0	-56.9	1.1
2	2.1	-55.2	-59.1	-3.9
3	3.1	-52.7	-55.7	-3.0

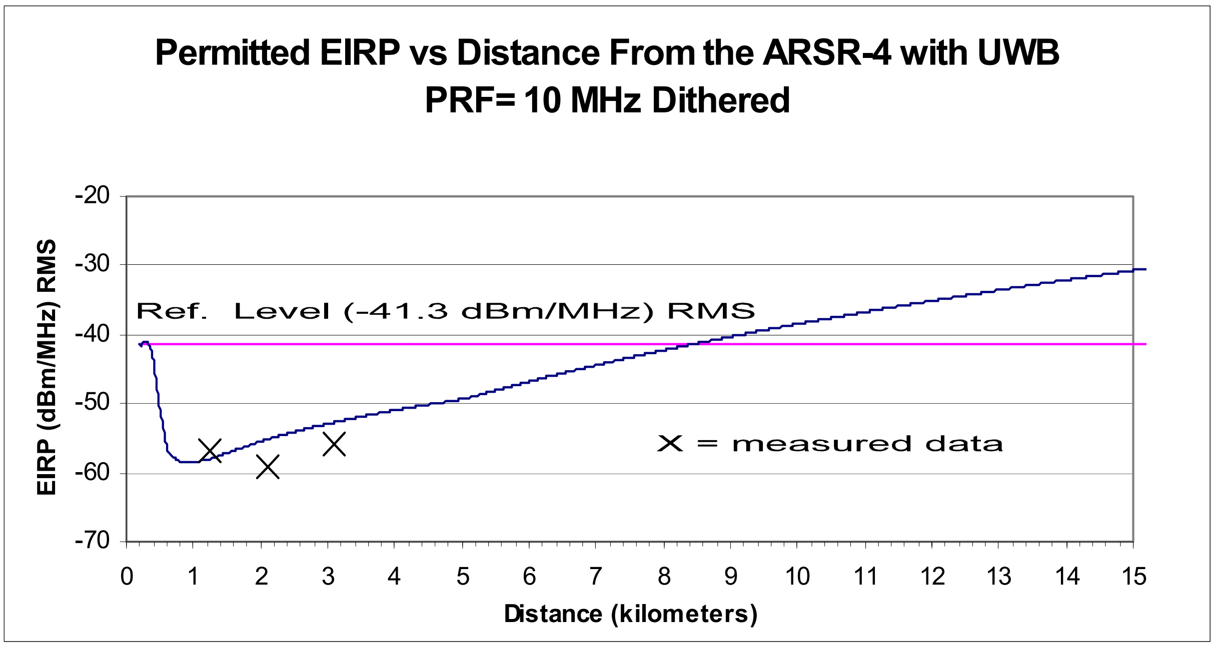

Figure 3-7. Comparison of Measured and Predicted Maximum Permitted EIRP versus Distance From ARSR-4 for 10 MHz Dithered UWB Signal

TABLE 3-4 shows a comparison of the analytical model results with the measured data taken on the ASR-8 for the 10 MHz non-dithered UWB signal. Figure 3-8 shows the predicted and measured maximum permitted EIRP as a function of distance for the ASR-8 for a 10 MHz non-dithered UWB signal. For the two measurement sites, the average difference between the predicted and measured EIRP for the 10 MHz non-dithered UWB signal was -7.0 dB.

TABLE 3-5 shows a comparison of the analytical model results with the measured data taken on the ASR-8 for the 10 MHz dithered UWB signal. Figure 3-9 shows the predicted and measured maximum permitted EIRP as a function of distance for the ASR-8 for a 10 MHz dithered UWB signal. For the two measurement sites, the average difference between the predicted an measured EIRP for the 10 MHz dithered UWB signal was -4.0 dB.

In summary, a comparison of measured maximum permitted EIRP limits with the analytical model indicates that for the ARSR-4 and ASR-8 systems, the analytical model and the measurements are within a few dB. The EIRP limits determined by measurements were generally lower. This difference may be due to several factors. For example:

1. The analytical model does not take into consideration exact terrain variations, and

2. The radar antenna elevation pattern used in the analytical model may not accurately represent the antenna gain in the direction of the UWB device.

TABLE 3-4
Comparison of Measurements and Analytical Model
For the ASR-8 and 10 MHz Non-Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	0.4	-48.0	-53.4	-5.4
2	1.4	-40.0	-48.7	-8.7

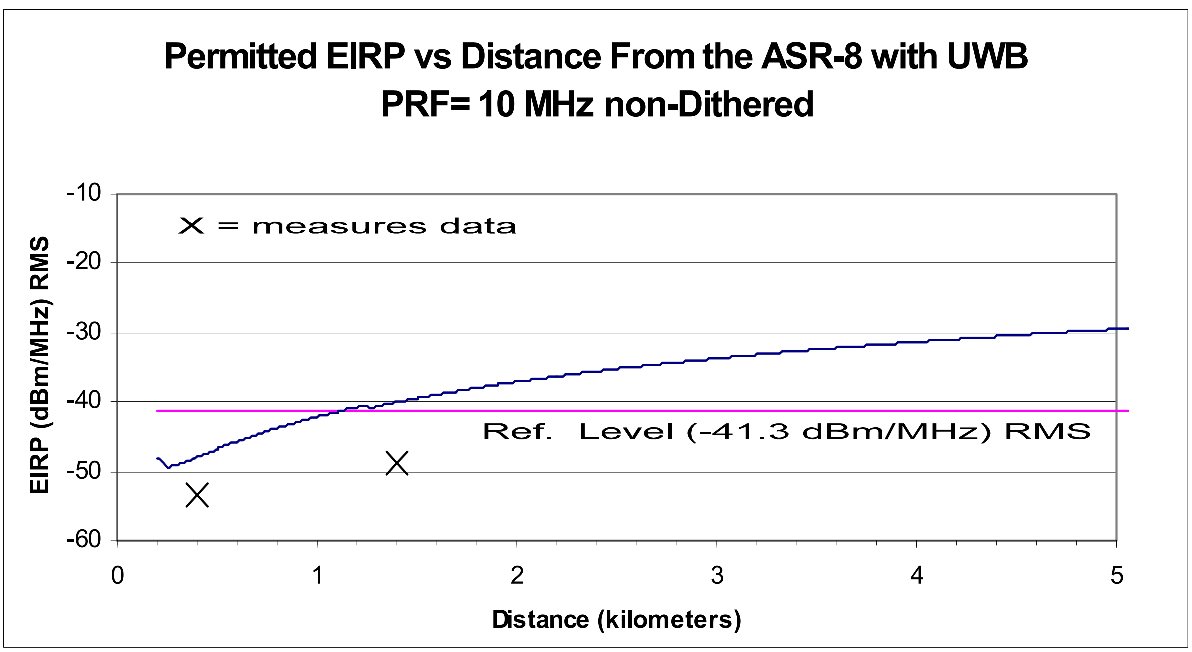

Figure 3-8. Comparison of Measured and Predicted Maximum Permitted EIRP versus Distance from ASR-8 for 10 MHz non-Dithered UWB Signal.

TABLE 3-5
Comparison of Measurements and Analytical Model
For the ASR-8 and 10 MHz Dithered UWB Signal

Site #	Distance to Receiver (km)	Predicted Maximum Permitted EIRP (dBm/MHz) RMS	Measured Maximum Permitted EIRP (dBm/MHz) RMS	Delta (dB)
1	0.4	-47.5	-49.7	-2.2
2	1.4	-39.6	-45.4	-5.8

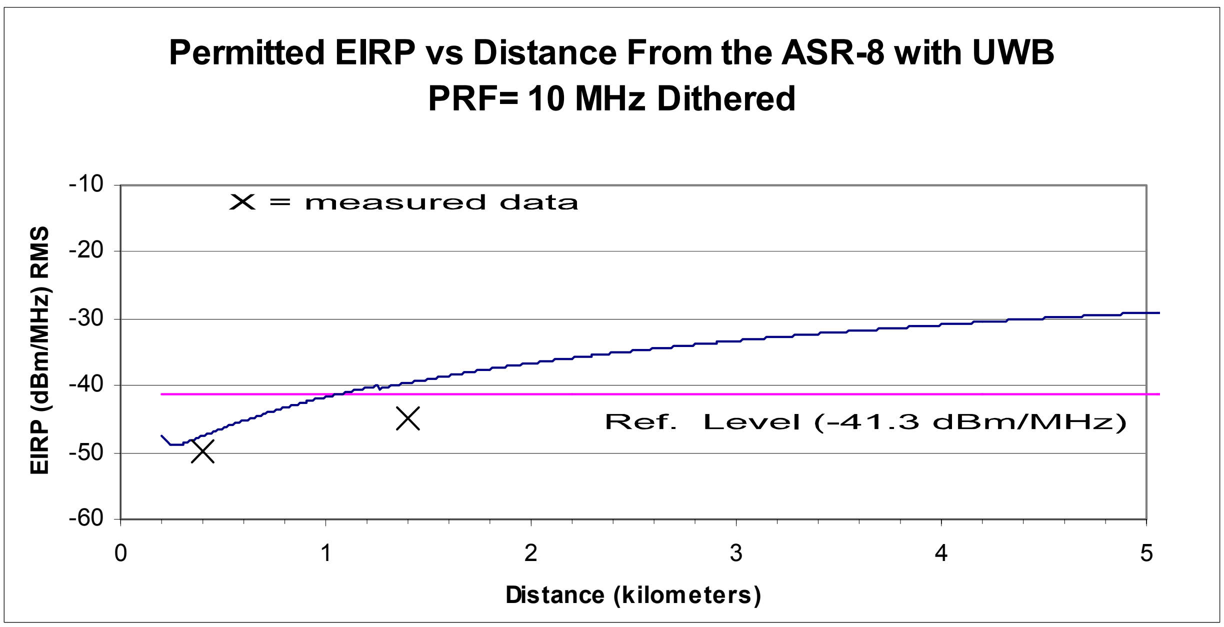

Figure 3-9. Comparison of Measured and Predicted Maximum Permitted EIRP Versus Distance From ASR-8 for 10 MHz Measured Dithered UWB Signal

SECTION 4

ASSESSMENT OF COMPATIBILITY FOR SINGLE UWB DEVICE

4.1 INTRODUCTION

The results of an EMC analyses for a single UWB device versus the following systems are contained in this section: the NEXRAD, ARSR-4, ASR-9, RF Altimeters, ATCRBS, DME, MLS, SARSAT LUT, a 4 GHz Earth station, a TDWR, and a shipboard maritime radionavigation radar.

A summary section for each system contains tables that show the maximum permitted UWB EIRP for a range of PRFs from 0.001 to 500 MHz. Also included in the tables are the required separation distances for the victim receiver and the UWB device when its EIRP is equal to the reference level of -41.3 dBm/MHz RMS. In cases where the maximum permitted EIRP is above the reference level, the required separation distance does not apply and "Not Applicable" or "NA" is put into the column. Sample graphs are provided which show the maximum permitted UWB EIRP versus distance from the victim receiver for various PRFs. The maximum permitted EIRP level for UWB devices is also discussed in relationship to the reference level and the effect that the UWB signal would have on the victim receiver.

For this analysis the average power is based on a spectrum analyzer RMS detector function.[33] At the end of this section is a discussion on system, operating frequency, maximum permissible UWB EIRP, and the minimum required separation distance when the UWB EIRP is equal to the reference level.

4.2 NEXRAD RADAR (2700-3000 MHz)

Analyses of potential interference from a single UWB device into a NEXRAD receiver was performed using the methodology described in Section 3, the NEXRAD characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-1. The NEXRAD radar antenna height in TABLE 4-1 is the average height of all the NEXRAD radars in the Government Master File (GMF) of frequency assignments.

[33] The measurement procedure used by the FCC is based on a log-average detector function.

TABLE 4-1
UWB and NEXRAD Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -6 dB (average (RMS) interference power)
Radar Antenna Height	28 meters
Radar Tilt Angle	0.5 degrees above horizon
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-2 for a UWB height of 2 meters. These results show that the NEXRAD interference protection criteria is exceeded with a UWB EIRP of -41.7 dBm or greater for UWB PRFs above 0.1 MHz. This is 0.4 dB below the reference level. For PRFs at and below 0.1 MHz the maximum UWB EIRP is -39.1 dBm, which is 2.2 dB above the reference level. For UWB devices with PRFs above 0.1 MHz, the required separation distance is 1.4 km when the UWB EIRP equals the reference level. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-1 for a PRF of 1 MHz.

TABLE 4-2
Non-Dithered UWB Signal into NEXRAD Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-2.6	-39.1	2.2	NA
.01	-2.6	-39.1	2.2	NA
.1	-2.6	-39.1	2.2	NA
1	0.0	-41.7	-0.4	1.4
10	0.0	-41.7	-0.4	1.4
100	0.0	-41.7	-0.4	1.4
500	0.0	-41.7	-0.4	1.4

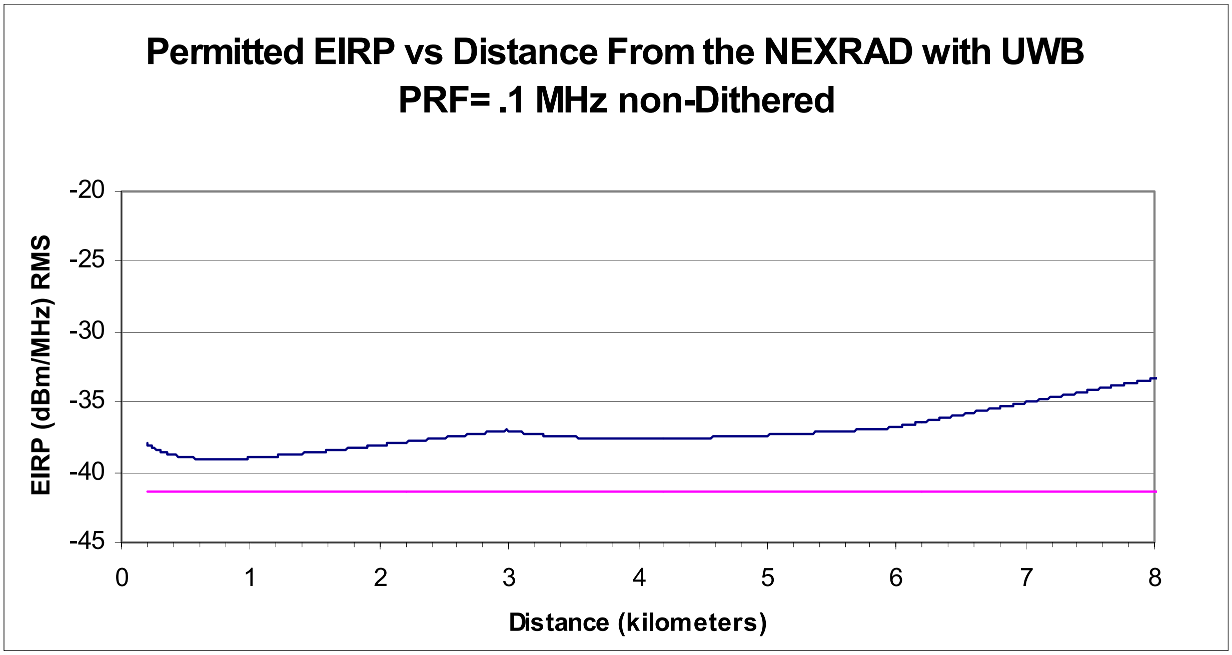

Figure 4-1. Maximum Permitted UWB EIRP for non-Dithered PRF of 0.1 MHz (UWB Height = 2m).

Above a PRF of 0.1 MHz, the BWCF is equal to zero and the graph will change. It is shown below in Figure 4-2.

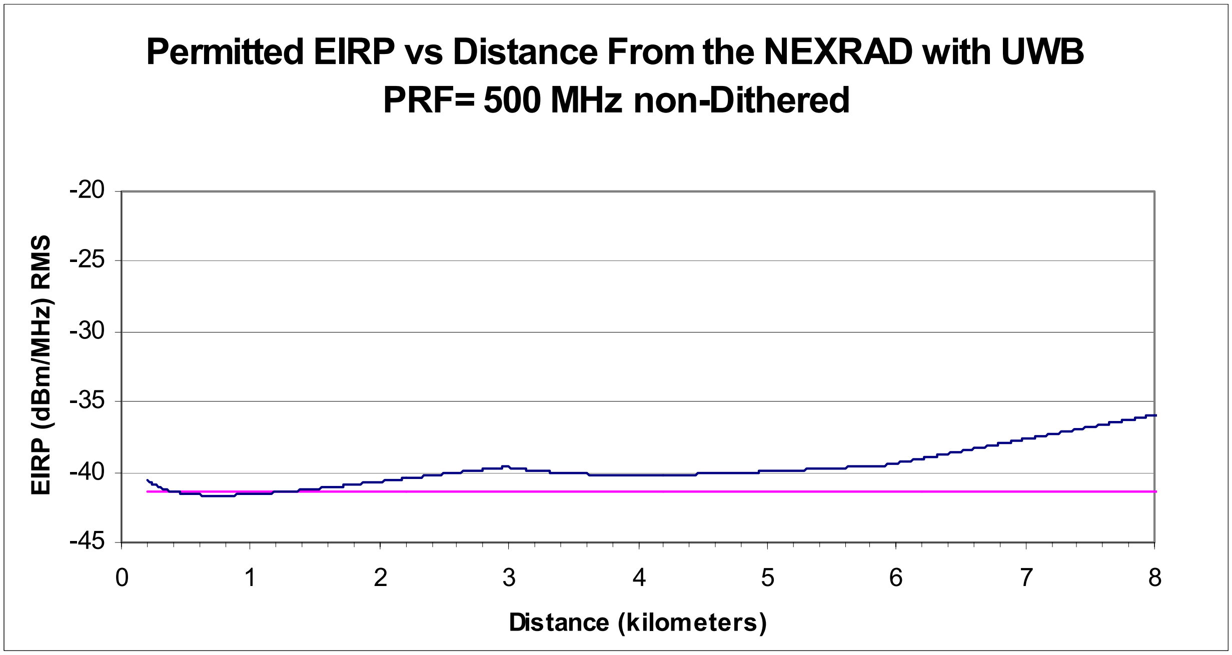

Figure 4-2. Maximum Permitted UWB EIRP for non-Dithered PRF of 500MHz (UWB Height = 2m).

The results for a dithered UWB signal analyses are shown in TABLE 4-3. The results for a dithered UWB signal show that the maximum allowable UWB EIRP is -39.1 dBm regardless of the PRF. The permitted UWB EIRP level is 2.2 dB above the -41.3 dBm/MHz RMS reference level. A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-3.

TABLE 4-3
Dithered UWB Signal into NEXRAD Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-2.6	-39.1	2.2	NA
.01	-2.6	-39.1	2.2	NA
.1	-2.6	-39.1	2.2	NA
1	-2.6	-39.1	2.2	NA
10	-2.6	-39.1	2.2	NA
100	-2.6	-39.1	2.2	NA
500	-2.6	-39.1	2.2	NA

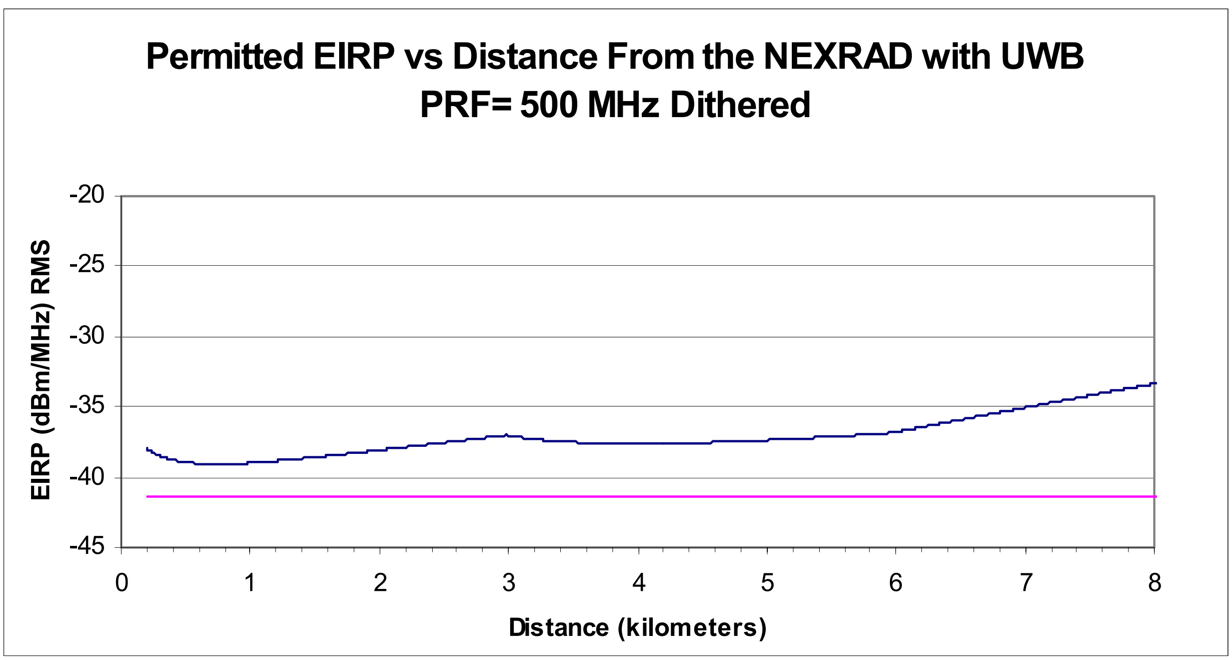

Figure 4-3. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 2m).

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal analyses are shown in TABLE 4-4. The results show that for UWB PRFs at and below 0.1 MHz the maximum permitted UWB EIRP is -73.3 dBm. For PRFs above 0.1 MHz the maximum permitted EIRP is -75.9 dBm. These levels are 32 and 34.6 dB below the reference level. The separation distances for a NEXRAD receiver and a UWB device with an EIRP equal to the reference level range from 5.8 km for UWB PRFs at and below 0.1 MHz to 7.8 km for PRFs above 0.1 MHz.

TABLE 4-4
Non-Dithered UWB Signal into NEXRAD Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-2.6	-73.3	-32.0	5.8
.01	-2.6	-73.3	-32.0	5.8
.1	-2.6	-73.3	-32.0	5.8
1	0	-75.9	-34.6	7.8
10	0	-75.9	-34.6	7.8
100	0	-75.9	-34.6	7.8
500	0	-75.9	-34.6	7.8

The results for a dithered UWB signal are shown in TABLE 4-5. The results show that the maximum permitted UWB EIRP is -73.3 dBm regardless of the UWB PRF. The separation distance for a NEXRAD receiver and a dithered UWB device with an EIRP equal to the reference level is 5.8 km. A graph of the maximum permitted dithered UWB EIRP versus distance for a UWB height of 30 meters is shown in Figure 4-4.

TABLE 4-5
Dithered UWB Signal into NEXRAD Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS (km)
.001	-2.6	-73.3	-32.0	5.8
.01	-2.6	-73.3	-32.0	5.8
.1	-2.6	-73.3	-32.0	5.8
1	-2.6	-73.3	-32.0	5.8
10	-2.6	-73.3	-32.0	5.8
100	-2.6	-73.3	-32.0	5.8
500	-2.6	-73.3	-32.0	5.8

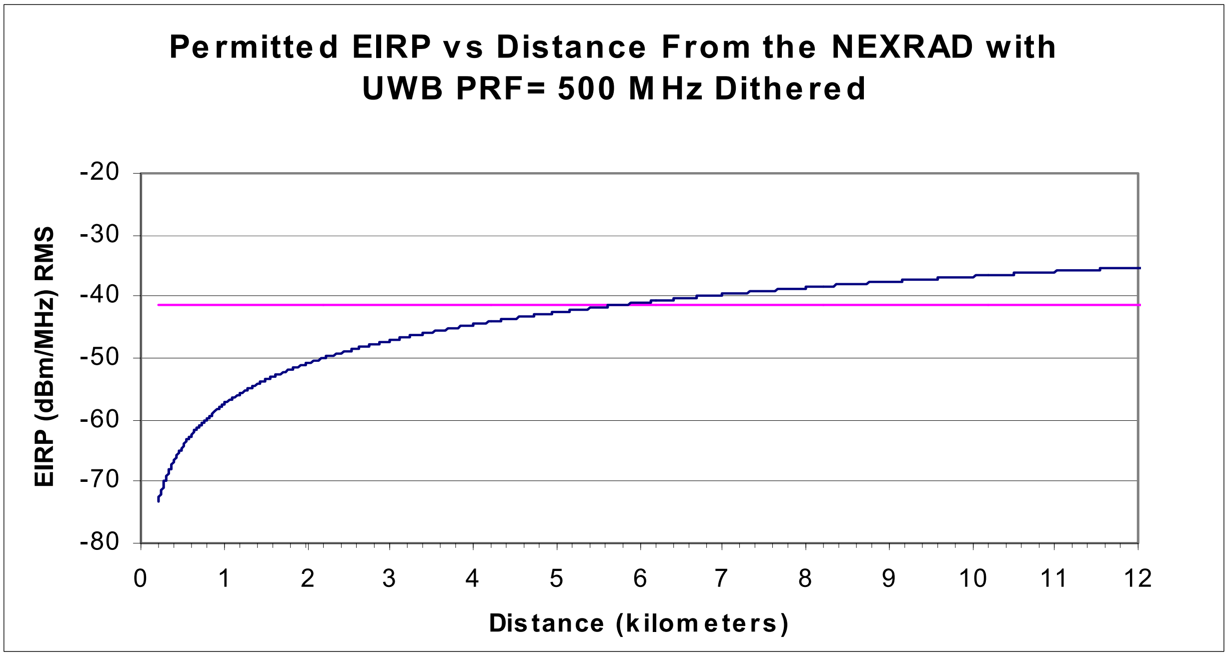

Figure 4-4. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 30 m).

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of NEXRAD radars and within the 2700-3000 MHz frequency band would exceed current interference protection requirements with UWB PRFs above 0.1 MHz and/or operating heights comparable to the NEXRAD antenna. UWB devices operating at that power level would add to the system noise, rendering the radar less capable of tracking and monitoring meteorological events.

Three factors significantly influence these results, namely, the radar antenna height, radar antenna tilt angle, and the height of the UWB device. When the radar antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater radar antenna gain. The analytical model takes into account the height of the radar, the height of the UWB device, and the radar tilt angle to compute the radar antenna gain, which is then used in the UWB interference calculations. For example, when the UWB height is 2 meters, the NEXRAD antenna height is 28 meters, and the distance is 1 km, the off-axis angle is -1.5 degrees, the NEXRAD tilt angle is 0.5 degrees, the radar antenna gain is 24.6 dBi (from Figure A-1 at -2 degrees). However, for a UWB height of 30 meters and a distance of 1 km the off-axis angle is +0.10 degrees and the radar antenna gain is 43 dBi.

A higher radar antenna gain raises the UWB interference power level in the radar receiver. For compatible operations, this requires a lower maximum permitted UWB EIRP and a longer separation distance to satisfy the receiver's protection criteria.

4.3 ARSR-4 RADAR (1215-1400 MHz)

Analyses of potential interference from a single UWB device into an ARSR-4 receiver was performed using the methodology described in Section 3, the ARSR-4 characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-6. The ARSR-4 radar antenna height in TABLE 4-6 is the average height of all the ARSR-4 radars in the GMF of frequency assignments.

TABLE 4-6
UWB and ARSR-4 Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (average (RMS) interference power)
Radar Antenna Height	22 meters
Radar Tilt Angle	2 degrees above horizon
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results of the non-dithered UWB device signal analyses are shown in TABLE 4-7 for a UWB height of 2 meters. These results show that the ARSR-4 interference protection criteria is exceeded with a UWB EIRP of -59.6 dBm or greater for UWB PRFs at or below 0.1 MHz. For PRFs above 0.1 MHz the criteria is exceeded for a UWB EIRP greater than -61.2 dBm. These levels are 18.3 and 19.9 dB below the -41.3 dBm/MHz RMS reference level. For UWB devices with PRFs at or above 0.1 MHz and the UWB EIRP equal the reference level, the distance separations range from 5.5 km to 6.1 km to satisfy the ARSR-4 interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-5 for a PRF of 0.1 MHz and a UWB height of 2 meters.

TABLE 4-7
Non-Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-59.6	-18.3	5.5
.01	-1.6	-59.6	-18.3	5.5
.1	-1.6	-59.6	-18.3	5.5
1	0.0	-61.2	-19.9	6.1
10	0.0	-61.2	-19.9	6.1
100	0.0	-61.2	-19.9	6.1
500	0.0	-61.2	-19.9	6.1

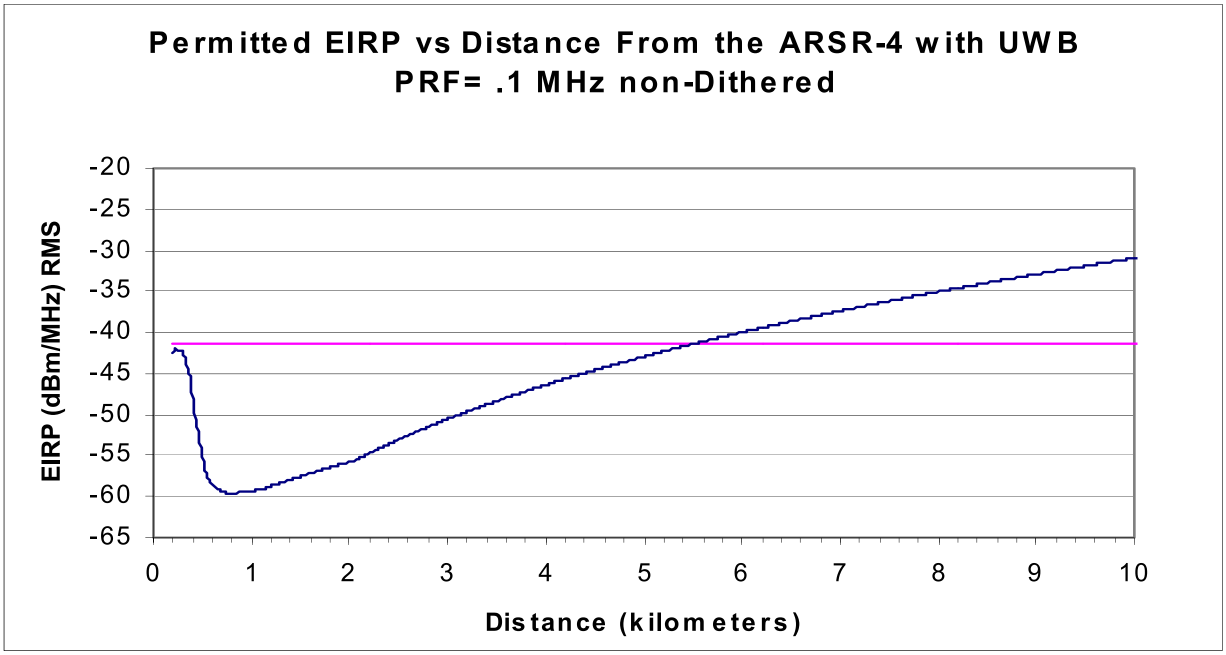

Figure 4-5. Maximum Permitted UWB EIRP for non-Dithered PRF of 0.1 MHz (UWB Height = 2m).

Above a PRF of 0.1 MHz, the BWCF is equal to zero and the graph will change. It is shown below in Figure 4-6.

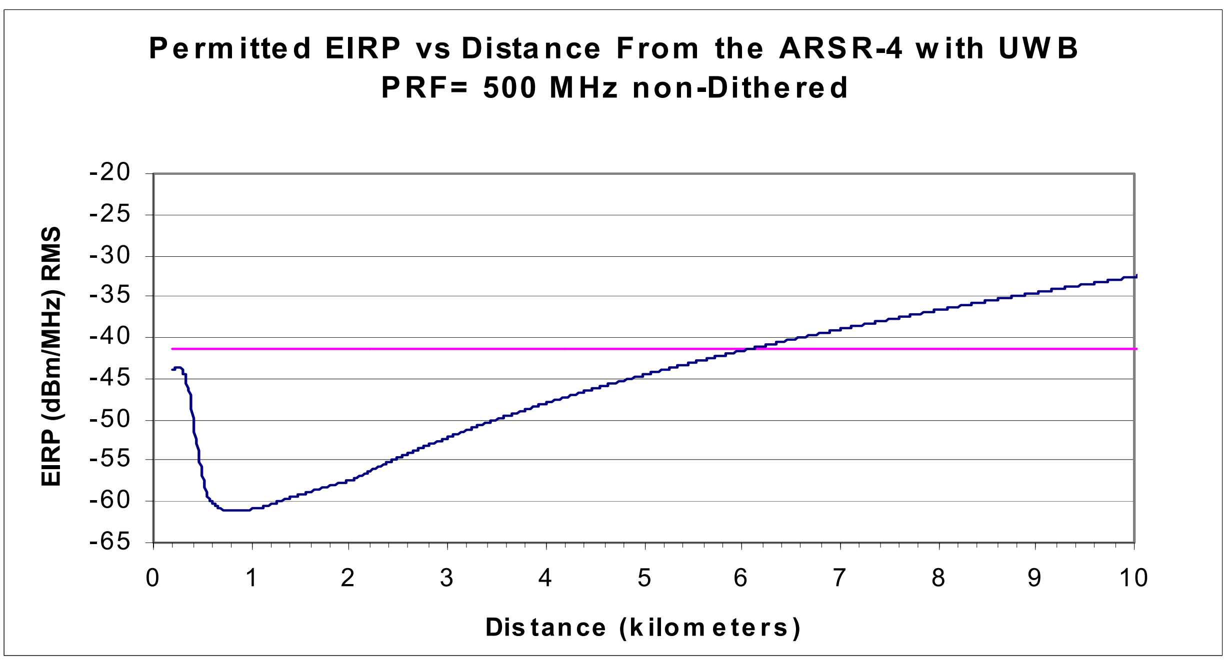

Figure 4-6. Maximum Permitted UWB EIRP for non-Dithered PRF of 500MHz (UWB Height = 2m).

The results for a dithered UWB signal are shown in TABLE 4-8. For a dithered signal the maximum allowable UWB EIRP is -59.6 dBm regardless of the PRF. The permitted UWB EIRP level is 18.3 dB below the -41.3 dBm/MHz RMS reference level. The distance separation is 5.5 km to satisfy the ARSR-4 interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-7.

TABLE 4-8
Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-59.6	-18.3	5.5
.01	-1.6	-59.6	-18.3	5.5
.1	-1.6	-59.6	-18.3	5.5
1	-1.6	-59.6	-18.3	5.5
10	-1.6	-59.6	-18.3	5.5
100	-1.6	-59.6	-18.3	5.5
500	-1.6	-59.6	-18.3	5.5

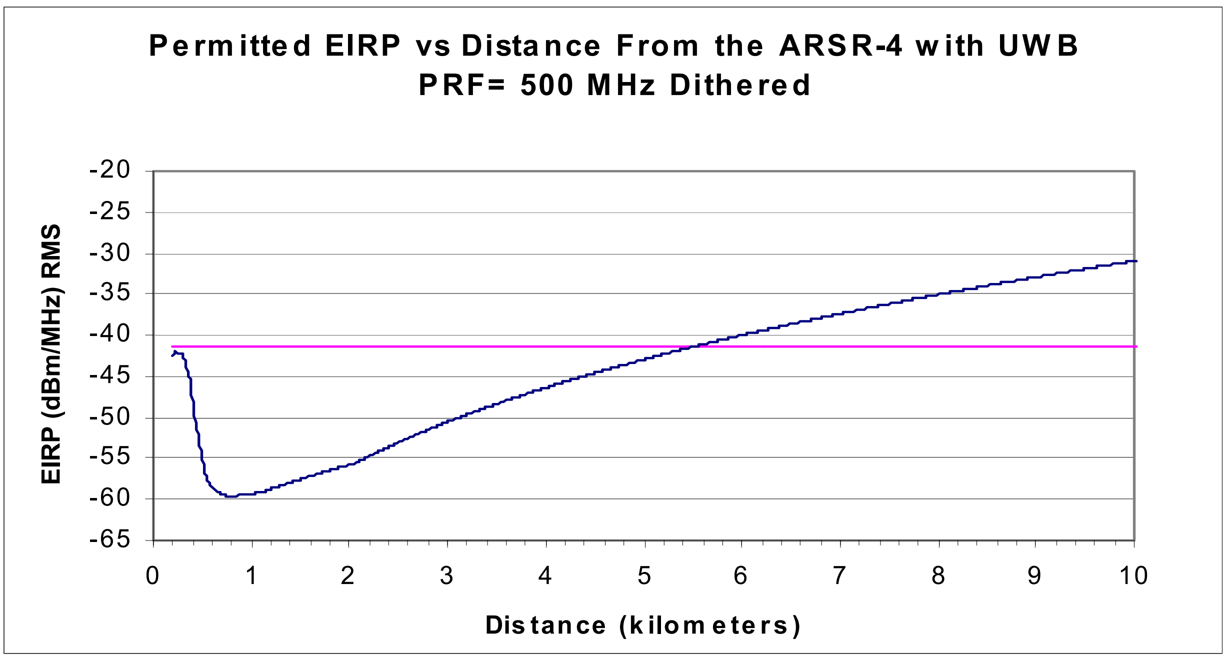

Figure 4-7. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 2m).

As the UWB device becomes closer than 1 km to the radar, the radar antenna gain used in the interference calculations rapidly drops off which allows a higher UWB EIRP. This effect is responsible for the minima in the graphs of Figures 4-5, 4-6, and 4-7.

The shape of the graph is independent of the UWB PRF because the dithering results in a BWCF of 1.6 dB regardless of the PRF.

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal are shown in TABLE 4-9. These results show that the ARSR-4 interference protection criteria is exceeded with a UWB EIRP of -80.0 dBm or greater for UWB PRFs at or below 0.1 MHz. For PRFs above 0.1 MHz the criteria is exceeded for a UWB EIRP greater than -81.6 dBm. These levels are 38.7 and 40.3 dB below the -41.3 dBm/MHz RMS reference level. For UWB devices with the UWB EIRP equal the reference level, the distance separations range are beyond 15 km to satisfy the ARSR-4 interference protection criteria.

TABLE 4-9
Non-Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-80.0	-38.7	>15
.01	-1.6	-80.0	-38.7	>15
.1	-1.6	-80.0	-38.7	>15
1	0	-81.6	-40.3	>15
10	0	-81.6	-40.3	>15
100	0	-81.6	-40.3	>15
500	0	-81.6	-40.3	>15

The results for a dithered interference analyses are shown in TABLE 4-10.

TABLE 4-10
Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-80.0	-38.7	>15
.01	-1.6	-80.0	-38.7	>15
.1	-1.6	-80.0	-38.7	>15
1	-1.6	-80.0	-38.7	>15
10	-1.6	-80.0	-38.7	>15
100	-1.6	-80.0	-38.7	>15
500	-1.6	-80.0	-38.7	>15

The results for a dithered UWB signal analyses show that the maximum UWB EIRP is -80.0 dBm regardless of the PRF, which is 38.7 dB below the reference level. The ARSR-4 and UWB device separation distance is beyond 15 km when the UWB EIRP is equal to the reference level.

A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-8 for a UWB height of 30 meters.

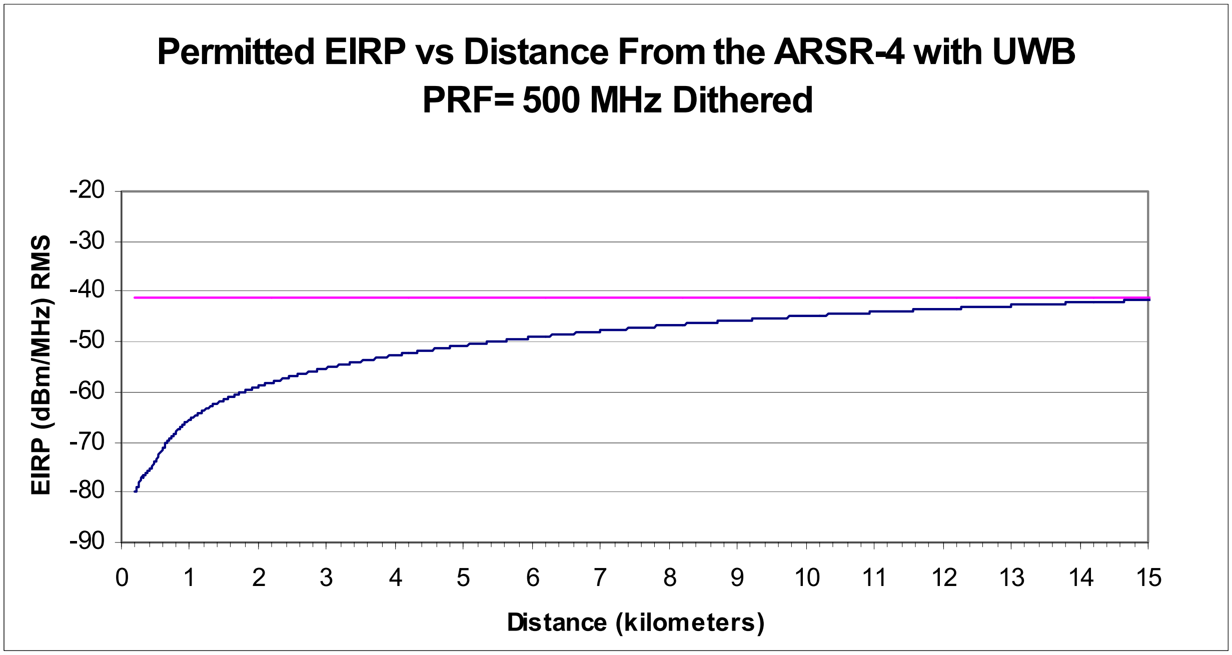

Figure 4-8. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 30 m).

The shape of the graph in Figure 4-8 is different than graphs in the previous figures because of the geometry of the scenario when the UWB height is 30 meters. At this height when the UWB device moves toward the radar, the gain of the radar antenna used in the interference calculations does not significantly change and the driving factor in calculating the maximum permissible UWB EIRP is the propagation loss.

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of ARSR-4 radars and within the 1215-1400 MHz frequency band would exceed current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the ARSR-4 radar less capable of tracking and detecting aircraft.

Three factors significantly influence these results, namely, the radar antenna height, radar antenna tilt angle, and the height of the UWB device. When the radar antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater radar antenna gain. The analytical model takes into account the height of the radar, the height of the UWB device, and the radar tilt angle to compute the radar antenna gain, which is then used in the UWB interference calculations. For example, when the UWB height is 2 meters and the distance is 1 km, the off-axis + tilt angle is -3.1 degrees and the radar antenna gain is 33.3 dBi. However, for a UWB height of 30 meters and a distance of 1 km the off-axis + tilt angle is -1.5 degrees and the radar antenna gain is 39.5 dBi.

A higher radar antenna gain raises the UWB interference power level in the radar receiver. For compatible operations, this requires a lower maximum permitted UWB EIRP and a longer separation distance to satisfy the receiver's protection criteria.

4.4 ASR-9 RADAR (2700-2900 MHz)

Analyses of potential interference from a single UWB device into an ASR-9 receiver was performed using the methodology described in Section 3, the ASR-9 characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-11. The ASR-9 radar antenna height in TABLE 4-11 is the average height of all the ASR-9 radars in the GMF of frequency assignments.

TABLE 4-11
UWB and ASR-9 Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (average (RMS) interference power)
Radar Antenna Height	17 meters
Radar Tilt Angle	2 degrees above horizon
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-12 for a UWB height of 2 meters. These results show that the ASR-9 interference protection criteria is exceeded with a UWB EIRP of -44.1 dBm or greater for UWB PRFs at and below 0.1 MHz. For PRFs above 0.1 MHz the criteria is exceeded for a UWB EIRP greater than -45.9 dBm. These levels are 2.8 and 4.6 dB below the -41.3 dBm/MHz RMS reference level. For UWB devices with PRFs at or above 0.1 MHz and the UWB EIRP equal the reference level, the distance separations range from 0.8 km to 1.1 km to satisfy the ASR-9 interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-9 for a non-dithered PRF of 0.1 MHz and in Figure 4-10 for a non-dithered PRF of 500 MHz.

TABLE 4-12
Non-Dithered UWB Signal into ASR-9 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-44.1	-2.8	0.8
.01	-1.9	-44.1	-2.8	0.8
.1	-1.9	-44.1	-2.8	0.8
1	0.0	-45.9	-4.6	1.1
10	0.0	-45.9	-4.6	1.1
100	0.0	-45.9	-4.6	1.1
500	0.0	-45.9	-4.6	1.1

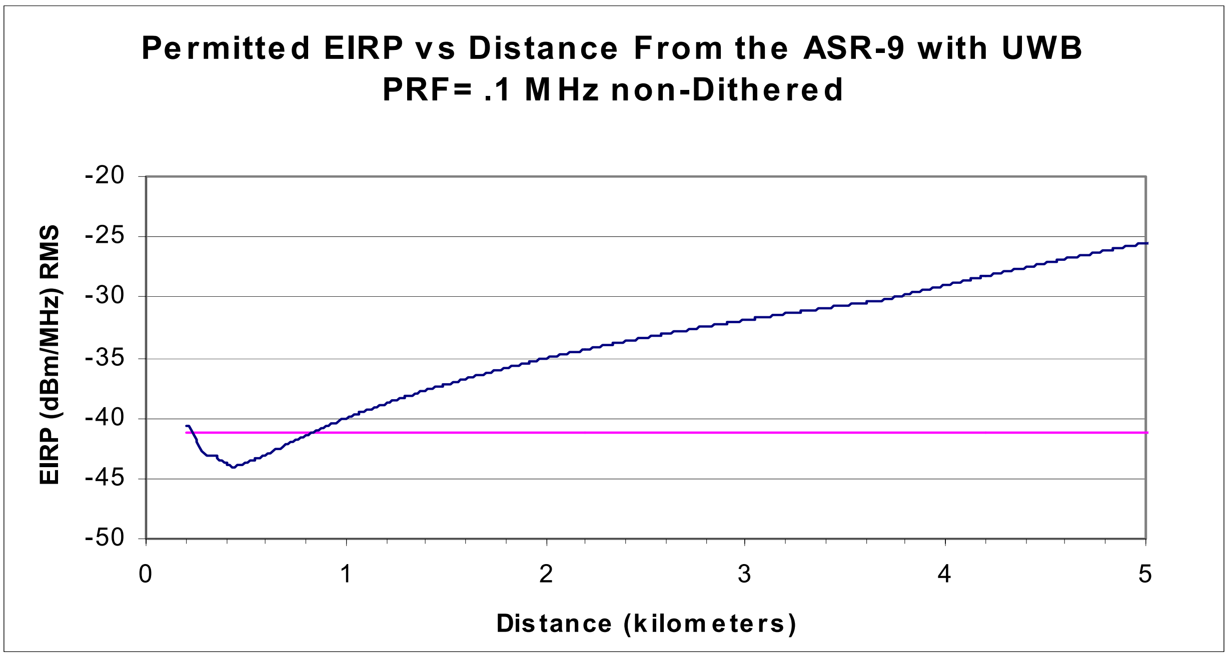

Figure 4-9. Maximum Permitted UWB EIRP for non-Dithered PRF of 0.1 MHz (UWB Height = 2m).

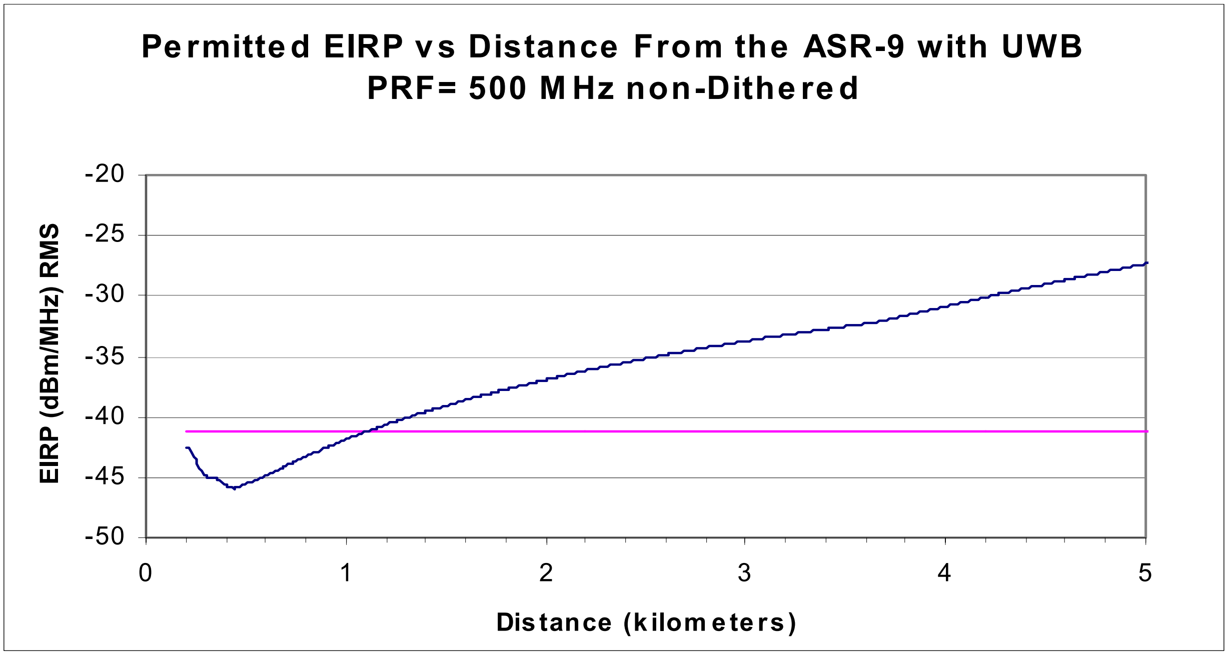

Figure 4-10. Maximum Permitted UWB EIRP for non-Dithered PRF of 500MHz (UWB Height = 2m).

The results for a dithered UWB signal analyses are shown in TABLE 4-13. The results for a dithered signal show that the maximum allowable UWB EIRP is -44.1 dBm regardless of the PRF. The permitted UWB EIRP level is 2.8 dB below the -41.3 dBm/MHz RMS reference level. The distance separation is 0.8 km to satisfy the ASR-9 interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-11 for a UWB height of 2 meters.

TABLE 4-13
Dithered UWB Signal into ASR-9 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS)	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-44.1	-2.8	0.8
.01	-1.9	-44.1	-2.8	0.8
.1	-1.9	-44.1	-2.8	0.8
1	-1.9	-44.1	-2.8	0.8
10	-1.9	-44.1	-2.8	0.8
100	-1.9	-44.1	-2.8	0.8
500	-1.9	-44.1	-2.8	0.8

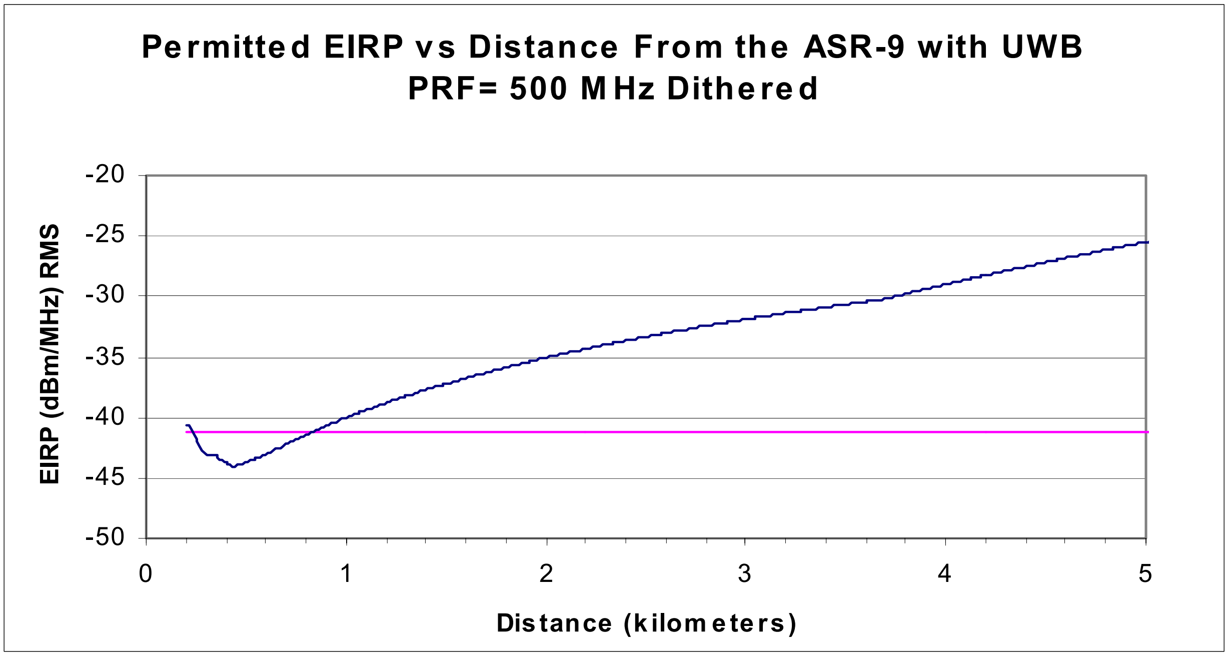

Figure 4-11. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 2m).

The shape of the graph is independent of the UWB PRF because the dithering results in a BWCF of -1.9 dB regardless of the PRF.

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal analyses are shown in TABLE 4-14. These results show that the ASR-9 interference protection criteria is exceeded with a UWB EIRP of -64.4 dBm or greater for UWB PRFs below 0.1 MHz. For PRFs above 0.1 MHz the criteria is exceeded for a UWB EIRP greater than -66.2 dBm. These levels are 23.1 and 24.9 dB below the -41.3 dBm/MHz RMS reference level. For UWB devices with PRFs at or above 0.1 MHz and the UWB EIRP equal the reference level, the distance separations range from 1.3 km to 1.5 km to satisfy the ASR-9 interference protection criteria.

TABLE 4-14
Non-Dithered UWB Signal into ASR-9 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-64.4	-23.1	1.3
.01	-1.9	-64.4	-23.1	1.3
.1	-1.9	-64.4	-23.1	1.3
1	0	-66.2	-24.9	1.5
10	0	-66.2	-24.9	1.5
100	0	-66.2	-24.9	1.5
500	0	-66.2	-24.9	1.5

The results for dithered UWB signal analyses are shown in TABLE 4-15.

TABLE 4-15
Dithered UWB Signal into ASR-9 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-64.5	-23.2	1.3
.01	-1.9	-64.5	-23.2	1.3
.1	-1.9	-64.5	-23.2	1.3
1	-1.9	-64.5	-23.2	1.3
10	-1.9	-64.5	-23.2	1.3
100	-1.9	-64.5	-23.2	1.3
500	-1.9	-64.5	-23.2	1.3

For a dithered signal the ASR-9 interference protection criteria is exceeded with a UWB EIRP of -64.5 dBm or greater regardless of the PRF. The distance separation is 1.3 km to satisfy the ASR-9 interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-12 for a UWB height of 30 meters and a PRF of 500 MHz.

Figure 4-12 shows that when the ASR-9 and the UWB device are close in height, the antenna gain does not change significantly with distance and the propagation loss is the prime factor in determining the maximum permitted UWB EIRP and/or the separation distance.

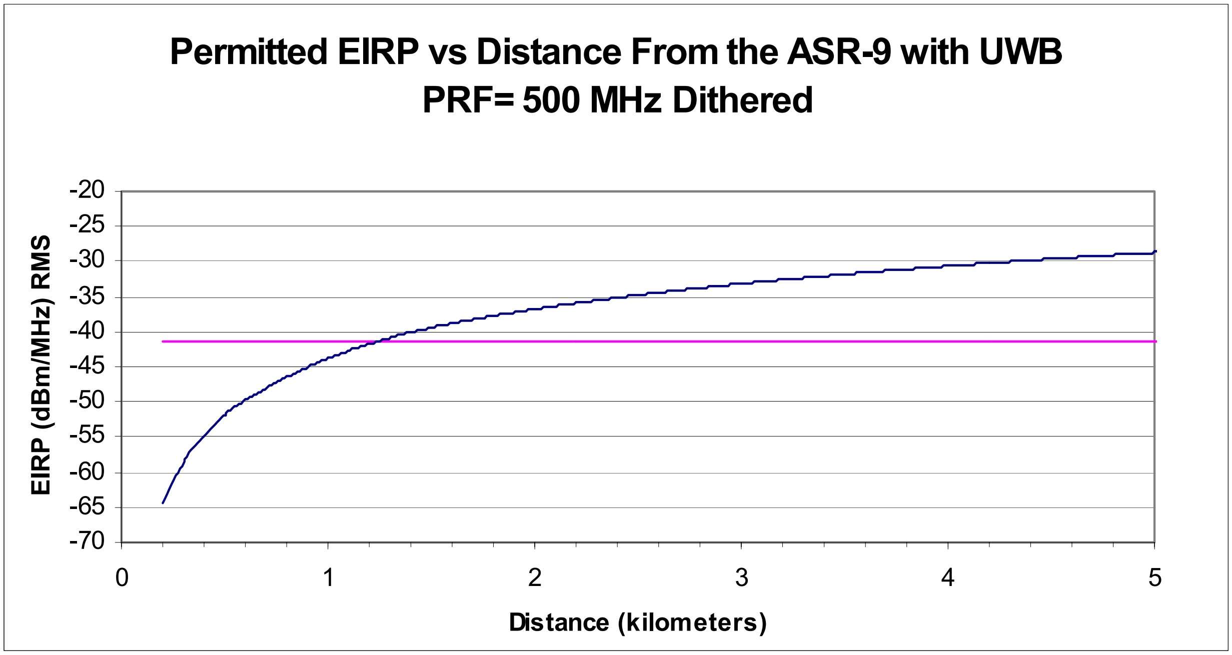

Figure 4-12. Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 30 m).

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of ASR-9 radars and within the 2700-2900 MHz frequency band would exceed current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the ASR-9 radar less capable of tracking and detecting aircraft.

Three factors significantly influence these results, namely, the radar antenna height, radar antenna tilt angle, and the height of the UWB device. When the radar antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater radar antenna gain. The analytical model takes into account the height of the radar, the height of the UWB device, and the radar tilt angle to compute the radar antenna gain, which is then used in the UWB interference calculations. For example, when the UWB height is 2 meters and the distance is 1 km, the off-axis + tilt angle is -2.9 degrees and the radar antenna gain is 23 dBi. However, for a UWB height of 30 meters and a distance of 1 km, the off-axis + tilt angle is -1.3 degrees and the radar antenna gain is 27 dBi.

A higher radar antenna gain raises the UWB interference power level in the radar receiver. For compatible operations, this requires a lower maximum permitted UWB EIRP and a longer separation distance to satisfy the receiver's protection criteria.

4.5 ALTIMETERS (4200-4400 MHz)

The results of the analyses using the equipment characteristics in Appendix A and the methodologies in Section 3 and RTCA Document DO-155 show that a UWB device operating at a power level of -41.3 dBm/1MHz RMS and within the 4200-4400 MHz frequency band will not exceed the interference protection criteria of the CW and pulsed altimeters considered in this report.

TABLE 4-16 shows the received desired signal power, S, for the minimum and maximum operational height of the CW and pulsed altimeters. Also included is the maximum permissible interference power, I, to satisfy the receiver's protection criteria and its relationship to the reference level of -41.3 dBm/1MHz RMS. For the CW altimeter at the minimum altitude of 30 meters, the received desired signal is -39.0 dBm and the maximum permissible interference power is -51.0 dBm to satisfy the receiver's protection criteria. This equates to a UWB EIRP level of 24.5 dBm, which is 65.8 dB above the reference level. At the maximum altitude of 762 meters, the received desired signal power is -67 dBm and the maximum permissible interference power is -79.0 dBm to satisfy the receivers protection criteria. This equates to a UWB EIRP of 25.2 dBm, which is 66.5 dB above the reference level. These levels are for a UWB height of 2 meters. The same description of the results also applies to the pulsed altimeter. These levels are for a dithered UWB signal.

TABLE 4-16
Altimeter Analyses Summary

System	Minimum Altitude CW Altimeter = 30 meters Pulsed Altimeter = 30 meters				Maximum Altitude CW Altimeter = 762 meters Pulsed Altimeter = 1524 meters			
	S (dBm)	I (dBm)	EIRP (dBm)	Delta Reference (dB)	S (dBm)	I (dBm)	EIRP (dBm)	Delta Reference (dB)
CW Altimeter	-39.0	-51.0	24.5	65.8	-67.0	-79.0	25.2	66.5
Pulsed Altimeter	-30.4	-36.3	14.3	55.6	-64.3	-70.4	14.9	56.2

The table shows that both systems provide sufficient desired signal power in the link budget to overcome the effects of a single UWB device when the UWB EIRP is equal to the reference level.

4.6 ATCRBS (1030 and 1090 MHz)

Analyses of potential interference from a single UWB device into an ATCRBS transponder and interrogator receiver was performed using the methodology described in Section 3, the ATCRBS characteristics given in Appendix A, and the analysis parameters shown in TABLEs 4-17and 4-18.

TABLE 4-17
UWB and ATCRBS Interrogator Analysis Parameters

Parameter	Value
Protection Criteria	S/I = 12 dB (average (RMS) interference power)
Desired Signal Power	-79 dBm
Maximum Interference	-91 dBm
Antenna Height	22 meters
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

TABLE 4-18
UWB and ATCRBS Transponder Analysis Parameters

Parameter	Value
Protection Criteria	S/I = 12 dB (average (RMS) interference power)
Desired Signal Power	-77 dBm
Maximum Interference	-89 dBm
Antenna Height	10 meters
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

Interrogator

The results for a non-dithered UWB signal analyses into an ATCRBS interrogator receiver are shown in TABLE 4-19 for a UWB height of 2 meters. These results show that the maximum permitted UWB EIRP is -30.5 dBm for PRFs at and below 1 MHz, which is 10.8 dB above the reference level. For PRFs above 1 MHz the maximum permitted UWB EIRP is -21.0, which is 20.3 dB above the reference level.

TABLE 4-19
Non-Dithered UWB Signal into ATCRBS Interrogator Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	9.5	-30.5	10.8	NA
.01	9.5	-30.5	10.8	NA
.1	9.5	-30.5	10.8	NA
1	9.5	-30.5	10.8	NA
10	0.0	-21.0	20.3	NA
100	0.0	-21.0	20.3	NA
500	0.0	-21.0	20.3	NA

The results for a dithered UWB signal analyses into an ATCRBS interrogator receiver are shown in TABLE 4-20. The maximum permitted UWB EIRP is -30.5 dBm regardless of the PRF, which is 10.8 dB above the reference level.

TABLE 4-20
Dithered UWB Signal into ATCRBS Interrogator Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	9.5	-30.5	10.8	NA
.01	9.5	-30.5	10.8	NA
.1	9.5	-30.5	10.8	NA
1	9.5	-30.5	10.8	NA
10	9.5	-30.5	10.8	NA
100	9.5	-30.5	10.8	NA
500	9.5	-30.5	10.8	NA

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered signal analyses are shown in TABLE 4-21. The results show that the maximum permitted UWB EIRP is -45.3 dBm for PRFs at and below 1 MHz, which is 4 dB below the reference level. For PRFs above 1 MHz the maximum permitted UWB EIRP is -35.7 dBm, which is 5.6 dB above the reference level. The required separation distances for PRFs at and below 1 MHz is 270 meters.

TABLE 4-21
Non-Dithered UWB Signal into ATCRBS Interrogator Receiver(UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	9.5	-45.3	-4.0	270
.01	9.5	-45.3	-4.0	270
.1	9.5	-45.3	-4.0	270
1	9.5	-45.3	-4.0	270
10	0.0	-35.7	5.6	NA
100	0.0	-35.7	5.6	NA
500	0.0	-35.7	5.6	NA

TABLE 4-22 shows that for a dithered signal, the maximum permitted UWB EIRP is -45.3 dBm regardless of the PRF, which is 4 dB below the reference level. The separation distance for a UWB device with an EIRP equal to the reference level and an ATCRBS interrogator receiver is 270 meters.

TABLE 4-22
Dithered UWB Signal into ATCRBS Interrogator Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	9.5	-45.3	-4.0	270
.01	9.5	-45.3	-4.0	270
.1	9.5	-45.3	-4.0	270
1	9.5	-45.3	-4.0	270
10	9.5	-45.3	-4.0	270
100	9.5	-45.3	-4.0	270
500	9.5	-45.3	-4.0	270

Discussion of Single Entry Results for ATCRBS Interrogator

These results indicate that operation of a UWB device at power a power level of -41.3 dBm/MHz RMS in the vicinity of a ATCRBS interrogator and on the frequency of 1090 MHz would exceed current ATCRBS interrogator interference protection requirements if the UWB device were operating in the same horizontal plane as the ATCRBS antenna and closer than 270 meters.

Transponder

The results for a non-dithered UWB signal analyses into an ATCRBS transponder receiver are shown in TABLE 4-23 for a UWB height of 2 meters. These results show that the maximum permitted UWB EIRP is -44.4 for PRFs at and below 1 MHz, which is 3.1 dB below the reference level. For PRFs at and above 10 MHz, the maximum permitted UWB EIRP is -37.0, which is 4.3 dB above the reference level. The horizontal separation distance for PRFs at and below 1 MHz is 20 meters.

TABLE 4-23
Non-Dithered UWB Signal into ATCRBS Transponder (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	7.4	-44.4	-3.1	.02
.01	7.4	-44.4	-3.1	.02
.1	7.4	-44.4	-3.1	.02
1	7.4	-44.4	-3.1	.02
10	0.0	-37.0	4.3	NA
100	0	-37.0	4.3	NA
500	0	-37.0	4.3	NA

The results for a dithered UWB signal analyses into an ATCRBS transponder receiver are shown in TABLE 4-24. The maximum permitted UWB EIRP is -44.4 dBm regardless of the PRF, which is 3.1 dB below the reference level.

TABLE 4-24
Dithered UWB Interference into ATCRBS Transponder (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	7.4	-44.4	-3.1	.02
.01	7.4	-44.4	-3.1	.02
.1	7.4	-44.4	-3.1	.02
1	7.4	-44.4	-3.1	.02
10	7.4	-44.4	-3.1	.02
100	7.4	-44.4	-3.1	.02
500	7.4	-44.4	-3.1	.02

Discussion of Single Entry Results for ATCRBS Transponder

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of an ATCRBS transponder and on the frequency of 1030 MHz would require 20 meters of horizontal separation distance to satisfy the ATCRBS transponder interference protection requirements.

4.7 DME (960-1200 MHz)

Analyses of potential interference from a single UWB device into a DME transponder and interrogator receiver was performed using the methodology described in Section 3, the DME characteristics given in Appendix A, and the analysis parameters shown in TABLEs 4-25 and 4-26.

TABLE 4-25
UWB and DME Interrogator Analysis Parameters

Parameter	Value
Protection Criteria	I/N=-7 dB (average (RMS) interference power)
Receiver Noise Power	-108 dBm
Maximum Interference	-115 dBm
Minimum Aircraft Height	30 meters
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

TABLE 4-26
UWB and DME Transponder Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -16dB (average (RMS) interference power)
Receiver Noise Power	-106 dBm
Maximum Interference	-122 dBm
Antenna Height	10 meters
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

Interrogator

The results for a non-dithered UWB signal analyses into a DME interrogator receiver are shown in TABLE 4-27 for a UWB height of 2 meters. These results show that the maximum permitted UWB EIRP for PRFs at and below 0.1 MHz is -45.5 dBm, which is 4.2 dB below the reference level. For PRFs above 0.1 MHz the maximum permitted UWB EIRP is -47.3 dBm, which is 6.0 dB below the reference level. For a UWB device with an EIRP equal to the reference level, the horizontal separation distance is 80 meters for PRFs at and below 0.1 MHz and 90 meters for PRFs above 0.1 MHz.

TABLE 4-27
Non-Dithered UWB Signal into DME Interrogator (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-45.5	-4.2	.08
.01	-1.9	-45.5	-4.2	.08
.1	-1.9	-45.5	-4.2	.08
1	0	-47.3	-6.0	.09
10	0	-47.3	-6.0	.09
100	0	-47.3	-6.0	.09
500	0	-47.3	-6.0	.09

The results for a dithered UWB signal into a DME interrogator receiver fora UWB height of 2 meters are shown in TABLE 4-28. The maximum permitted UWB EIRP is -45.5 dBm regardless of the PRF, which is 4.2 dB below the reference level.

TABLE 4-28
Dithered UWB Signal into DME Interrogator Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.9	-45.5	-4.2	.08
.01	-1.9	-45.5	-4.2	.08
.1	-1.9	-45.5	-4.2	.08
1	-1.9	-45.5	-4.2	.08
10	-1.9	-45.5	-4.2	.08
100	-1.9	-45.5	-4.2	.08
500	-1.9	-45.5	-4.2	.08

Analyses were not performed for a UWB height of 30 meters due to the geometry of the interference scenario.

Discussion of Single Entry Results for DME Interrogator

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of a DME interrogator and within the 960-1215 MHz frequency band would need 80 to 90 meters of horizontal separation distance to satisfy the current DME interrogator interference protection requirements.

Transponder

The results for a non-dithered UWB signal analyses into a DME transponder receiver are shown in TABLE 4-29 for a UWB height of 2 meters. These results show that the maximum permitted UWB EIRP is -63.2 dBm for PRFs at and below 0.1 MHz, which is 21.9 dB below the reference level. For PRFs above 0.1 MHz the maximum permitted UWB EIRP is -64.2 dBm, which is 22.9 dB below the reference level. The separation distances for a DME transponder and a UWB device with a EIRP equal to the reference level range from 0.26 km for PRFs at and below 0.1 MHz to 0.29 km for PRFs above 0.1 MHz.

TABLE 4-29
Non-Dithered UWB Signal into DME Transponder Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.0	-63.2	-21.9	.26
.01	-1.0	-63.2	-21.9	.26
.1	-1.0	-63.2	-21.9	.26
1	0.0	-64.2	-22.9	.29
10	0.0	-64.2	-22.9	.29
100	0.0	-64.2	-22.9	.29
500	0.0	-64.2	-22.9	.29

The results for a dithered UWB signal analyses into a DME transponder receiver are shown in TABLE 4-30 for a UWB height of 2 meters. The maximum permitted UWB EIRP is -63.2 dBm regardless of the PRF, which is 21.9 dB below the reference level. The separation distance is 0.26 km to satisfy the protection criteria with the UWB EIRP equal to the reference level.

TABLE 4-30
Dithered UWB Signal into DME Transponder Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.0	-63.2	-21.9	.26
.01	-1.0	-63.2	-21.9	.26
.1	-1.0	-63.2	-21.9	.26
1	-1.0	-63.2	-21.9	.26
10	-1.0	-63.2	-21.9	.26
100	-1.0	-632	-21.9	.26
500	-1.0	-63.2	-21.9	.26

Analyses was also performed for a UWB height of 30 meters and are shown in TABLE 4-31. These results show that the maximum permitted UWB EIRP is -56.3 dBm for PRFs at and below 0.1 MHz, which is 15.0 dB below the reference level. For PRFs above 0.1 MHz the maximum permitted UWB EIRP is -57.3 dBm, which is 16.0 dB below the reference level. The separation distances for a UWB device with a EIRP equal to the reference level range from 0.26 km for PRFs at and below 0.1 MHz to 0.29 km for PRFs above 0.1 MHz.

TABLE 4-31
Non-Dithered UWB Signal into DME Transponder Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS)
.001	-1.0	-56.3	-15.0	.26
.01	-1.0	-56.3	-15.0	.26
.1	-1.0	-56.3	-15.0	.26
1	0.0	-57.3	-16.0	.29
10	0.0	-57.3	-16.0	.29
100	0.0	-57.3	-16.0	.29
500	0.0	-57.3	-16.0	.29

The results for a dithered UWB signal analyses into a DME transponder receiver are shown in TABLE 4-32 for a UWB height of 30 meters. The maximum permitted UWB EIRP is -56.3 dBm regardless of the PRF, which is 15.0 dB below the reference level. The separation distance is 0.26 km to satisfy the protection criteria with the UWB EIRP equal to the reference level.

TABLE 4-32
Dithered UWB Signal into DME Transponder Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.0	-56.3	-15.0	.26
.01	-1.0	-56.3	-15.0	.26
.1	-1.0	-56.3	-15.0	.26
1	-1.0	-56.3	-15.0	.26
10	-1.0	-56.3	-15.0	.26
100	-1.0	-56.3	-15.0	.26
500	-1.0	-56.3	-15.0	.26

Discussion of Single Entry Results for DME Transponder

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of a DME transponder and within the 960-1215 MHz frequency band would need 0.26 to 0.29 km of separation distance to satisfy the current DME transponder interference protection requirements.

4.8 MLS (5000-5250 MHz)

Analyses of potential interference from a single UWB device into a MLS receiver was performed using the methodology described in Section 3, the MLS characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-33. The MLS receiver height represents an aircraft Category II landing decision height, including terrain.

TABLE 4-33
UWB and MLS Analysis Parameters

Parameter	Value
Permissible Interference	I=-134 dBm (average (RMS) interference power)
Minimum Aircraft Height	30 meters
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-34 for a UWB height of 2 meters. These results show that for PRFs at and below 0.1 MHz the maximum permitted UWB EIRP -45.4 dBm, which is 4.1 dB below the reference level. For PRFs at and above 1 MHz the maximum EIRP is -56.3 dB, which is 12.3 dB below the reference level. For a UWB device with an EIRP equal to the reference level this requires a horizontal separation distance of 70 meters to satisfy the MLS receiver protection criteria for PRFs at and below 0.1 MHz and 160 meters for PRFs above 0.1 MHz.

TABLE 4-34
Non-Dithered UWB Signal into MLS Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-8.2	-45.4	-4.1	0.07
.01	-8.2	-45.4	-4.1	0.07
.1	-8.2	-45.4	-4.1	0.07
1	0	-56.3	-12.3	0.16
10	0	-56.3	-12.3	0.16
100	0	-56.3	-12.3	0.16
500	0	-56.3	-12.3	0.16

The results for a dithered UWB signal are shown in TABLE 4-35. These results show that the maximum permitted UWB EIRP is -45.4 dBm regardless of the PRF, which is 4.1 dB below the reference level. The horizontal separation distance is 70 meters.

TABLE 4-35
Dithered UWB Signal into MLS Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-8.2	-45.4	-4.1	0.07
.01	-8.2	-45.4	-4.1	0.07
.1	-8.2	-45.4	-4.1	0.07
1	-8.2	-45.4	-4.1	0.07
10	-8.2	-45.4	-4.1	0.07
100	-8.2	-45.4	-4.1	0.07
500	-8.2	-45.4	-4.1	0.07

Analyses was not performed for a UWB height of 30 meters due to the geometry of the scenario. Figure 4-13 shows the maximum permitted UWB EIRP for a height of 2 meters.

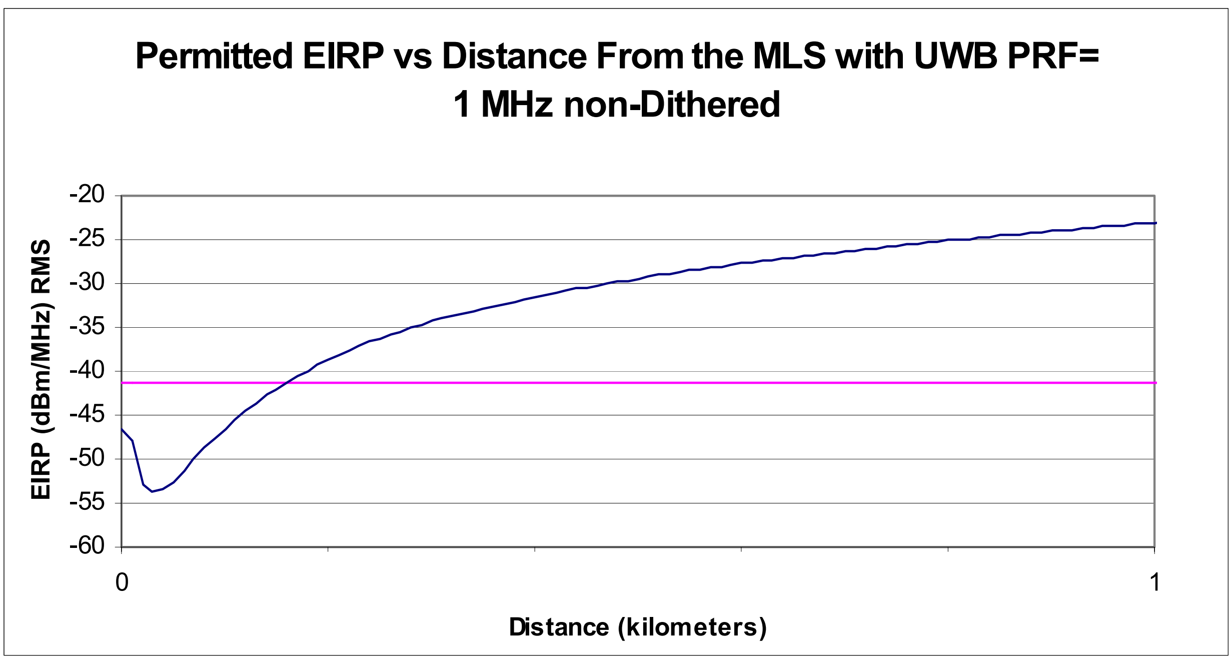

Figure 4-13. **Maximum Permissible UWB EIRP for non-Dithered 1 MHz PRF (UWB Height = 2 m).**

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of MLS receivers and within the 5030-5091 MHz frequency band would require about 70 to 160 meters of horizontal separation distance (measured from centerline of aircraft at 30 meter altitude) to satisfy the MLS receiver protection criteria.

4.9 SARSAT LUT (1544-1545 MHz)

The SARSAT LUT analyses consists of two subsections delineating protection criteria with an average (RMS) interference power and peak interference, respectively.

4.9.a SARSAT LUT (1544-1545 MHz)

Analyses of potential interference from a single UWB device into a SARSAT LUT receiver was performed using the methodology described in Section 3, the SARSAT LUT characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-36a. The SARSAT LUT antenna height in TABLE 4-36a is a typical value.

TABLE 4-36a
UWB and SARSAT LUT Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -9 dB (average (RMS) interference power)
Antenna Height	12 meters
Antenna Vertical Tilt Angle	0 degrees
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-37a for a UWB height of 2 meters. These results show that for PRFs at and below 0.1 MHz the maximum permitted UWB EIRP is -68.4 dBm/MHz, which is 27.1 dB below the reference level. For PRFs at and above 1 MHz the level is -69.4 dBm/MHz, which is 28.1 dB below the reference level. The separation distance for a UWB device with an EIRP equal to the reference level and a SARSAT LUT is 2.9 km for UWB PRFs at and below 0.1 MHz and 3.1 km for PRFs at and above 1 MHz. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-13a for a non-dithered PRF of 1 MHz and a UWB height of 2 meters.

TABLE 4-37a
Non-Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 2m)

PRF (MHz)	Average BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP equals -41.3 dBm/MHz RMS
.001	-1.0	-68.4	-27.1	2.9
.01	-1.0	-68.4	-27.1	2.9
.1	-1.0	-68.4	-27.1	2.9
1	0.0	-69.4	-28.1	3.1
10	0.0	-69.4	-28.1	3.1
100	0.0	-69.4	-28.1	3.1
500	0.0	-69.4	-28.1	3.1

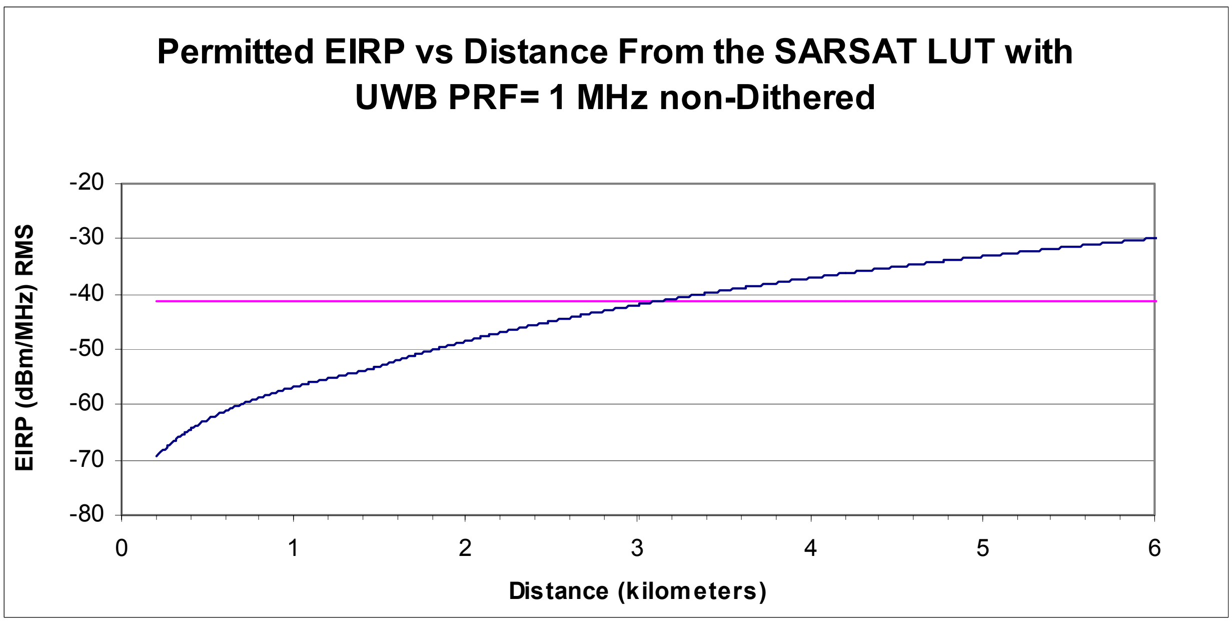

Figure 4-13a. Maximum Permitted UWB EIRP for non-Dithered PRF of 1 MHz (UWB Height = 2m).

The results for a dithered UWB signal analyses are shown in TABLE 4-38a for a UWB height of 2 meters. These results show that the maximum permitted UWB EIRP is -68.4 dBm regardless of the PRF, which is 27.1 dB below the reference level. The separation distance for a dithered UWB device with an EIRP equal to the reference level and a SARSAT LUT is 2.9 km regardless of the UWB PRF. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-14a for a dithered PRF of 1 MHz and a UWB height of 2 meters.

TABLE 4-38a
Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 2m)

PRF (MHz)	Average BWCF (dB)	Maximum Permitted UWB EIRP (dBm)	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP equals-41.3 dBm/MHz RMS (km)
.001	-1.0	-68.4	-27.1	2.9
.01	-1.0	-68.4	-27.1	2.9
.1	-1.0	-68.4	-27.1	2.9
1	-1.0	-68.4	-27.1	2.9
10	-1.0	-68.4	-27.1	2.9
100	-1.0	-68.4	-27.1	2.9
500	-1.0	-68.4	-27.1	2.9

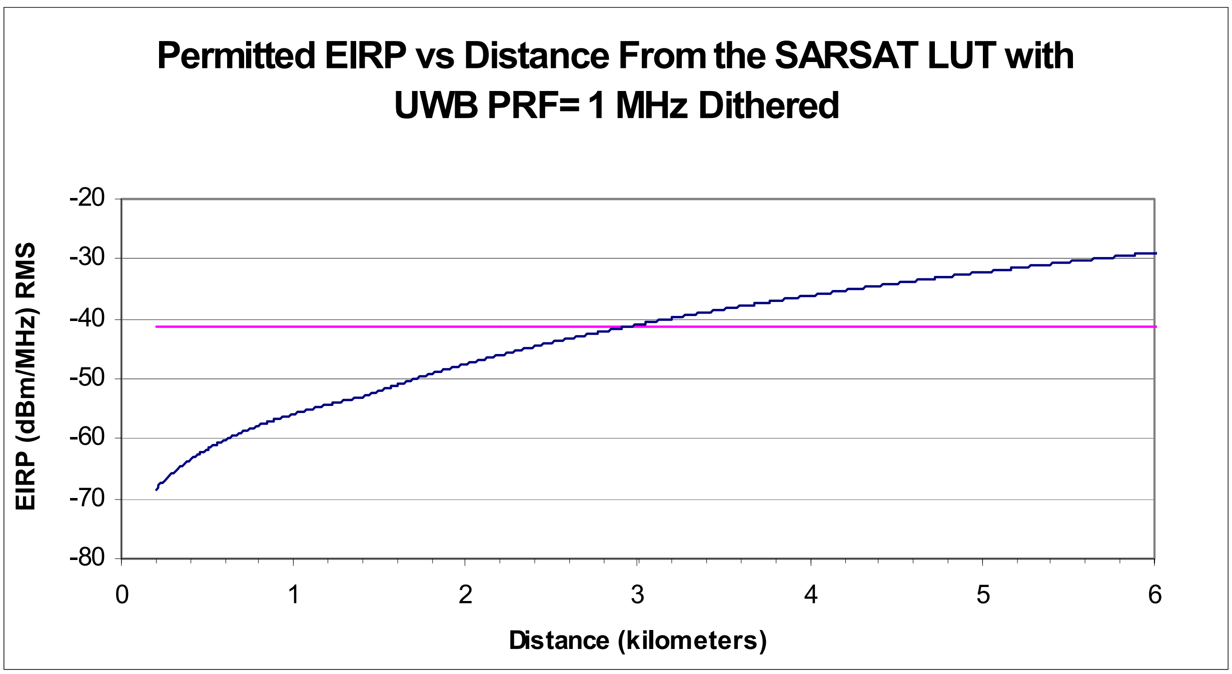

Figure 4-14a. Maximum Permitted UWB EIRP for Dithered PRF of 1 MHz (UWB Height = 2m).

Analyses was also performed for a UWB height of 30m. The results for a non-dithered UWB signal analyses are shown in TABLE 4-39a.

TABLE 4-39a
Non-Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 30m)

PRF (MHz)	Average BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
001	-1.0	-65.0	-23.7	5.5
.01	-1.0	-65.0	-23.7	5.5
.1	-1.0	-65.0	-23.7	5.5
1	0.0	-66.0	-24.7	6.1
10	0.0	-66.0	-24.7	6.1
100	0.0	-66.0	-24.7	6.1
500	0.0	-66.0	-24.7	6.1

These results show that for PRFs at and below 0.1 MHz the maximum permitted UWB EIRP is -65.0 dBm/MHz, which is 23.7 dB below the reference level. For PRFs at and above 1 MHz the level is -66.0 dBm/MHz, which is 24.7 dB below the reference level. The separation distance for a UWB device with an EIRP equal to the reference level and a SARSAT LUT is 5.5 km for UWB PRFs at and below 0.1 MHz and 6.1 km for PRFs at and above 1 MHz. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-15a for a non-dithered PRF of 1 MHz and a UWB height of 30 meters.

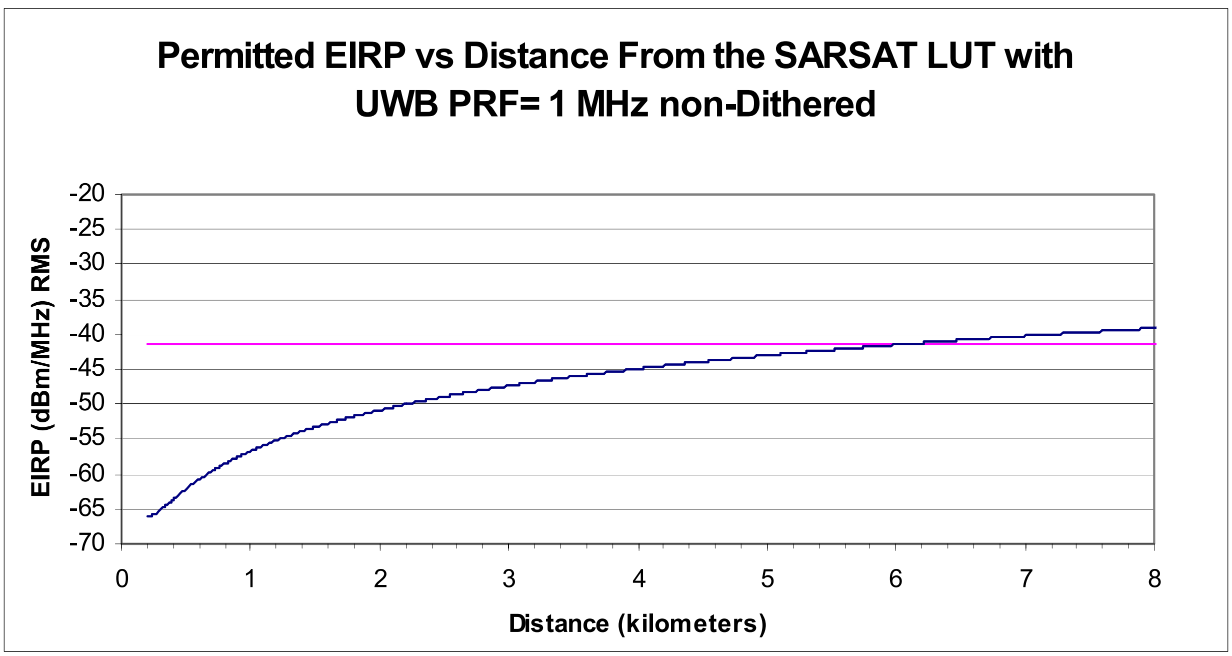

Figure 4-15a. Maximum Permitted UWB EIRP for non-Dithered PRF of 1MHz (UWB Height =30m).

The results for a dithered UWB signal analyses are shown in TABLE 4-40a for a UWB height of 30 meters.

TABLE 4-40a
Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 30m)

PRF (MHz)	Average BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.0	-65.0	-23.7	5.5
.01	-1.0	-65.0	-23.7	5.5
.1	-1.0	-65.0	-23.7	5.5
1	-1.0	-65.0	-23.7	5.5
10	-1.0	-65.0	-23.7	5.5
100	-1.0	-65.0	-23.7	5.5
500	-1.0	-65.0	-23.7	5.5

These results show that the maximum permitted UWB EIRP is -65.0 dBm regardless of the PRF, which is 23.7 dB below the reference level. The separation distance for a dithered UWB device with an EIRP equal to the reference level and a SARSAT LUT is 5.5 km regardless of the UWB PRF. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-16a for a dithered PRF of 1 MHz and a UWB height of 30 meters.

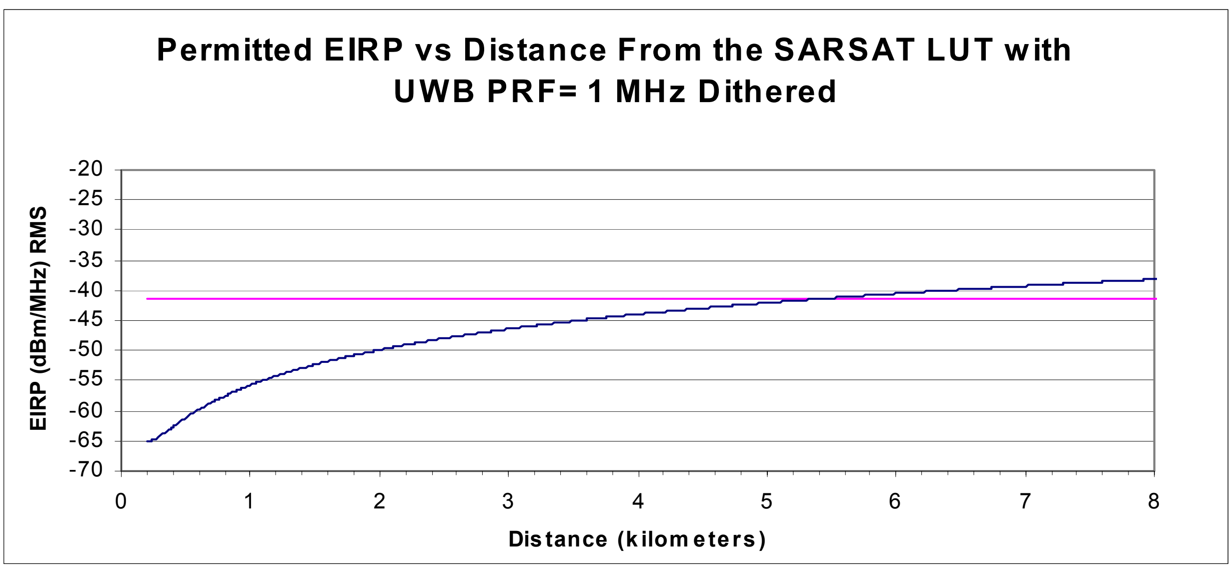

Figure 4-16a. Maximum Permitted UWB EIRP for Dithered PRF of 1MHz (UWB Height =30m).

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of a SARSAT LUT and within the 1544-1545 MHz frequency band would exceed the current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the SARSAT LUT less capable of receiving distress alert transmissions from satellites relayed from maritime, aviation, and land users.

Four factors significantly influence these results, namely, the LUT antenna height, LUT antenna tilt angle, the height of the UWB device, and the UWB PRF. When the LUT antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater LUT antenna gain. The analytical model takes into account the height of the LUT, the height of the UWB device, and the LUT tilt angle to compute the LUT antenna gain, which is then used in the UWB interference calculations. A higher antenna gain results in a lower maximum permitted UWB EIRP and increases the separation distance when the EIRP is equal to the reference level.

Using the average BWCF in this analyses results in a small BWCF of -1.0 dB. This equates to separation distances of up to 6.1 km if they are operated in the main beam of the LUT. In Section 4.10b the analyses is based on a peak BWCF, which results in significantly larger separation distances and/or stricter limits on the UWB EIRP.

4.9.b SARSAT LUT (1544-1545 MHz)

Analyses of potential interference from a single UWB device into a SARSAT LUT receiver was performed using the methodology described in Section 3, the SARSAT LUT characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-36b. The SARSAT LUT antenna height in TABLE 4-36b is a typical value.

TABLE 4-36b
UWB and SARSAT LUT Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -9 dB peak interference
Antenna Height	12 meters
Antenna Tilt Angle	0 degrees
UWB Device Height	2 meters, 30 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-37b for a UWB height of 2 meters. These results show that the SARSAT LUT interference protection criteria is exceeded for all UWB PRFs in TABLE 4-37b. The maximum permitted UWB EIRP ranges from -104.4 dBm for a PRF of 0.001 MHz to -69.4 dBm for a PRF of 500 MHz. These levels are 63.1 and 28.1 dB below the reference level. For UWB devices with an EIRP equal to the reference level, the distance separations range from beyond 15 km for a PRF of 0.001 MHz to 3.1 km for a PRF of 500 MHz to satisfy the SARSAT LUT interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-13b for a non-dithered PRF of 1 MHz and a UWB height of 2 meters.

TABLE 4-37b
Non-Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 2m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	35.0	-104.4	-63.1	>15
.01	25.0	-94.4	-53.1	12.0
.1	15.0	-84.4	-43.1	7.3
1	5.0	-74.4	-33.1	4.2
10	0.0	-69.4	-28.1	3.1
100	0.0	-69.4	-28.1	3.1
500	0.0	-69.4	-28.1	3.1

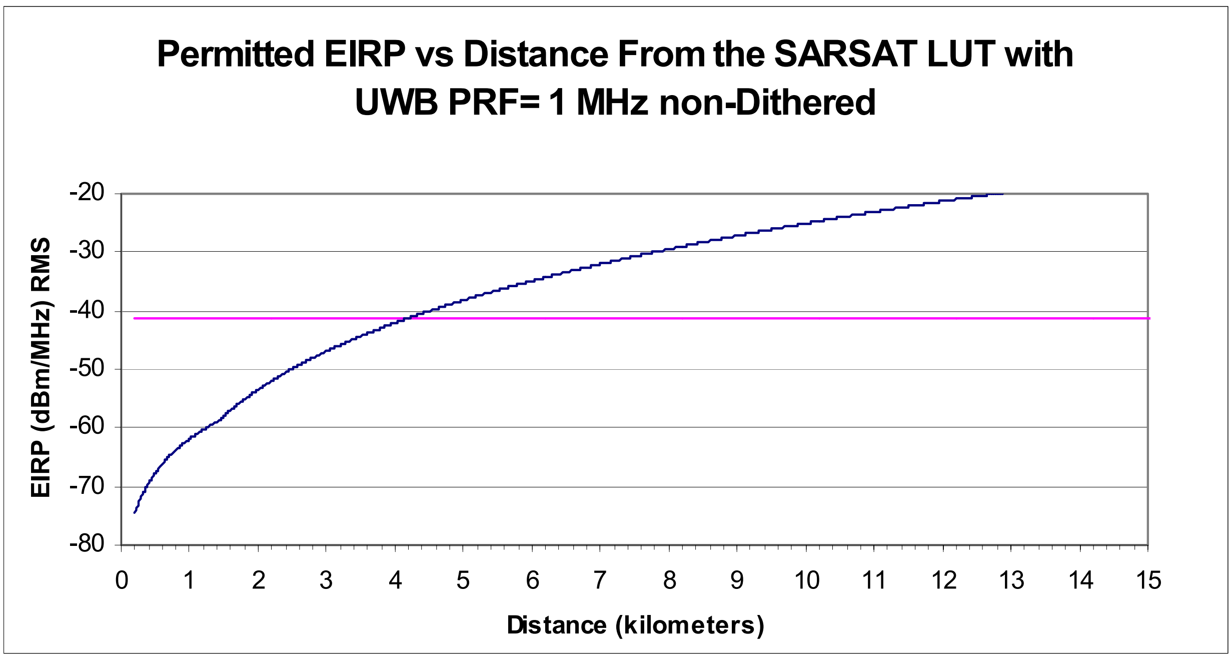

Figure 4-13b. Maximum Permitted UWB EIRP for non-Dithered PRF of 1 MHz (UWB Height = 2m).

The results for a dithered UWB signal analyses are shown in TABLE 4-38b for a UWB height of 2 meters. These results show that the SARSAT LUT interference protection criteria is exceeded for all UWB PRFs in TABLE 4-38b. The maximum permitted UWB EIRP ranges from -104.4 dBm for a PRF of 0.001 MHz to -68.4 dBm for a PRF of 500 MHz. These levels are 63.1 and 27.1 dB below the reference level. For UWB devices with an EIRP equal to the reference level, the distance separations range from beyond 15 km for a PRF of 0.001 MHz to 2.9 km for a PRF of 500 MHz km to satisfy the SARSAT LUT interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-14b for a dithered PRF of 1 MHz and a UWB height of 2 meters.

TABLE 4-38b
Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 2m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	35.1	-104.4	-63.1	>15
.01	25.1	-94.4	-53.1	12.0
.1	15.1	-84.4	-43.1	7.3
1	5.1	-74.4	-33.1	4.2
10	-1.0	-68.4	-27.1	2.9
100	-1.0	-68.4	-27.1	2.9
500	-1.0	-68.4	-27.1	2.9

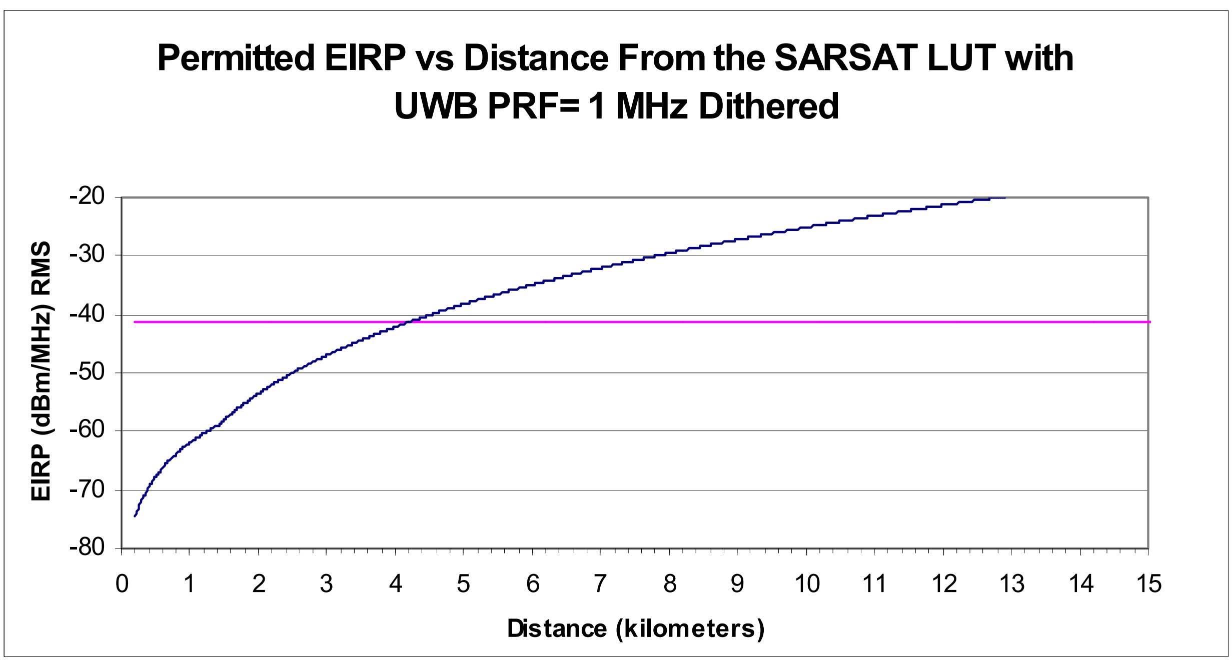

Figure 4-14b. Maximum Permitted UWB EIRP for Dithered PRF of 1 MHz (UWB Height = 2m).

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal analyses are shown in TABLE 4-39b.

TABLE 4-39b
Non-Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 30 m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	35.0	-100.90	-59.6	>15
.01	25.0	-90.9	-49.6	>15
.1	15.0	-80.9	-39.6	>15
1	5.0	-70.9	-29.6	11.3
10	0.0	-65.9	-24.6	6.1
100	0.0	-65.9	-24.6	6.1
500	0.0	-65.9	-24.6	6.1

These results show that the SARSAT LUT interference protection criteria is exceeded for all UWB PRFs in TABLE 4-39b. The maximum permitted UWB EIRP ranges from -101 dBm for a PRF of 0.001 MHz to -66 dBm for a PRF of 500 MHz. These levels are 59.6 and 24.6 dB below the reference level. For UWB devices with an EIRP equal to the reference level, the distance separations range from beyond 15 km for a PRF of 0.001 MHz to 6.1 km for a PRF of 500 MHz to satisfy the SARSAT LUT interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-15b for a non-dithered PRF of 1 MHz and a UWB height of 30 meters.

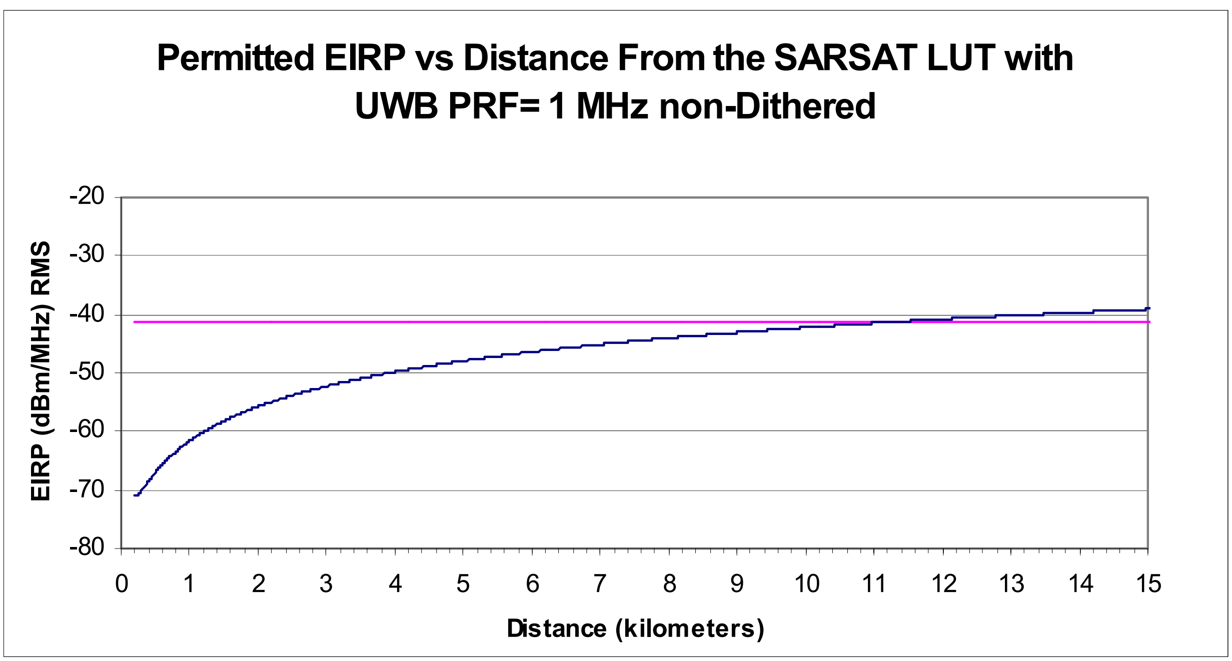

Figure 4-15b. Maximum Permitted UWB EIRP for non-Dithered PRF of 1MHz (UWB Height =30 m).

The results for a dithered UWB signal analyses are shown in TABLE 4-40b for a UWB height of 30 meters.

TABLE 4-40b
Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 30 m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	35.1	-100.9	-59.6	>15
.01	25.1	-90.9	-49.6	>15
.1	15.1	-80.9	-39.6	>15
1	5.1	-70.9	-29.6	11.4
10	-1.0	-64.9	-23.6	5.4
100	-1.0	-64.9	-23.6	5.4
500	-1.0	-64.9	-23.6	5.4

These results show that the SARSAT LUT interference protection criteria is exceeded for all UWB PRFs in TABLE 4-40b. The maximum permitted UWB EIRP ranges from -100.9 dBm for a PRF of 0.001 MHz to -64.9 dBm for a PRF of 500 MHz. These levels are 59.6 and 23.6 dB below the reference level. For UWB devices with an EIRP equal to the reference level, the distance separations range from beyond 15 km for a PRF of 0.001 MHz to 5.4 km for a PRF of 500 MHz to satisfy the SARSAT LUT interference protection criteria. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-16b for a dithered PRF of 1 MHz and a UWB height of 30 meters.

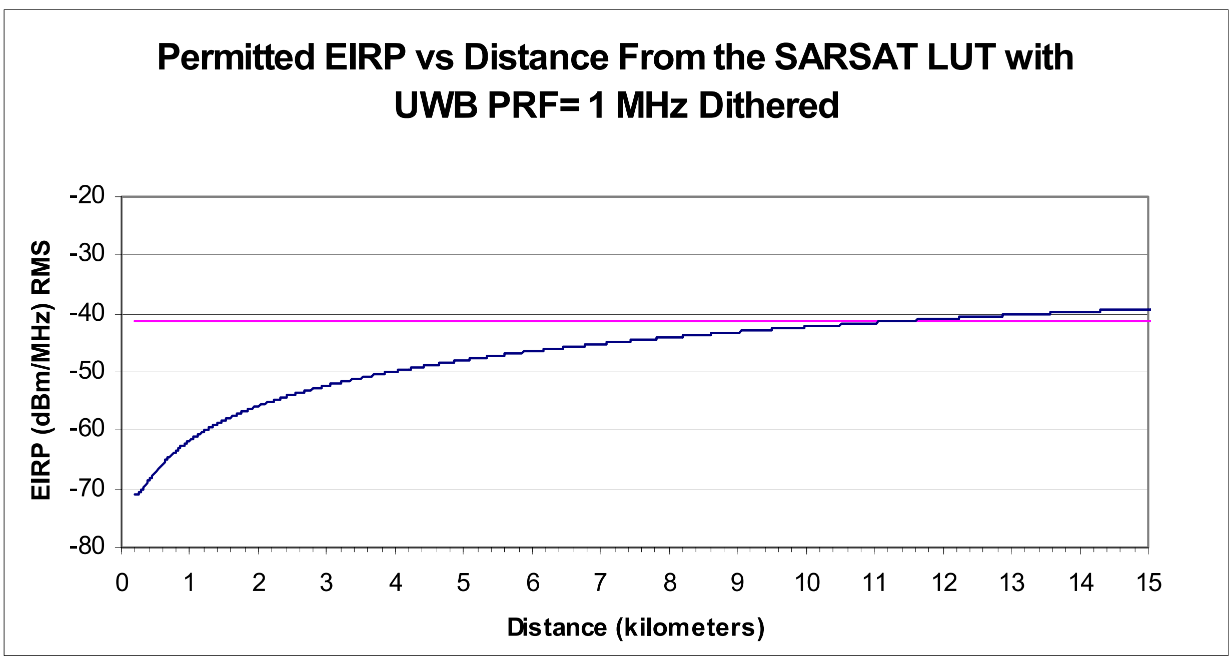

Figure 4-16b. Maximum Permitted UWB EIRP for Dithered PRF of 1MHz (UWB Height = 30 m).

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of a SARSAT LUT and within the 1544-1545 MHz frequency band would exceed the current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the SARSAT LUT less capable of receiving distress alert transmissions from satellites relayed from maritime, aviation, and land users.

Four factors significantly influence these results, namely, the LUT antenna height, LUT antenna tilt angle, the height of the UWB device, and the UWB PRF. When the LUT antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater LUT antenna gain. The analytical model takes into account the height of the LUT, the height of the UWB device, and the LUT tilt angle to compute the LUT antenna gain, which is then used in the UWB interference calculations. A higher antenna gain results in a lower maximum permitted UWB EIRP and increases the separation distance when the EIRP is equal to the reference level.

The PRF of the UWB device determines the BWCF in the analyses. At low UWB PRFs the BWCF is large which makes the maximum permitted UWB EIRP lower and increases the separation distances when the UWB EIRP is equal to the reference level.

4.10 4 GHz EARTH STATION (3750 MHz)

This analysis of the 4 GHz Earth station consists of four subsections. As with the SARSAT LUT, the 4 GHz Earth station analyses consider protection criteria with an average (RMS) interference power and peak interference coupled with antenna elevation angles at 5 and 20 degrees.

4.10.a 4 GHz Earth Station (3750 MHz with 5 Degree Elevation)

Analyses of potential interference from a single UWB device into a 4 GHz Earth station receiver was performed using the methodology described in Section 3, the 4 GHz Earth station characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-41a. The 4 GHz Earth station radar antenna height in TABLE 4-41a is a typical value.

TABLE 4-41a
UWB and 4 GHz Earth Station Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (average (RMS) interference power)
Antenna Height	3 meters
Antenna Tilt Angle	5 degrees above horizon
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz

The results for a non-dithered UWB signal analyses are shown in TABLE 4-42a for a UWB height of 2 meters. These results show that the 4 GHz Earth station interference protection criteria is exceeded with UWB PRFs slightly above 10 MHz. For PRFs slightly above 10 MHz the maximum permitted EIRP is -34.8 dBm, which is 6.5 dB above the reference level. For UWB devices with PRFs at or below 10 MHz and the UWB EIRP equal the reference level, the distance separations range from 200 to 630 meters to satisfy the 4 GHz Earth station interference protection criteria. A graph of the maximum permitted UWB EIRP for a non-dithered PRF of 10 MHz versus distance is shown in Figure 4-18a.

TABLE 4-42a
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
0.001	16.0	-50.8	-9.5	0.63
0.01	16.0	-50.8	-9.5	0.63
0.1	16.0	-50.8	-9.5	0.63
1	16.0	-40.8	-9.5	0.63
10	6.0	-42.3	0.5	0.2
100	0.0	-34.8	6.5	0.2
500	0.0	-34.8	6.5	0.2

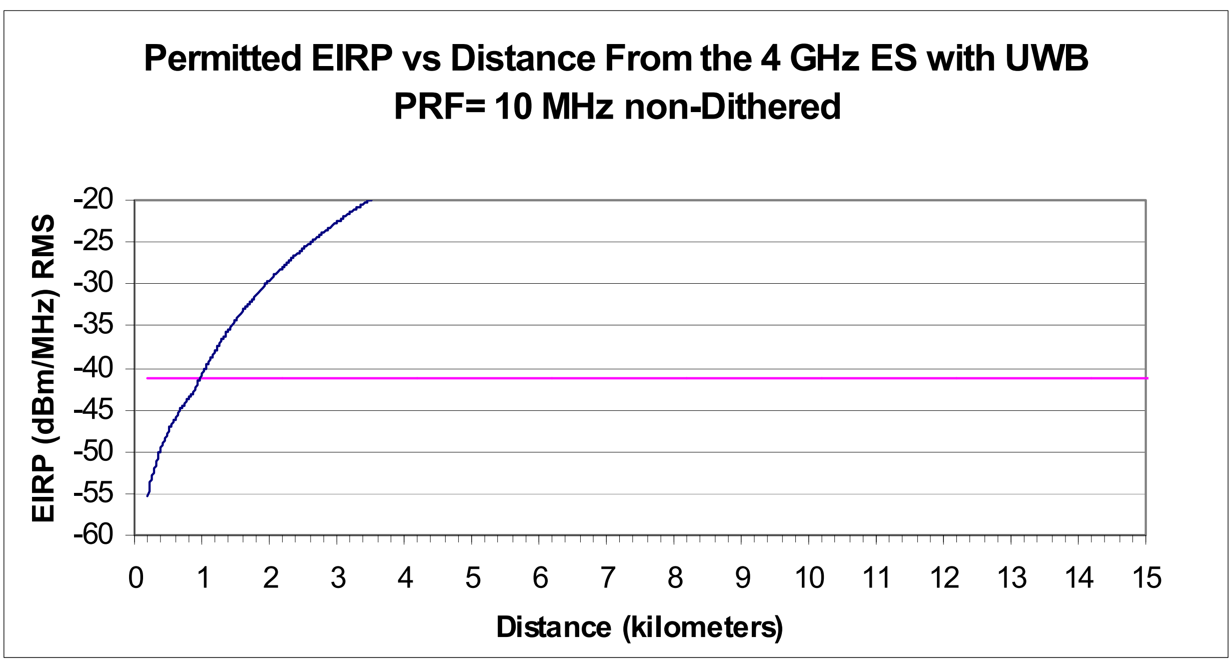

Figure 4-18a. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 2m).

The results for a dithered UWB signal are shown in TABLE 4-43a for a UWB height of 2 meters. The results for a dithered signal show that the maximum allowable UWB EIRP is below the reference level for all PRFs in TABLE 4-43a. The distance separation is 630 meters to satisfy the 4 GHz Earth station interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted UWB EIRP for a dithered PRF of 10 MHz versus distance is shown in Figure 4-19a.

TABLE 4-43a
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
0.001	16.0	-50.8	-9.5	0.63
0.01	16.0	-50.8	-9.5	0.63
0.1	16.0	-50.8	-9.5	0.63
1	16.0	-50.8	-9.5	0.63
10	16.0	-50.8	-9.5	0.63
100	16.0	-50.8	-9.5	0.63
500	16.0	-50.8	-9.5	0.63

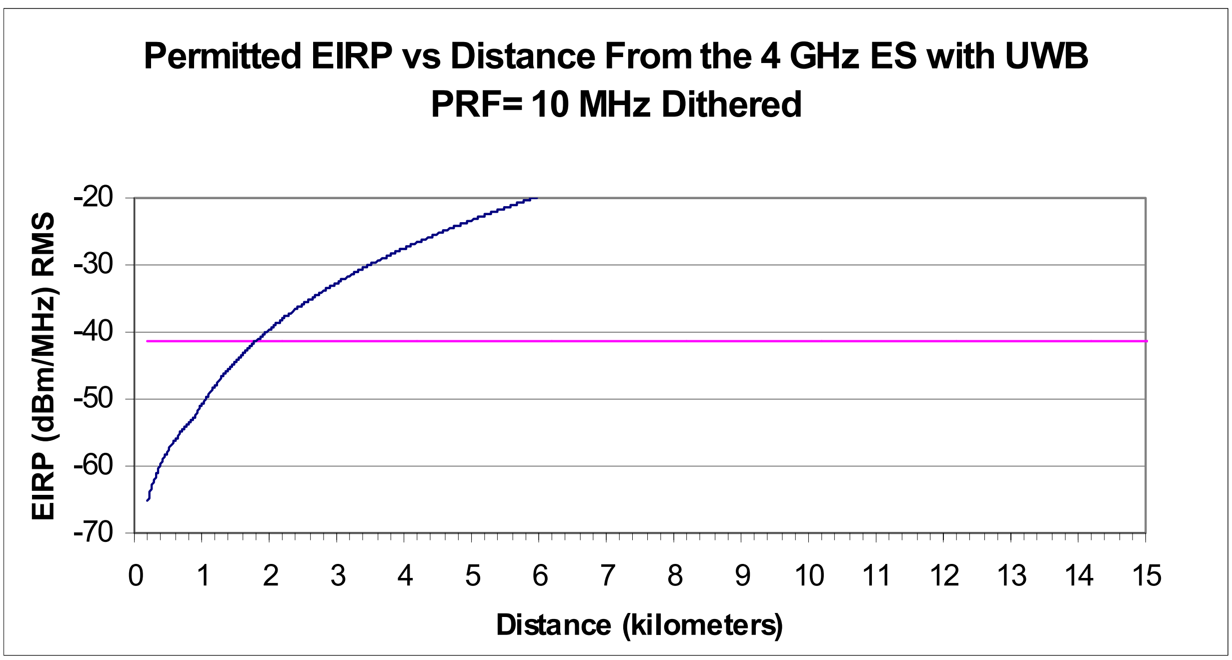

Figure 4-19a. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 2m).

Analyses was also performed for a UWB height of 30m. The results for a non-dithered UWB signal are shown in TABLE 4-44a.

TABLE 4-44a
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht =30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS (km)
0.001	16.0	-76.6	-35.3	1.01
0.01	16.0	-76.6	-35.3	1.01
0.1	16.0	-76.6	-35.3	1.01
1	16.0	-76.6	-35.3	1.01
10	6.0	-66.6	-25.3	0.56
100	0.0	-60.6	-19.3	0.44
500	0.0	-60.6	-19.3	0.44

The table shows that the maximum permitted UWB EIRP ranges from -76.6 dBm for a PRF of .001 MHz to -60.6 dBm for a PRF of 500 MHz. The separation distances range from beyond 1 km to 0.44 km to satisfy the Earth station interference protection criteria when the UWB EIRP is equal to the reference level.

The results for a dithered signal and a UWB height of 30 meters are shown in TABLE 4-45a. The table shows that the maximum permitted UWB EIRP ranges from -78.1 dBm for all PRFs. The separation distance is 1.13 km to satisfy the Earth station interference protection criteria when the EIRP is equal to the reference level. A graph of the maximum permitted UWB EIRP for a 10 MHz dithered PRF versus distance for a UWB height of 30 meters is shown in Figure 4-20a.

TABLE 4-45a
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht =30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference level (dB)	Distance Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS (km)
0.001	16.0	-76.6	-35.3	1.01
0.01	16.0	-76.6	-35.3	1.01
0.1	16.0	-76.6	-35.3	1.01
1	16.0	-76.6	-35.3	1.01
10	16.0	-76.6	-35.3	1.01
100	16.0	-76.6	-35.3	1.01
500	16.0	-76.6	-35.3	1.01

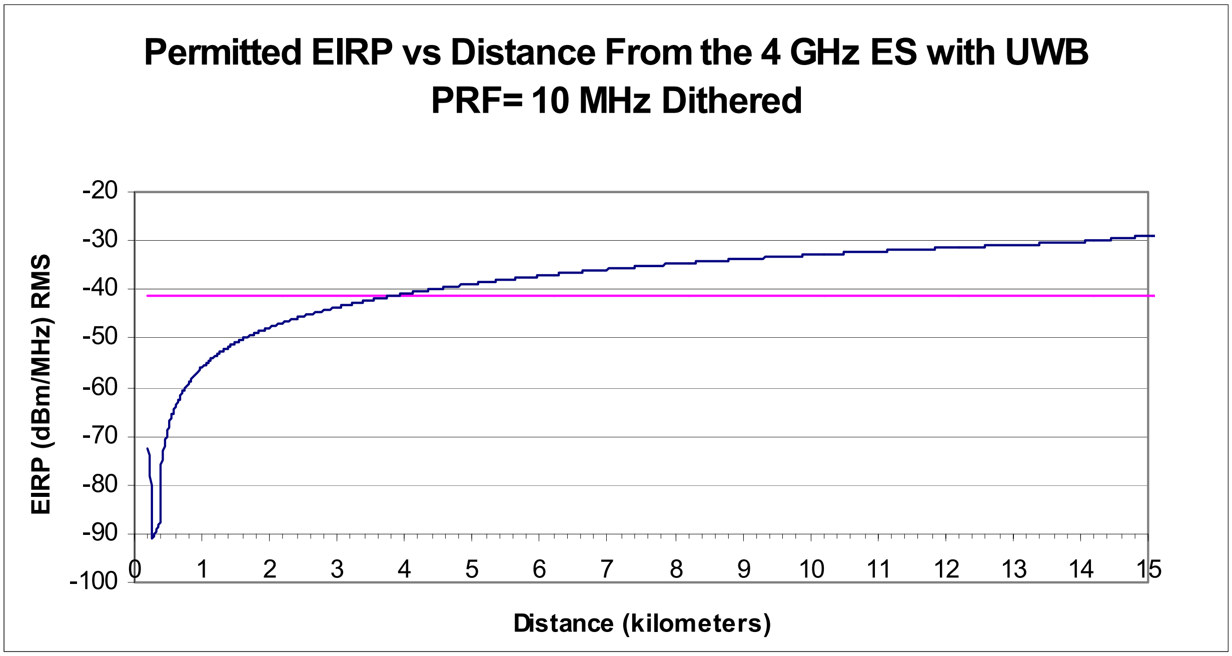

Figure 4-20a. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 30m).

Discussion of Single Entry Results

These results indicate that operation of UWB devices at an average (RMS) power level of -41.3 dBm in the vicinity of 4 GHz Earth station and at 3750 MHz would exceed current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the Earth station less capable of receiving satellite downlink transmissions.

Four factors significantly influence these results, namely, the Earth station antenna height, Earth station antenna tilt angle, the height of the UWB device, and the UWB PRF. When the Earth station antenna and the UWB device align such that main beam coupling occurs, the Earth station antenna will gather more UWB interference than the case of sidelobe coupling, which raises the overall noise power level. This effect is shown in Figure 4-20a. For compatible operations, this requires a lower permitted UWB EIRP and a longer separation distance than the Earth station and the UWB device coupling off axis. The Earth station antenna gathers less UWB interference when sidelobe coupling occurs which will allow a higher UWB EIRP and shorten the separation distance.

The PRF of the UWB device determines the BWCF in the analyses. At low UWB PRFs the BWCF is large which makes the maximum permitted UWB EIRP lower and increases the separation distances when the UWB EIRP is equal to the reference level.

4.10b 4 GHz Earth Station (Peak Power BWCF, 3750 MHz with 5 Degree Elevation)

Analyses of potential interference from a single UWB device into a 4 GHz Earth station receiver was performed using the methodology described in Section 3, the 4 GHz Earth station characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-41b. The 4 GHz Earth station radar antenna height in TABLE 4-41b is a typical value.

TABLE 4-41b
UWB and 4 GHz Earth Station Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (peak interference power)
Antenna Height	3 meters
Antenna Tilt Angle	5 degrees above horizon
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-42b for a UWB height of 2 meters. These results show that the 4 GHz Earth station interference protection criteria is exceeded with UWB PRFs at or below 10 MHz. For PRFs above 10 MHz the maximum permitted EIRP is -34.8 dBm, which is 6.5 dB above the reference level. For UWB devices with PRFs at or below 10 MHz and the UWB EIRP equal the reference level, the distance separations range from 1.0 km to 12.3 km to satisfy the 4 GHz Earth station interference protection criteria. A graph of the maximum permitted UWB EIRP for a non-dithered PRF of 10 MHz versus distance is shown in Figure 4-18b.

TABLE 4-42b
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	69.0	-103.8	-62.5	12.3
.01	59.0	-93.8	-52.5	8.4
.1	49.0	-83.8	-42.5	5.1
1	39.0	-73.8	-32.5	3.0
10	19.0	-53.8	-12.5	1.0
100	0.0	-34.8	6.5	NA
500	0.0	-34.8	6.5	NA

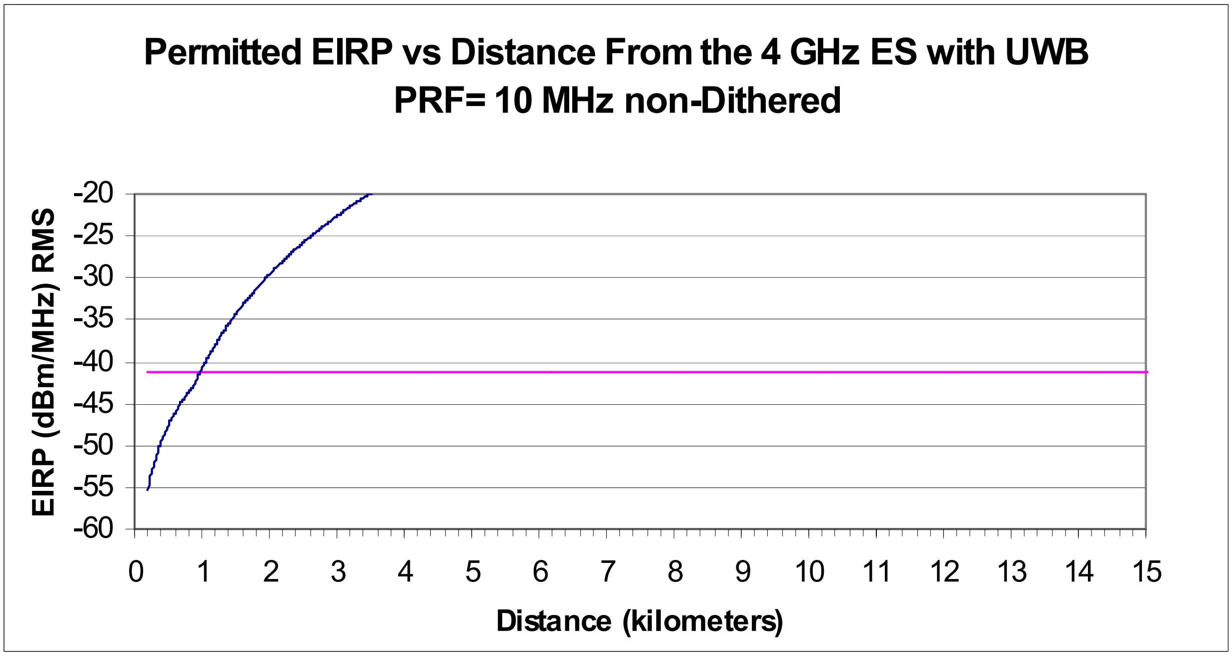

Figure 4-18b. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 2m).

The results for a dithered UWB signal are shown in TABLE 4-43b for a UWB height of 2 meters. The results for a dithered signal show that the maximum allowable UWB EIRP is below the reference level for all PRFs in TABLE 4-43b. The distance separations range from 0.60 km to 13.2 km to satisfy the 4 GHz Earth station interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted UWB EIRP for a dithered PRF of 10 MHz versus distance is shown in Figure 4-19b.

TABLE 4-43b
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Height = 2m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	69.0	-103.8	-62.5	13.2
.01	59.0	-93.8	-52.5	8.4
.1	49.0	-83.8	-42.5	5.1
1	39.0	-73.8	-32.5	3.0
10	29.0	-63.8	-22.5	1.7
100	19.0	-53.8	-12.5	1.0
500	16.0	-50.8	-9.5	.60

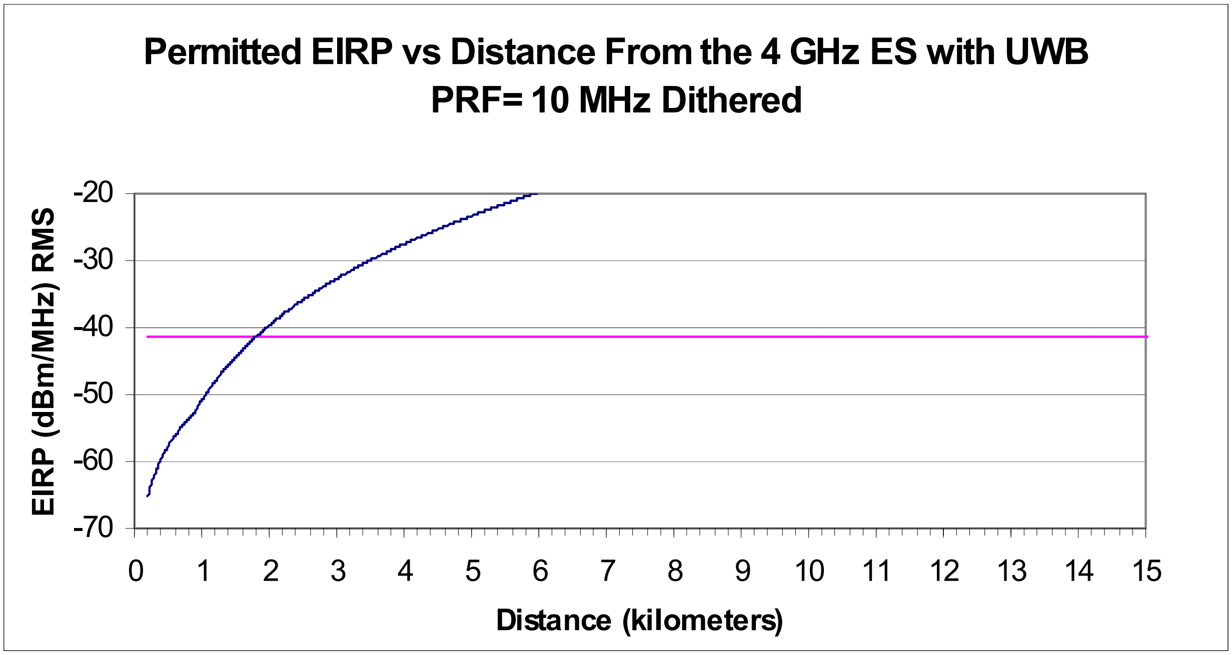

Figure 4-19b. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 2m).

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal are shown in TABLE 4-44b.

TABLE 4-44b
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Height = 30 m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	69.0	-129.6	-88.3	>15
.01	59.0	-119.6	-78.3	>15
.1	49.0	-109.6	-68.3	>15
1	39.0	-99.6	-58.3	10.1
10	19.0	-79.6	-38.3	1.3
100	0.0	-60.6	-19.3	.44
500	0.0	-60.6	-19.3	.44

The table shows that the maximum permitted UWB EIRP ranges from -129.6 dBm for a PRF of 0.001 MHz to -60.6 dBm for a PRF of 500 MHz. The separation distances range from beyond 15 to 0.44 km to satisfy the Earth station interference protection criteria when the UWB EIRP is equal to the reference level.

The results for a dithered signal and a UWB height of 30 meters are shown in TABLE 4-45b.

TABLE 4-45b
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Height = 30 m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	69.0	-129.6	-88.3	>15
.01	59.0	-119.6	-78.3	>15
.1	49.0	-109.6	-68.3	>15
1	39.0	-99.6	-58.3	10.2
10	29.0	-89.6	-48.3	3.3
100	19.0	-79.6	-38.3	1.3
500	16.0	-76.6	-35.3	1.0

The table shows that the maximum permitted UWB EIRP ranges from -129.6 dBm for a PRF of 0.001 MHz to -76.6 dBm for a PRF of 500 MHz. The separation distances range from beyond 15 to 1.0 km to satisfy the Earth station interference protection criteria when the EIRP is equal to the reference level. A graph of the maximum permitted UWB EIRP for a 10 MHz dithered PRF versus distance for a UWB height of 30 meters is shown in Figure 4-20b.

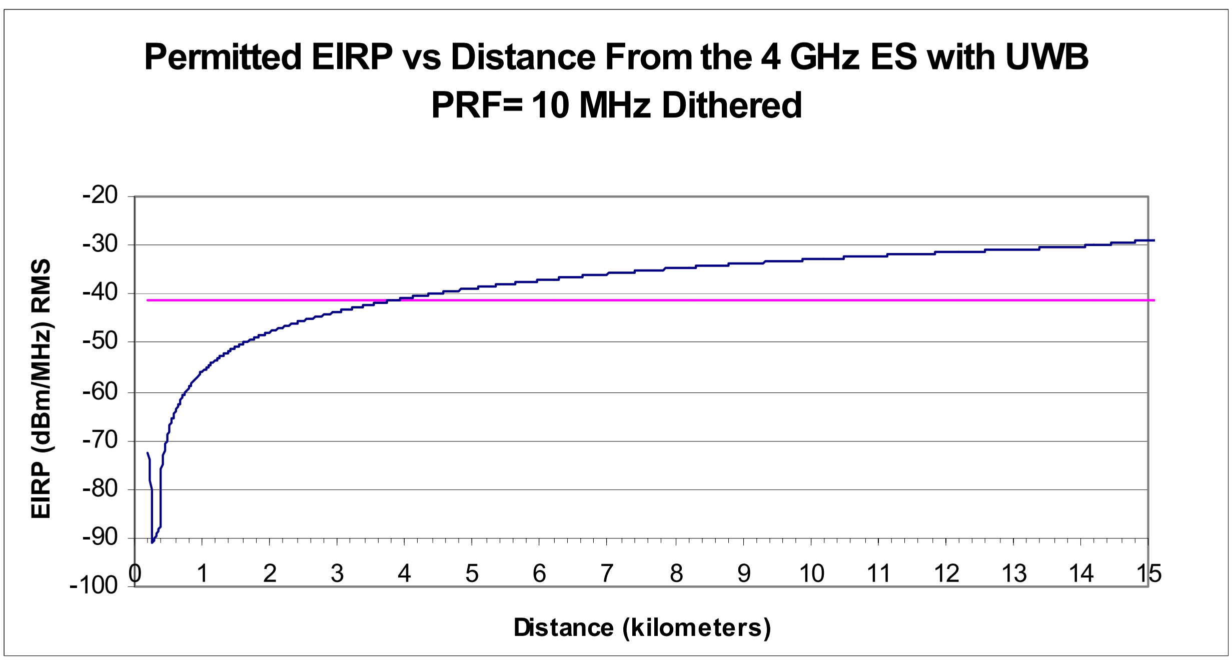

Figure 4-20b. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz (UWB Height = 30m).

Discussion of Single Entry Results

These results indicate that operation of UWB devices at a peak power level of -41.3 dBm in the vicinity of 4 GHz Earth station and at 3750 MHz would exceed current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the Earth station less capable of receiving satellite downlink transmissions.

Four factors significantly influence these results, namely, the Earth station antenna height, Earth station antenna tilt angle, the height of the UWB device, and the UWB PRF. When the Earth station antenna and the UWB device align such that main beam coupling occurs, the Earth station antenna will gather more UWB interference than the case of sidelobe coupling, which raises the overall noise power level. This effect is shown in Figure 4-20b. For compatible operations, this requires a lower permitted UWB EIRP and a longer separation distance than the Earth station and the UWB device coupling off axis. The Earth station antenna gathers less UWB interference when sidelobe coupling occurs which will allow a higher UWB EIRP and shorten the separation distance.

The PRF of the UWB device determines the BWCF in the analyses. At low UWB PRFs the BWCF is large which makes the maximum permitted UWB EIRP lower and increases the separation distances when the UWB EIRP is equal to the reference level.

4.10c 4 GHz Earth Station (3750 MHz with 20 Degree Elevation)

Analyses of potential interference from a single UWB device into a 4 GHz Earth station receiver with an elevation angle of 20 degrees was performed using the methodology described in Section 3, the 4 GHz Earth station characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-41c. The 4 GHz Earth station radar antenna height in TABLE 4-45c is a typical value.

TABLE 4-41c
UWB and 4 GHz Earth Station Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (average (RMS) interference power)
Antenna Height	3 meters
Antenna Tilt Angle	20 degrees above horizon
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-42c for a UWB height of 2 meters. These results show that the 4 GHz Earth station interference protection criteria is not exceeded for any UWB PRF at separation distance. This is indicated in the table by NA in the separation distance column. A graph of the maximum permitted UWB EIRP for a non-dithered PRF of 10 MHz versus distance is shown in

Figure 4-18c. As shown in graph, the maximum permitted EIRP is above the -41.3 dBm EIRP reference level.

TABLE 4-42c
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
0.001	16.0	-36.2	5.1	NA
0.01	16.0	-36.2	5.1	NA
0.1	16.0	-36.2	5.1	NA
1	16.0	-36.2	5.1	NA
10	6.0	-26.2	15.1	NA
100	0.0	-20.2	21.1	NA
500	0.0	-20.2	21.1	NA

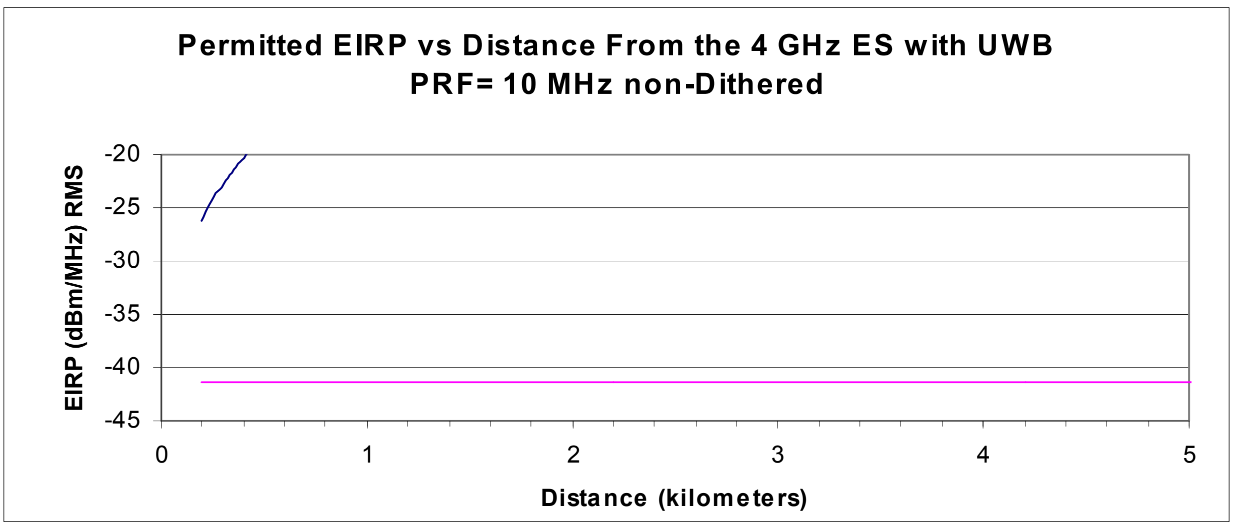

Figure 4-18c. Maximum Permitted UWB EIRP for non-Dithered PRF 10 MHz (UWB Ht = 2m).

The results for a dithered UWB signal are shown in TABLE 4-43c for a UWB height of 2 meters. These results show that the 4 GHz Earth station interference protection criteria is not exceeded for any UWB PRF.

TABLE 4-43c
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS (km)
0.001	16.0	-36.2	5.1	NA
0.01	16.0	-36.2	5.1	NA
0.1	16.0	-36.2	5.1	NA
1	16.0	-36.2	5.1	NA
10	16.0	-36.2	5.1	NA
100	16.0	-36.2	5.1	NA
500	16.0	-36.2	5.1	NA

Analyses was also performed for a UWB height of 30m. The results for a non-dithered UWB signal are shown in TABLE 4-44c. These results show that the 4 GHz Earth station interference protection criteria is only exceeded for by a marginal amount (0.3 dB) fro UWB PRFs of 1 MHz or less.

TABLE 4-44c
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
0.001	16.0	-41.6	-0.3	.2
0.01	16.0	-41.6	-0.3	.2
0.1	16.0	-41.6	-0.3	.2
1	16.0	-41.6	-0.3	.2
10	6.0	-31.6	9.7	NA
100	0.0	-25.6	15.7	NA
500	0.0	-25.6	15.7	NA

The results for a dithered signal and a UWB height of 30 meters are shown in TABLE 4-45c and again shows that the interference criteria is not exceeded.

TABLE 4-45c
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
0.001	16.0	-41.6	-0.3	NA
0.01	16.0	-41.6	-0.3	NA
0.1	16.0	-41.6	-0.3	NA
1	16.0	-41.6	-0.3	NA
10	16.0	-41.6	-0.3	NA
100	16.0	-41.6	-0.3	NA
500	16.0	-41.6	-0.3	NA

A graph of the maximum permitted UWB EIRP for a non-dithered PRF of 10 MHz versus distance is shown in Figure 4-19c. As shown in graph, the maximum permitted EIRP is only slightly below the -41.3 dBm EIRP reference level for separation distances of less than 200 meters.

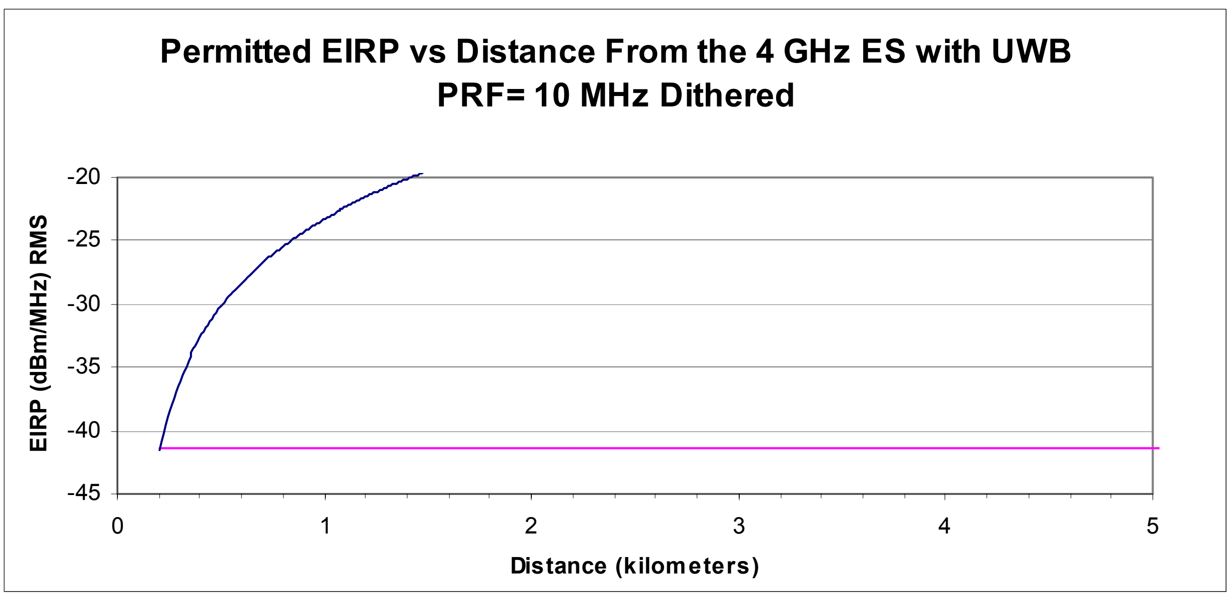

Figure 4-19c. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz UWB Height = 30m.

Discussion of Single Entry Results

These results indicate that operation of UWB devices at a average power level of -41.3 dBm in the vicinity of 4 GHz Earth station and at 3750 MHz and an antenna elevation angle of 20 degrees would not exceed current interference protection requirements as long as separation distances are approximately 200 meters.

4.10d 4 GHz Earth Station (Peak Power BWCF, 3750 MHz with 20 Degree Elevation)

Analyses of potential interference from a single UWB device into a 4 GHz Earth station receiver was performed using the methodology described in Section 3, the 4 GHz Earth station characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-41d. The 4 GHz Earth station radar antenna height in TABLE 4-41d is a typical value.

TABLE 4-41d
UWB and 4 GHz Earth Station Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (peak interference power)
Antenna Height	3 meters
Antenna Tilt Angle	20 degrees above horizon
UWB Device Height	2 meters
Measurement Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-42d for a UWB height of 2 meters. These results show that the 4 GHz Earth station interference protection criteria is exceeded with UWB PRFs at or below 1 MHz. For PRFs above 10 MHz the maximum permitted EIRP is -34.8 dBm, which is 6.5 dB above the reference level. For UWB devices with PRFs at or below 10 MHz and the UWB EIRP equal the reference level, the distance separations range from 1.0 km to 12.3 km to satisfy the 4 GHz Earth station interference protection criteria. A graph of the maximum permitted UWB EIRP for a non-dithered PRF of 10 MHz versus distance is shown in Figure 4-18d.

TABLE 4-42d
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm)	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP equals -41.3 dBm/MHz RMS (km)
.001	69.0	-89.2	-47.9	6.6
.01	59.0	-79.2	-37.9	3.9
.1	49.0	-69.2	-27.9	2.2
1	39.0	-59.2	-17.9	1.2
10	19.0	-39.2	2.1	NA
100	0.0	-20.2	21.1	NA
500	0.0	-20.2	21.2	NA

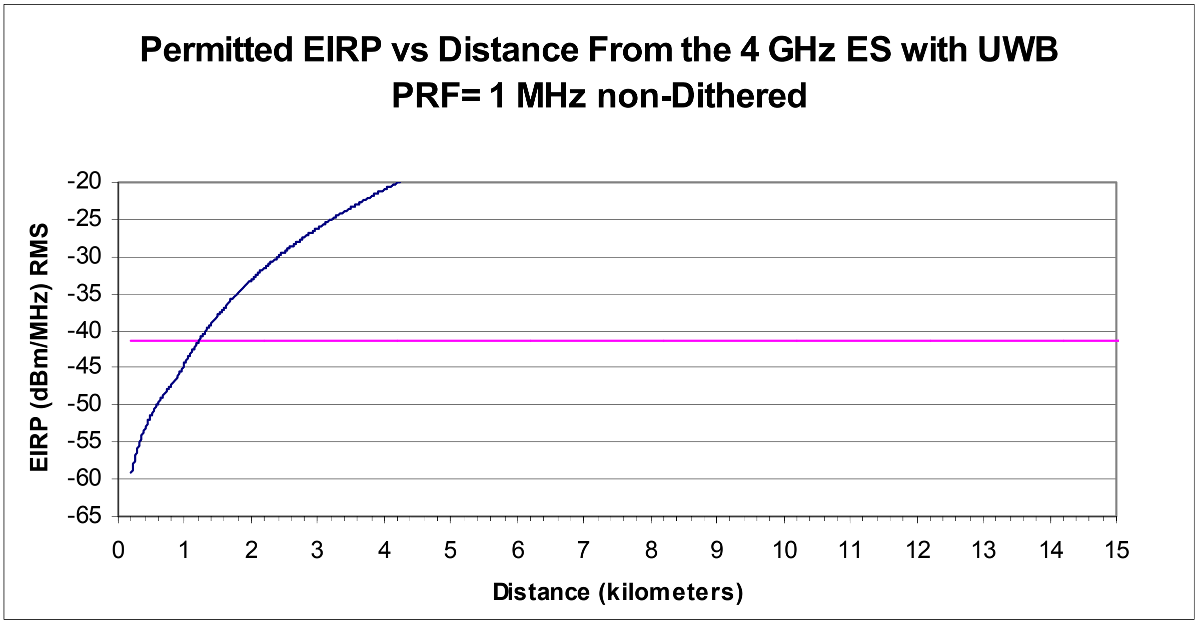

Figure 44-18d. **Maximum Permitted UWB EIRP for non-Dithered PRF of 1 MHz (UWB Height = 2 m).**

The results for a dithered UWB signal are shown in TABLE 4-43d for a UWB height of 2 meters. The results for a dithered signal show that the maximum allowable UWB EIRP is below the reference level for PRFs less than 100 Mz. The distance separations range from .05 km to 6.6 km to satisfy the 4 GHz Earth station interference protection criteria with the UWB EIRP equal to the reference level. A graph of the maximum permitted UWB EIRP for a dithered PRF of 10 MHz versus distance is shown in Figure 4-19d.

TABLE 4-43d
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB H t= 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm)	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	69.0	-89.2	-47.9	6.6
.01	59.0	-79.2	-37.9	3.9
.1	49.0	-69.2	-27.9	2.2
1	39.0	-59.2	-17.9	1.2
10	29.0	-49.2	-7.9	0.5
100	19.0	-39.2	2.1	NA
500	16.0	-36.2	5.2	NA

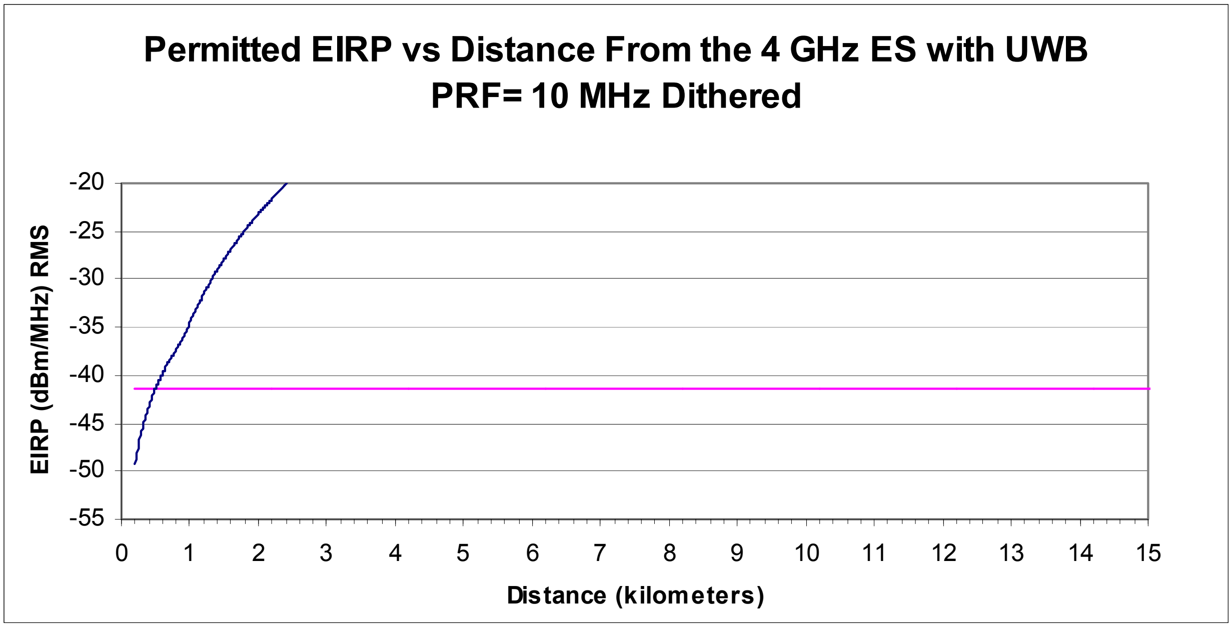

Figure 4-19d. Maximum Permitted UWB EIRP for Dithered 10 MHz UWB (Height = 2m).

Analyses was also performed for a UWB height of 30m. The results for a non-dithered UWB signal are shown in TABLE 4-44d.

TABLE 4-44d
Non-Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht = 30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm)	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP equals - 41.3 dBm/MHz RMS (km)
.001	69.0	-94.6	-53.3	>15
.01	59.0	-84.6	-43.3	>15
.1	49.0	-74.6	-33.3	5.2
1	39.0	-64.6	-23.3	1.7
10	19.0	-44.6	-3.3	.25
100	0.0	-25.6	15.7	NA
500	0.0	-25.6	15.7	NA

The TABLE shows that the maximum permitted UWB EIRP ranges from -94.6 dBm for a PRF of .001 MHz to -25.6 dBm for a PRF of 500 MHz. The separation distances range from beyond 15 to .25 km to satisfy the Earth station interference protection criteria when the UWB EIRP is equal to the reference level for PRFs below 10 MHz.

The results for a dithered signal and a UWB height of 30 meters are shown in TABLE 4-45d.

TABLE 4-45d
Dithered UWB Signal into 4 GHz Earth Station Receiver (UWB Ht =30m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm)	Delta Reference Level (dB)	Distance Where Permitted UWB EIRP Equals - 41.3 dBm/MHz RMS (km)
.001	69.0	-94.6	-53.3	>15
.01	59.0	-84.6	-43.3	>15
.1	49.0	-74.6	-33.3	5.3
1	39.0	-64.6	-23.3	1.7
10	29.0	-54.6	-13.3	0.6
100	19.0	-44.6	-3.3	0.25
500	16.0	-41.6	-0.3	0.2

The table shows that the maximum permitted UWB EIRP ranges from -94.6 dBm for a PRF of .001 MHz to -41.6 dBm for a PRF of 500 MHz. The separation distances range from beyond 15 to 0.2 km to satisfy the Earth station interference protection criteria when the EIRP is equal to the reference level. A graph of the maximum permitted UWB EIRP for a 10 MHz dithered PRF versus distance for a UWB height of 30 meters is shown in Figure 4-20d.

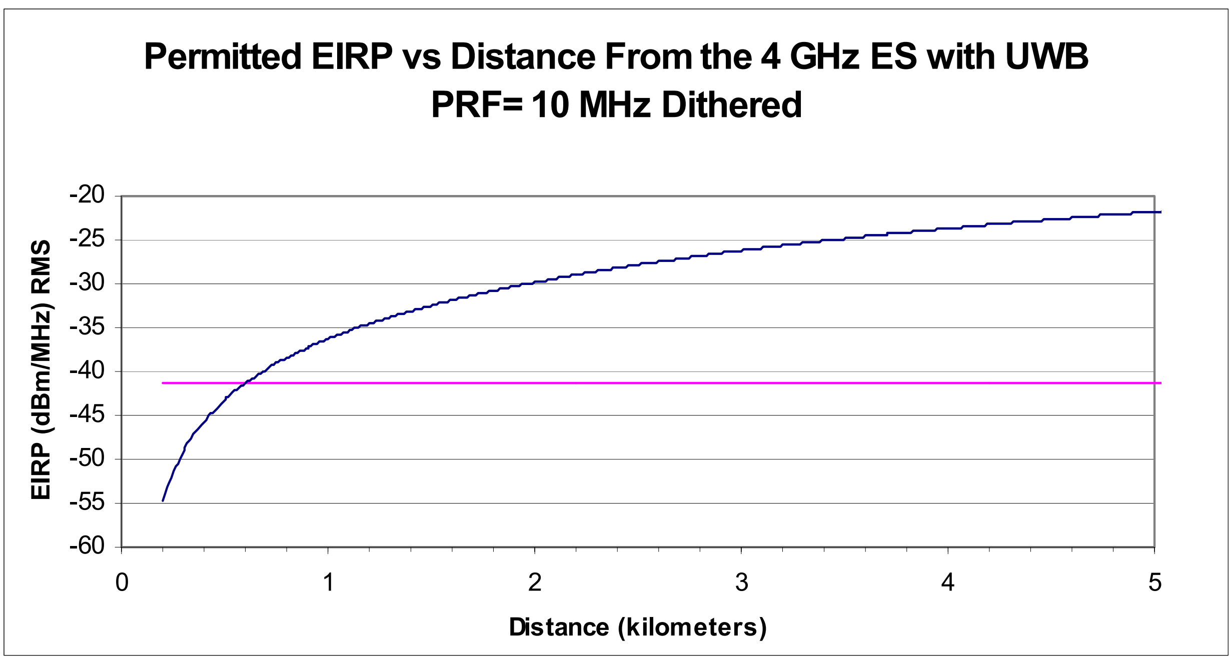

Figure 4-20d. Maximum Permitted UWB EIRP for Dithered PRF of 10 MHz UWB Height = 30m.

Discussion of Single Entry Results

These results indicate that operation of UWB devices at a peak power level of -41.3 dBm in combination with PRFs below about 10 MHz, in the vicinity of 4 GHz Earth station and at 3750 MHz would exceed current interference protection requirements. UWB devices operating at that power level would add to the system noise, rendering the Earth station less capable of receiving satellite downlink transmissions.

Four factors significantly influence these results, namely, the Earth station antenna height, Earth station antenna tilt angle, the height of the UWB device, and the UWB PRF. When the Earth station antenna and the UWB device align such that main beam coupling occurs, the Earth station antenna will gather more UWB interference than the case of sidelobe coupling, which raises the overall noise power level. This effect is shown in Figure 4-3d. For compatible operations, this requires a lower permitted UWB EIRP and a longer separation distance than the Earth station and the UWB device coupling off axis. The Earth station antenna gathers less UWB interference when sidelobe coupling occurs which will allow a higher UWB EIRP and shorten the separation distance.

The PRF of the UWB device determines the BWCF in the analyses. At low UWB PRFs the BWCF is large which makes the maximum permitted UWB EIRP lower and increases the separation distances when the UWB EIRP is equal to the reference level.

4.11 TDWR RADAR (5600-5650 MHz)

Analyses of potential interference from a single UWB device into a TDWR receiver was performed using the methodology described in Section 3, the TDWR characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-46. The TDWR radar antenna height in TABLE 4-46 is the average height of all the TDWR radars in the GMF of frequency assignments.

TABLE 4-46
UWB and TDWR Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -6 dB (average (RMS) interference power)
Radar Antenna Height	27 meters
Radar Tilt Angle	.2 degrees
UWB Device Height	2 meters, 30 meters
Reference Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-47 for a UWB height of 2 meters. These results show that the TDWR interference protection is met with a UWB EIRP of -34.9 dBm or less for UWB PRFs at and below 0.1 MHz. This level is 6.4 dB above the -41.3 dBm/MHz RMS reference level. For PRFs above 0.1 MHz the maximum permitted UWB EIRP is -35.3 dBm which is 6 dB above the reference level. A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-21 for a non-dithered PRF of 1 MHz and a UWB height of 2 meters.

TABLE 4-47
Non-Dithered UWB Signal into TDWR Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-0.4	-34.9	6.4	NA
.01	-0.4	-34.9	6.4	NA
.1	-0.4	-34.9	6.4	NA
1	0.0	-35.3	6.0	NA
10	0.0	-35.3	6.0	NA
100	0.0	-35.3	6.0	NA
500	0.0	-35.3	6.0	NA

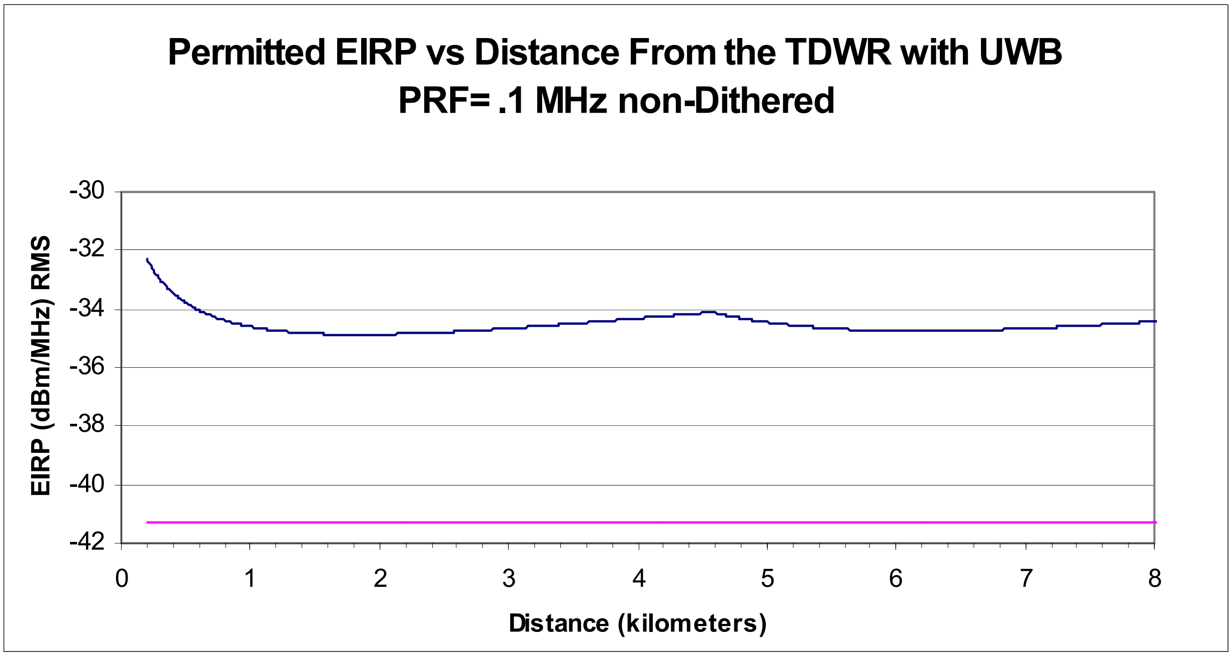

Figure 4-21. Maximum Permitted UWB EIRP for non-Dithered PRF of 1 MHz (UWB Height = 2m).

Above a PRF of 0.1 MHz, the BWCF is equal to zero and the graph will change. It is shown below in Figure 4-22.

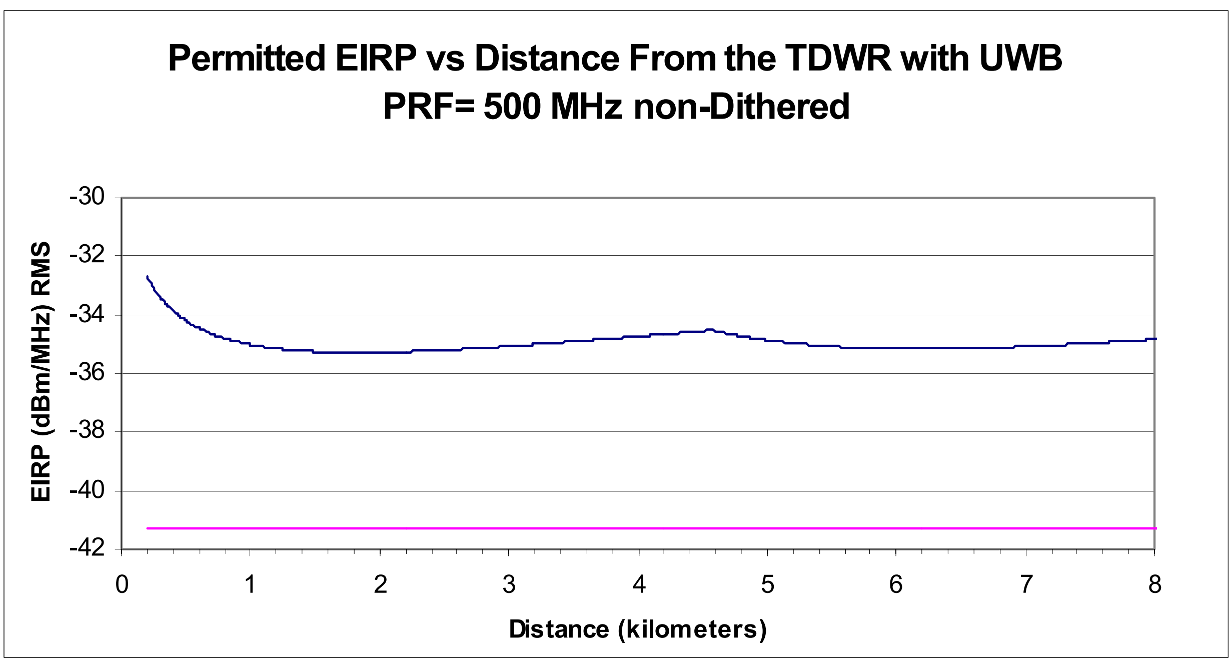

Figure 4-22 Maximum Permitted UWB EIRP for non-Dithered PRF of 500 MHz (UWB Height = 2m).

The results for a dithered UWB signal analyses are shown in TABLE 4-48 for a UWB height of 2 meters. The results show that the maximum allowable UWB EIRP is -34.9 dBm regardless of the PRF. The permitted UWB EIRP level is 6.4 dB above the -41.3 dBm/MHz RMS reference level. A graph of the maximum permitted dithered UWB EIRP versus distance is shown in Figure 4-23 for a PRF of 500 MHz and a UWB height of 2 meters.

TABLE 4-48
Dithered UWB Signal into TDWR Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-0.4	-34.9	6.4	NA
.01	-0.4	-34.9	6.4	NA
.1	-0.4	-34.9	6.4	NA
1	-0.4	-34.9	6.4	NA
10	-0.4	-34.9	6.4	NA
100	-0.4	-34.9	6.4	NA
500	-0.4	-34.9	6.4	NA

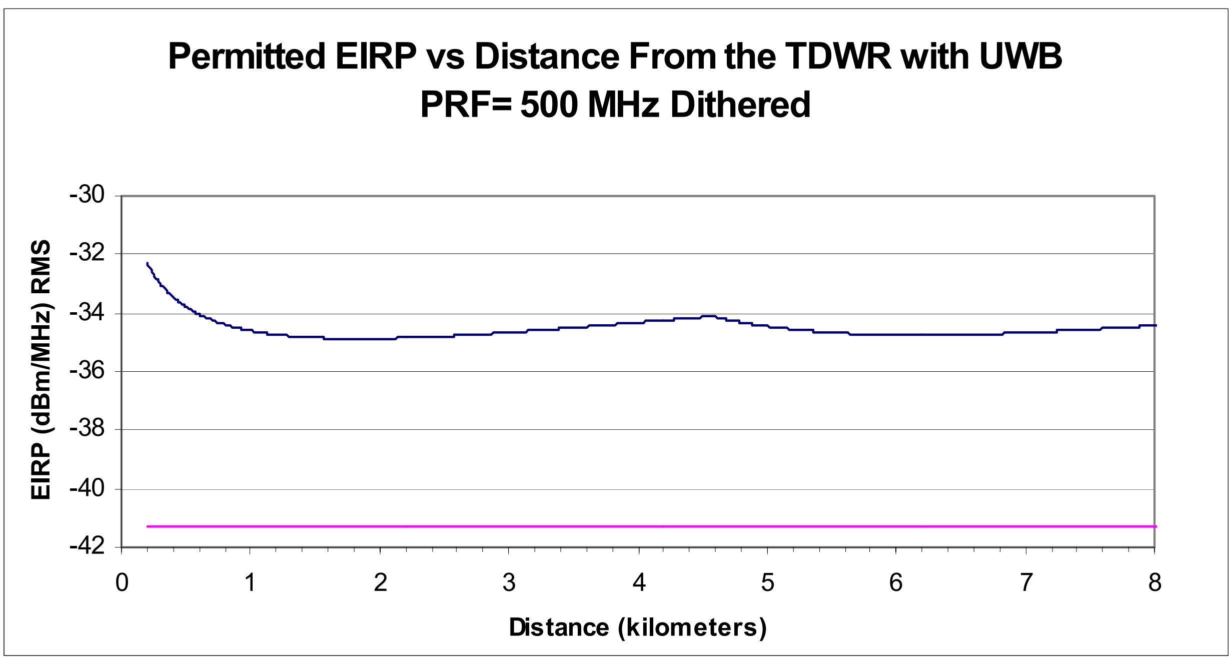

Figure 4-23 Maximum Permitted UWB EIRP for Dithered PRF (UWB Height = 2m).

Analyses was also performed for a UWB height of 30 meters. The results for a non-dithered UWB signal analyses are shown in TABLE 4-49. The results show that the maximum permitted UWB EIRP is -62.9 dBm for PRFs at and below 0.1 MHz. For PRFs above 0.1 MHz the maximum permitted UWB EIRP is -63.3 dBm. These levels are 21.6 and 22 dB below the reference level. The separation distances for the TDWR and a UWB device with an EIRP equal to the reference level is 6.0 km for PRFs at and below 0.1 MHz and 6.2 km for PRFs above 0.1 MHz.

TABLE 4-49
Non-Dithered UWB Signal into TDWR Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-0.4	-62.9	-21.6	6.0
.01	-0.4	-62.9	-21.6	6.0
.1	-0.4	-62.9	-21.6	6.0
1	0.0	-63.3	-22.0	6.2
10	0.0	-63.3	-22.0	6.2
100	0.0	-63.3	-22.0	6.2
500	0.0	-63.3	-22.0	6.2

The results for a dithered UWB signal analyses are shown in TABLE 4-50 for a UWB height of 30 meters. The results show that the maximum permitted UWB EIRP is -62.9 dBm for regardless of the PRFs. The separation distance for the TDWR and a dithered UWB device with an EIRP equal to the reference level is 6.0 km.

TABLE 4-50
Dithered UWB Signal into TDWR Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-0.4	-62.9	-21.6	6.0
.01	-0.4	-62.9	-21.6	6.0
.1	-0.4	-62.9	-21.6	6.0
1	-0.4	-62.9	-21.6	6.0
10	-0.4	-62.9	-21.6	6.0
100	-0.4	-62.9	-21.6	6.0
500	-0.4	-62.9	-21.6	6.0

A graph of the maximum permitted UWB EIRP versus distance is shown in Figure 4-24 for a dithered PRF of 500 MHz and UWB height of 30 meters.

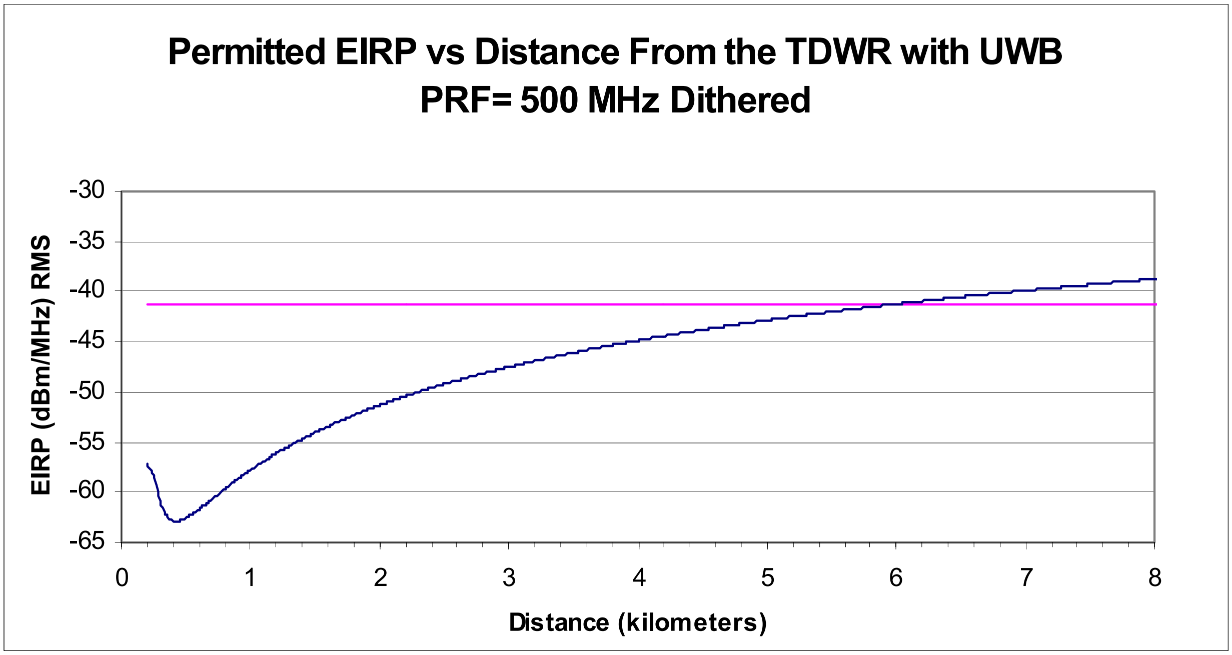

Figure 4-24 Maximum Permitted UWB EIRP for UWB Height =30 m.

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of TDWR radars and within the 5600-5650 MHz frequency band would not exceed current interference protection requirements if the UWB device were operating at 2 meters above the ground. However, UWB devices operating at that power level at a height close to the height of the TDWR antenna would add to the system noise, rendering the radar less capable of monitoring the atmosphere for weather events.

Three factors significantly influence these results, namely, the radar antenna height, radar antenna tilt angle, and the height of the UWB device. When the radar antenna and the UWB device are operating in the same horizontal plane, the vertical elevation angle between them is zero degrees which results in a greater radar antenna gain. The analytical model takes into account the height of the radar, the height of the UWB device, and the radar tilt angle to compute the radar antenna gain, which is then used in the UWB interference calculations. For example, when the UWB height is 2 meters and the distance is 1 km, the off-axis + tilt angle is -1.6 degrees and the radar antenna gain is 26.8 dBi. However, for a UWB height of 30 meters and a distance of 1 km, the off-axis + tilt angle is 0 degrees and the radar antenna gain is 50 dBi.

A higher radar antenna gain raises the UWB interference power level in the radar receiver. For compatible operations, this requires a lower maximum permitted UWB EIRP and a longer separation distance to satisfy the receiver's protection criteria.

4.12 MARITIME RADIONAVIGATION RADAR (2900–3100 MHz)

Analyses of potential interference from a single UWB device into a maritime radionavigation radar receiver was performed using the methodology described in Section 3, the maritime radionavigation radar characteristics given in Appendix A, and the analysis parameters shown in TABLE 4-51.

TABLE 4-51
UWB and Maritime Radionavigation Radar Analysis Parameters

Parameter	Value
Protection Criteria	I/N = -10 dB (average (RMS) interference power)
Radar Antenna Height	20 meters
Radar Tilt Angle	0 degrees
UWB Device Height	2 meters, 30 meters
Reference Bandwidth	1 MHz
Reference Power Level	-41.3 dBm/MHz average (RMS), EIRP

The results for a non-dithered UWB signal analyses are shown in TABLE 4-52 for a UWB height of 2 meters. These results show that the maritime radionavigation radar interference protection is met with a UWB EIRP of -56.3 dBm or less for UWB PRFs at and below 1 MHz. This level is 15.0 dB below the -41.3 dBm/MHz RMS reference level. For PRFs above 1 MHz the maximum permitted UWB EIRP is -50.3 dBm which is 9 dB below the reference level.

The separation distance for a UWB device with an EIRP equal to the reference level and a maritime radionavigation radar is 1.2 km for PRFs at and below 1 MHz and 0.60 km for PRFs above 1 MHz.

TABLE 4-52
Non-Dithered UWB Signal into
Maritime Radionavigation Radar Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	6.0	-56.3	-15.0	1.2
.01	6.0	-56.3	-15.0	1.2
.1	6.0	-56.3	-15.0	1.2
1	6.0	-56.3	-15.0	1.2
10	0.0	-50.3	-9.0	.60
100	0.0	-50.3	-9.0	.60
500	0.0	-50.3	-9.0	.60

The results for a dithered UWB signal analyses are shown in TABLE 4-53 for a UWB height of 2 meters. The results show that the maximum allowable UWB EIRP is -56.3 dBm regardless of the PRF. The maximum permitted UWB EIRP level is 15.0 dB below the reference level. The separation distance to satisfy the marine receiver protection criteria is 1.2 km when the UWB EIRP is equal to the reference level.

TABLE 4-53
Dithered UWB Signal into
Maritime Radionavigation Radar Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	6.0	-56.3	-15.0	1.2
.01	6.0	-56.3	-15.0	1.2
.1	6.0	-56.3	-15.0	1.2
1	6.0	-56.3	-15.0	1.2
10	6.0	-56.3	-15.0	1.2
100	6.0	-56.3	-15.0	1.2
500	6.0	-56.3	-15.0	1.2

A graph of the maximum permitted UWB EIRP is shown below in Figure 4-25 for a non-dithered PRF of 1 MHz.

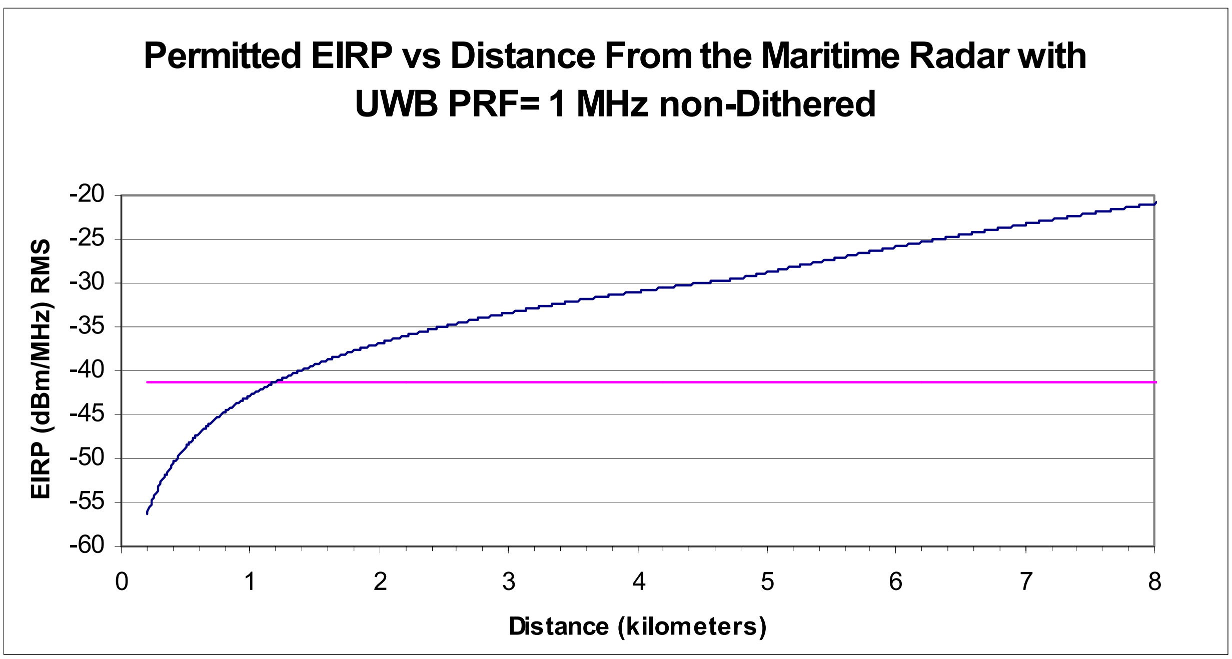

Figure 4-25 Maximum Permitted UWB EIRP for non-Dithered PRF of 1 MHz (UWB Height = 2m).

The results for a non-dithered UWB signal analyses are shown in TABLE 4-54 for a UWB height of 30 meters. These results show that the maritime radionavigation radar interference protection is met with a UWB EIRP of -56.8 dBm or less for UWB PRFs at and below 1 MHz. This level is 15.5 dB below the -41.3 dBm/MHz RMS reference level. For PRFs above 1 MHz the maximum permitted UWB EIRP is -50.8 dBm which is 9.5 dB below the reference level.

The separation distance for a UWB device with an EIRP equal to the reference level and a maritime radionavigation radar is 1.2 km for PRFs at and below 1 MHz and 0.6 km for PRFs above 1 MHz.

TABLE 4-54
Non-Dithered UWB Signal into
Maritime Radionavigation Radar Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	6.0	-56.8	-15.5	1.2
.01	6.0	-56.8	-15.5	1.2
.1	6.0	-56.8	-15.5	1.2
1	6.0	-56.8	-15.5	1.2
10	0.0	-50.8	-9.5	.60
100	0.0	-50.8	-9.5	.60
500	0.0	-50.8	-9.5	.60

The results for a dithered UWB signal analyses are shown in TABLE 4-55 for a UWB height of 30 meters. The results show that the maximum allowable UWB EIRP is -56.8 dBm regardless of the PRF. The maximum permitted UWB EIRP level is 15.5 dB below the reference level. The separation distance to satisfy the marine receiver protection criteria is 1.2 km when the UWB EIRP is equal to the reference level.

TABLE 4-55
Dithered UWB Signal into
Maritime Radionavigation Radar Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	6.0	-56.8	-15.5	1.2
.01	6.0	-56.8	-15.5	1.2
.1	6.0	-56.8	-15.5	1.2
1	6.0	-56.8	-15.5	1.2
10	6.0	-56.8	-15.5	1.2
100	6.0	-56.8	-15.5	1.2
500	6.0	-56.8	-15.5	1.2

Discussion of Single Entry Results

These results indicate that operation of a UWB device at a power level of -41.3 dBm/MHz RMS in the vicinity of maritime radionavigation radars and within the 2900-3100 MHz frequency band would exceed current maritime radionavigation radar receiver interference protection requirements. This may result in the ship's captain or navigator being unable to pilot the ship using radar as a guidance tool in inclement weather and/or foggy conditions. The separation distance may be up to 1.2 km for low UWB PRFs, which may be unobtainable for ships operating in narrow waterways and UWB devices located on shore.

4.13 SINGLE UWB DEVICE SUMMARY TABLES

TABLE 4-56 shows the maximum permitted UWB EIRP for UWB heights of 2 and 30 meters for average UWB interference power. The table also shows the minimum required separation distance to satisfy the receiver's protection criteria when the UWB EIRP is equal to the reference level of -41.3/1MHz dBm RMS.

TABLE 4-57 shows the maximum permitted UWB EIRP for UWB heights of 2 and 30 meters for peak UWB interference power. The table also shows the minimum required separation distance to satisfy the receiver's protection criteria when the UWB EIRP is equal to the reference level of -41.3/1MHz dBm RMS.

TABLE 4-56
Summary Assessment of Effects of UWB Devices on Federal Systems For Average Power Interactions[34]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	Non-Dithered				Dithered			
			UWB Ht = 2m		UWB Ht = 30m		UWB Ht = 2m		UWB Ht = 30m	
			Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS
DME Interrogator Airborne Rcvr	960- 1215	≤0.1 ≥1	-46 -47	0.08 0.09			-46 -46	0.08 0.08		
DME Ground Transponder Rcvr	1025- 1150	≤0.1 ≥1	-63 -64	0.26 0.29	-56 -57	0.26 0.29	-63 -63	0.26 0.26	-56 -56	0.26 0.26
ATCRBS Ground Interrogator Rcvr	1090	≤1 ≥10	-31 -21	NA NA	-45 -36	0.27 NA	-31 -31	NA NA	-45 -45	0.27 0.27
ATCRBSAirborne Transponder Rcvr	1030	≤1 ≥10	-44 -37	0.02 NA			-44 -44	0.02 0.02		
ARSR-4	1240- 1370	≤0.1 ≥0.1	-60 -61	5.5 6.1	-80 -82	>15 >15	-60 -60	5.5 5.5	-80 -80	>15 >15
SARSAT LUT	1544- 1545	≤0.1 ≥1	-68 -69	2.9 3.1	-65 -66	5.5 6.1	-68 -68	2.9 2.9	-65 -65	5.5 5.5
ASR-9	2700- 2900	≤0.1 ≥1	44 -46	0.8 1.1	-64 -66	1.3 1.5	-44 -44	0.8 0.8	-65 -65	1.3 1.3
NEXRAD	2700- 2900	≤0.1 ≥1	-39 -42	NA 1.4	-73 -76	5.8 7.9	-39 -39	NA NA	-73 -73	5.8 5.8
Maritime Radars	2900- 3100	≤1 ≥10	-56 -50	1.2 0.6	-57 -51	1.2 0.6	-56 -56	1.2 1.2	-57 -57	1.2 1.2
FSS Earth Station (20° Elevation – Common For Domestic Satellites)	3700- 4200	≤1 10 ≥100	-36 -26 -20	NA NA NA	-42 -32 -26	.20 NA NA	-36 -36 -36	NA NA NA	-42 -42 -42	.20 .20 .20
FSS Earth Station (5° Elevation – More Likely For International Satellites)	3700- 4200	≤1 10 ≥100	-51 -41 -35	0.60 NA NA	-77 -67 -61	1.0 0.6 0.4	-51 -51 -51	0.60 0.63 0.63	-77 -77 -77	1.0 1.0 1.0
CW Radar Altimeters at Minimum Altitude	4200- 4400	≤0.1 ≥1	25 14	NA NA			25	NA NA		
Pulsed Radar Altimeters at Minimum Altitude	4200- 4400	≤1 10 ≥10	14.3 24.3 29.0	NA NA NA			14 14 14	NA NA NA		
MLS	5030- 5091	≤ 0.1 ≥1	-45 -54	0.07 0.16			-45 -45	0.07 0.07		
TDWR	5600- 5650	≤1 ≥10	-35 -35	NA NA	-63 -63	6.0 6.0	-35 -35	NA NA	-63 -63	6.0 6.0

[34] Notes: (1) The calculations were made at UWB PRF Values of, 0.001, 0.01, 0.1, 1, 10, 100, and 500 MHz. When the distance values and Maximum EIRP values were the same for a range were the same, they were grouped together to save space in the table. Thus, for the first row, the calculations for PRF values of 0.001, 0.01, and, 0.1 MHz were the same and are shown in the row labeled ≤0.1 MHz, while the calculations for 1, 10, 100, and 500 were the same and are shown in the row labeled ≥MHz. (2) The shaded areas represent implausible scenarios where the UWB and aircraft would be at the same altitude (i.e., a collision course). (3) The symbol NA indicates that the reference level requires no separation distance beyond the limits of the model, which are usually 100-200 meters.

TABLE 4-57
Summary Assessment of Effects of UWB Devices on Federal Systems For Peak Power Interactions with Digitally Modulated Systems[35]

SYSTEM	Freq. (MHz)	UWB PRF (MHz)	Non-Dithered				Dithered			
			UWB Ht = 2m		UWB Ht = 30m		UWB Ht = 2m		UWB Ht = 30m	
			Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS	Maximum Permitted EIRP (dBm/MHz) RMS	Separation Distance (km) for EIRP=-41.3 dBm/MHz RMS
SARSAT LUT Ground Station	1544-1545	0.001	-104	>15	-101	>15	-104	>15	-101	>15
		0.01	-94	12.0	-91	>15	-94	12.0	-91	>15
		0.1	-84	7.3	-81	>15	-84	7.3	-81	>15
		1	-74	4.2	-71	11.3	-74	4.2	-71	11.4
		≥10	-69	3.1	-66	6.1	-68	2.9	-65	5.4
FSS Earth Station (20° Elevation – Common For Domestic Satellites)	3700-4200	0.001	-89	6.6	-95	>15	-89	6.6	-95	>15
		0.01	-79	3.9	-85	>15	-79	3.9	-85	>15
		0.1	-69	2.2	-75	5.3	-69	2.2	-75	5.3
		1	-59	1.2	-65	1.7	-59	1.2	-65	1.7
		10	-39	NA	-45	0.25	-50	0.5	-55	0.6
		100	-20	NA	-26	NA	-40	NA	-45	0.25
		500	-20	NA	-26	NA	-36	NA	-42	.20
FSS Earth Station (5° Elevation – More Likely For International Satellites)	3700-4200	0.001	-104	12.3	-130	>15	-104	13.2	-130	>15
		0.01	-94	8.4	-120	>15	-94	8.4	-120	>15
		0.1	-84	5.1	-110	>15	-84	5.1	-110	>15
		1	-74	3.0	-100	10.1	-74	3.0	-100	10.2
		10	-54	1.0	-80	1.3	-64	1.7	-90	3.3
		100	-35	NA	-61	0.44	-54	1.0	-80	1.3
		500	-35	NA	-61	0.44	-51	0.6	-77	1.0

35 The shaded areas are for PRF values that would result in peak to average power levels greater than 30 dB.

SECTION 5
AGGREGATE INTERFERENCE ANALYSIS

5.1 INTRODUCTION

Section 4 has discussed potential UWB interference impact based on single emitter measurements and analyses. The question of whether any additional radiated power constraint may be applicable based on potential effects of multiple emitters is addressed in this section.

While the comments received thus far to the NOI[36] vary in conclusion, the FCC has tentatively agreed with those that suggest that cumulative impact will be minimal.[37] Thus, the FCC is suggesting that the maximum permitted UWB radiated power level be determined based on single emitter studies alone.[38]

To address this issue, NTIA has undertaken the development of statistical and analysis tools to estimate aggregate interference levels in various receivers. These tools attempt to address concerns of various commenters regarding the inadequacy of applying measurements and analyses of only a few emitters, with realistic emitter numbers potentially in the millions.[39]

In addition to these analysis efforts, NTIA has undertaken limited measurements on aggregate affects. This section will discuss the implications of these measurements, will provide an overview of the analysis model used, a comparison of the results derived from several available aggregate interference methods, and will conclude with a description of the model results on the same systems addressed in Section 4.

5.2 RESULTS OF AGGREGATE MEASUREMENTS

While the potential impact of a single UWB device on the operation of other radiocommunication devices has been the principal focus of this overall NTIA measurement and analysis effort, the potential effects of an aggregation of these devices are also of significant interest. It has been suggested by many UWB proponents that this technology could lead to widespread use with potentially high emitter densities. In highly populated areas, one might envision that hundreds, thousands or even more of these

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[36] *See* UWB NOI, *supra* note 10.

[37] *See* UWB NPRM, *supra* note 2, at ¶ 46.

[38] *Id.* at ¶ 47.

[39] Supplemental Comments of Sprint PCS, *In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, ET 98-153, at 9 (filed Oct. 6, 2000).

devices might be employed per square kilometer.[40] This leads naturally to the issue of potential aggregate interference.

For conventional narrowband radiocommunication signals, it has been a long-held spectrum management axiom that the average (RMS) power from multiple sources add linearly in a receiver. This is well supported by theoretical considerations. For example, communications theory texts clearly show that for stationary, stochastic processes, average (RMS) power from multiple independent sources do indeed add linearly.[41] Consideration of peak power is more complex, which in general, does not add linearly. As discussed below, amplitude probability statistics are useful in describing peak power aggregation. Given the non-conventional nature of UWB signals, some questions have arisen regarding the additive nature of UWB spectral power density, that is, the average (RMS) power per unit bandwidth. Nevertheless, most researchers of UWB aggregate interference have adopted the concept that average (RMS) power per unit bandwidth in a receiver from multiple sources is linearly additive.

Most of the studies completed of UWB aggregate interference make two fundamental assumptions: 1) that the victim receiver is located in the midst of a large number of uniformly distributed UWB emitters, and 2) that the received average (RMS) power per unit bandwidth from multiple UWB devices is additive. However, opposing results are found regarding the predicted interference impact to receivers, namely: 1) that any aggregate effects are always dominated by the single nearest UWB emitter and therefore aggregate effects need not be further considered; or 2) that aggregate received interference levels increase linearly with emitter density and therefore there always exists some density at which aggregate interference will dominate over that from a single emitter.

This subsection discusses limited NTIA measurements completed addressing the nature of aggregate received UWB signals. As described in the ITS Report, limited measurements were completed showing the amplitude statistics and average (RMS) power for the sum of two independent UWB signals of equal level. Three such cases are described below, where the individual UWB signals appear noise-like and pulse-like in a receiver. TABLE 5-1, derived from the ITS report shows the individual and aggregate detector values for these three cases. In each case, the RMS aggregate level was approximately twice, or 3 dB higher than the individual RMS levels.

Figure 5.2-1 shows the case where two UWB signals are dithered and the measurement bandwidth (1 MHz) is much less than the UWB PRF. In this case, UWB signals individually and in the aggregate closely follow the statistics of Gaussian noise in the measurement bandwidth.

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[40] Some studies have even investigated the effects of millions of UWB devices per square kilometer.

[41] *See* e.g., Athanasios Papoulis, Probability, Random Variables and Stochastic Processes, at Chapter 10 (McGraw-Hill 1965).

TABLE 5-1
Detector Values for Aggregate Tests

Figure	Source	PRF	Dither	Ave Log	Ave Volt	RMS	Peak
Figure 5.2-1	# 1	10 MHz	50%	-49.2	-47.9	-46.9	-39
	# 2	10 MHz	50%	-49.2	-47.9	-46.9	-39
	# 1 & # 2	- - -	- - -	-46.5	-45.1	-44.1	-36.5
Figure 5.2-2	# 1	100 kHz	none	-87.2	-76.6	-67.9	-54
	# 2	100 kHz	none	-87.2	-76.6	-67.9	-54
	# 1 & # 2	- - -	- - -	-84.1	-72.1	-65.2	-49
Figure 5.2-3	# 1	100 kHz	50%	-86.9	-76.6	-67.9	-54
	# 2	100 kHz	50%	-86.9	-76.6	-67.9	-54
	# 1 & # 2	- - -	- - -	-84.0	-72.1	-65.2	-49

Figure 5.2-2 shows the situation where the measurement bandwidth is much wider than the UWB PRF with non-dithered signals. In this case the amplitude probability distribution (APD) statistics show the characteristics of a pulsed signal having a high peak power for low percentages of time and showing only measurement system noise for high percentages of time. While the additive nature of these UWB signals are not as evident in the APD statistics, the measured RMS values again showed close agreement with expected results.

Figure 5.2-3 shows the same situation as above except that the UWB devices are dithered with nearly identical APD statistics.

These limited measurements are in good agreement with both theoretical results as well as results of other UWB measurement efforts. It can be concluded that the well-accepted principle of linear addition of average (RMS) power from multiple sources holds equally well for average (RMS) power per unit bandwidth regardless of the nature of the UWB signal.

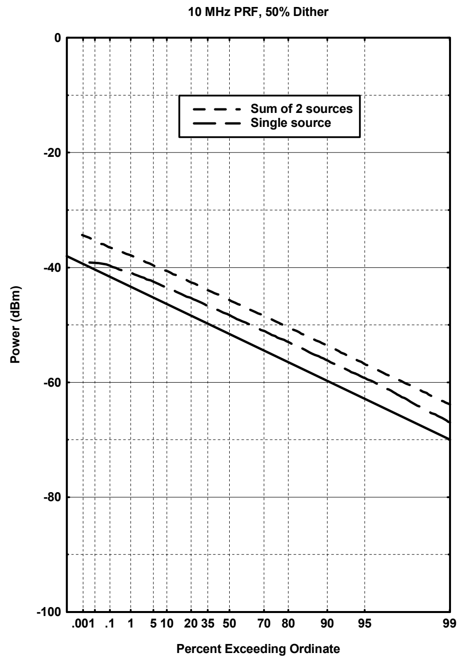

Figure 5.2-1. Aggregate Case 1

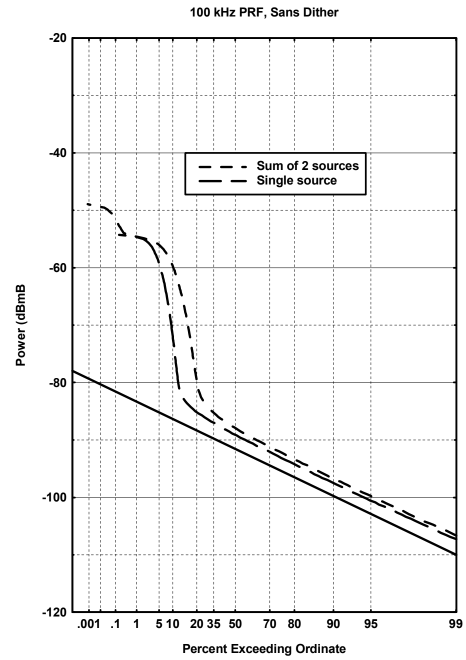

Figure 5.2-2. Aggregate Case 2

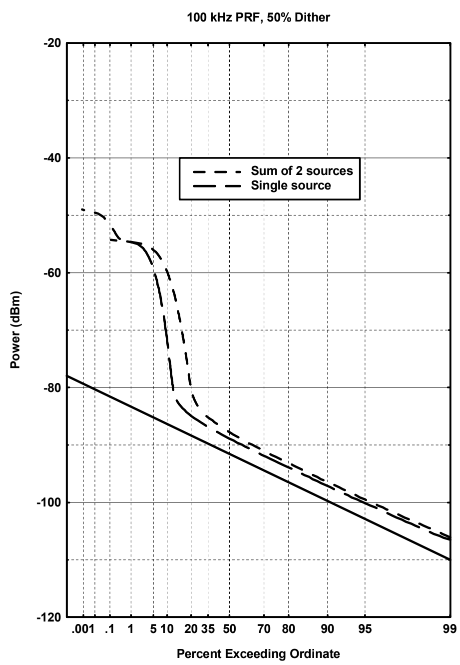

Figure 5.2-3. Aggregate Case 3

5.3 OVERVIEW OF ANALYTICAL MODEL

5.3.1 Background

UWBRings is a computer program that was created to provide an easy and straightforward way to quantify aggregate UWB emitter affects into terrestrial, airborne, and satellite victim receivers. The UWBRings model provides enough detail and flexibility to analyze a wide variety of equipment and scenarios to illuminate the significance of UWB aggregate affects.

UWBRings was written in Microsoft Excel 97 (©1996). A spreadsheet format is used to display and adjust inputs, as well as to display outputs, which include a chart and associated data points. For each simulation the data points are determined after adjusting the inputs and clicking the "Calculate" button. When this control is actuated a series of Visual Basic© procedures run in the background which implement an assortment of specialized algorithms to determine output data points and to draw the chart.

The chart plots any one of various interference criteria as a function of active emitter density.[42] Specifically, the charts to follow in Section 5.5 cover a range of densities from a single emitter per square kilometer to a density of 10,000 per square kilometer. To get a feel for the meaning of these densities it is helpful to note that emitters are spaced roughly $K^{-½}$ where K is the emitter density. Thus, 1 emitter per square kilometer has emitters spaced 1 kilometer apart. Ten thousand emitters per square kilometer has emitters spaced only 10 meters apart. Another view of these densities comes by multiplying density by area. Looking at it this way a 10,000 emitter per square kilometer density will produce 1 million emitters in a radius of only 5.6 km.

5.3.2 UWBRings Assumptions

The following are assumptions used in UWBRings:

1. The fundamental assumption of the program is that the average (RMS) power contributions of UWB devices sum in the victim receiver.

2. The cumulative effects are noise-like and can be considered additive to the receiver noise.

3. All UWB emitters radiate at the same effective power and are considered to be radiating in the direction of the victim receiver.

4. All UWB emitters are distributed uniformly on the surface of a smooth Earth such that the distance from any emitter to its closest neighbor remains approximately constant throughout the distribution.

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[42] Active emitter density acknowledges that not all existing UWB emitters in a given area are radiating simultaneously.

5.3.3 UWB Emitter Distribution

The emitter distribution used in UWBRings is modeled after the RINGS program described in NTIA TM-89-139 "Single and Aggregate Emission Level Models for Interference Analysis".[43] This distribution considers that all emitters are confined to placement on concentric circles about the victim receive antenna. Figure 5.3.1 depicts the RINGS concept as described in the document. The emitter density is spread over each ring such that the ratio of emitters to ring radius remains constant over all rings. In addition, the emitters are evenly spaced on each ring, and the spacing between rings is also kept constant throughout. The effect of these spacing rules is that emitters are approximately evenly spaced from each other over the entire area enclosed between innermost and outermost rings.

The RINGS concept as depicted in the documentation was intended to protect terrestrial microwave receivers. Figure 5.3.1 shows a receive antenna pointing to the right. For simplicity the emitter density is modeled using only 10 concentric rings (actual program simulations may use several thousand rings). The motivation for the simplified ring concept is to greatly reduce the number of calculations necessary to determine the aggregate power level. Specifically, the path loss from each emitter need not be calculated, but only the path loss from each ring, since all emitters on a given ring are the same distance from the victim receiver.

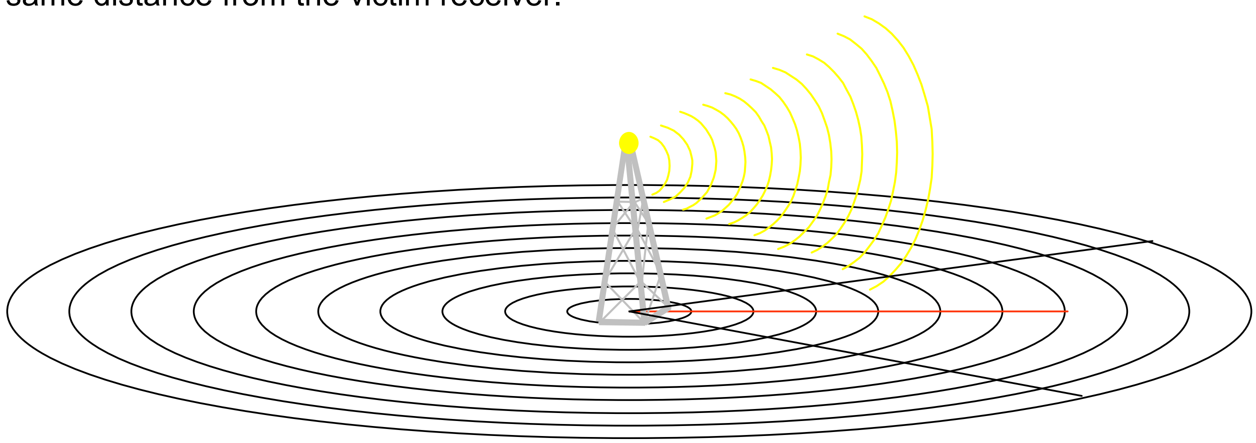

Figure 5.3.1

The radial line in Figure 5.3.1 shows a sample step in the overall calculation, namely, the calculation of the distance to one of the rings. From this distance the path loss from that ring is calculated. Using this loss a UWB power level into the receiver is calculated, which is then multiplied by the number of emitters on that ring. This process is repeated throughout, summing total power contributions from each ring.

[43] National Telecommunications and Information Administration, U.S. Dept. of Commerce, Single and Aggregate Emission Level Models for Interference Analysis, NTIA Report 89-139, at 3-1 through 3-16 (March 1989) [hereinafter Single and Aggregate Models].

Once this topology is understood there are a number of special effects which can be used to model specific scenarios. For example, in Figure 5.3.1 the receive antenna is assigned a horizontal beamwidth. This effectively sectors off a portion of the rings (as shown). The ratio of sector angle to full annulus can be multiplied by the expression used to find the total number of emitters in the j^{th} ring. The main beam gain and appropriate path loss are then applied to this scaled down number of emitters. Emitter power contributions from all rings thus obtained are used to represent the total received aggregate power into the victim receiver for cases where a directional receive antenna is used.

5.3.4 UWBRings Extends the Concepts of NTIA TM-89-139

UWBRings increases the flexibility of the RINGS program described in the documentation in several ways. First, by considering the use of an omni-directional receive antenna we can extend the concept to model a vertical pointing receive antenna. For terrestrial cases, such as a VHF repeater, the antenna can be viewed as pointed vertically such that its radiation pattern includes all emitters on the annulus (see Figure 5.3.2). To model an airborne receiver the antenna can be viewed as pointing at nadir. The antenna pattern can be omni-directional to include all emitters on the annulus, or it can be directional. UWBRings provides for three directional patterns for vertical antenna pointing, namely, a conical[44] main beam of user-specified beamwidth, a 2-level pattern which adds a single-level backlobe to a conical main beam, and an ITU-R antenna radiation pattern.

To more accurately model aircraft at higher altitudes UWBRings further extends the RINGS concept by resting each ring over the surface of a spherical Earth. This provides for determination of line of sight and calculation of realistic receiver field of view. Another UWBRings improvement is that the distance used for determining path loss from the rings is the actual distance to the antenna (not the antenna base). This improvement becomes

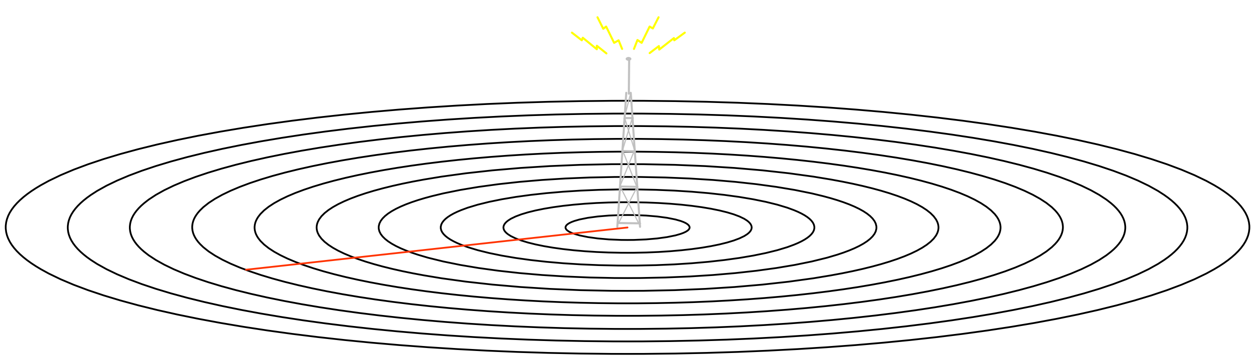

Figure 5.3.2

[44] Conical indicates the pattern resulting from spinning the beamwidth 180°about the antenna boresight.

significant as antenna altitude increases. Figure 5.3.3 shows how the emitter distribution is modeled in UWBRings. As shown in the figure, there is no reason not to extend this topology to model interference into a satellite receiver, at any altitude.

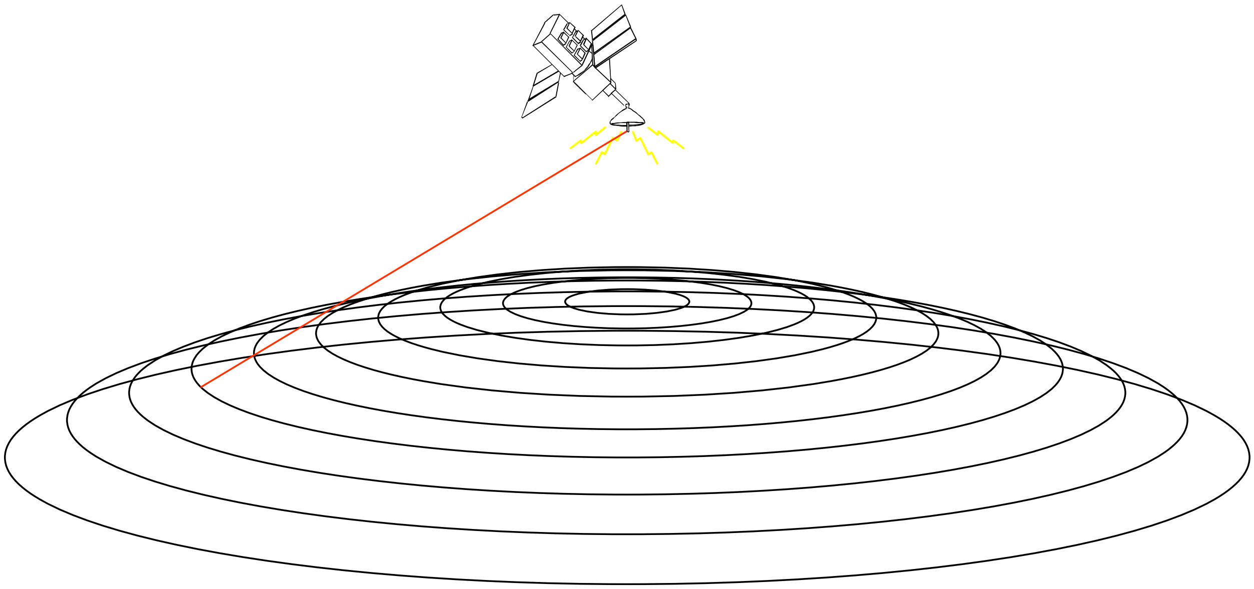

Figure 5.3.3.

5.3.5 Additional UWBRings Features

In addition to extending the RINGS program to include vertical antenna pointing and pattern options UWBRings also extends the horizontal pointing antenna to include both a horizontal and vertical beamwidth, and an antenna pointing elevation angle. Based on these beamwidth values, the spreadsheet calculates what the theoretical backlobe would be if the simplifying assumptions were made that the backlobe is a constant level, and the antenna efficiency is 100 percent. The user specifies both beamwidths and chooses whether or not to include the backlobe. If the backlobe is not included, the program considers only those emitters which fall within the receive antenna main beam. In this case it is possible that inner rings of the emitter distribution could be omitted if the vertical beamwidth is not wide enough to include them. If the backlobe is included, all other emitter contributions are added to the aggregate at the backlobe gain level.

Besides a horizontal and vertical beamwidth for horizontal pointing antennas, several patterns have been included to model various ground based radar, radionavigation, and satellite Earth terminal systems.

UWBRings also extends the path loss options by adding to free space loss the empirical Okumura/Hata model, as well as the Area Prediction Mode of the Irregular Terrain Model (ITM).[45] The ITM model includes options for propagation losses over various

[45] *See* ITM Report, *supra* note 31.

types of smooth or rough ground terrain and water, while the Okumura model covers urban, suburban, and open types of land environments.

5.4 COMPARISON OF DETERMINISTIC AND STATISTICAL METHODS

The analytic approach and model described above uses a deterministic method for representing a uniform distribution of UWB emitters in the environment. In this method, the UWB emitters are distributed with approximately even spacing between each, based on a chosen emitter density, using a concentric ring representation. The average (RMS) power received from each individual UWB emitter is linearly summed to arrive at an aggregate total average (RMS) power. The benefit of this approach is the ease and flexibility to accommodate various radio propagation models, 3-dimensional antenna patterns, and other factors.

Other methodologies are available, however, and four such models, all statistical, were reviewed and compared with results from the deterministic approach described above. While each of these methods used slightly different formulations to arrive at an aggregate interference level, all resulted in very similar results. In the ITS Report, a statistical method is described where the UWB emitters are assumed to be randomly distributed in the environment with a uniform distribution. In that approach, an average emitter density rather than individual emitters is used to represent the UWB environment.

A second statistical approach was described in a filing to the FCC in the UWB proceeding by Fantasma Networks, Inc.[46] This methodology uses a similar but simpler statistical approach, being limited to free space propagation and omnidirectional antennas. In this method, account is not taken of propagation or antenna factors related to differences in antenna height between UWB emitters and the receiver. However, in this simpler case, a closed form solution is derived for the calculated aggregate interference levels.

A third statistical methodology, described in NTIA Report 89-139,[47] develops a closed form solution for the case of aggregate interference to an airborne receiver. A fourth method, described in the EMC 2000 Symposium[48] arrives at an identical formulation.

It is expected that in simply-defined UWB aggregate scenarios where no antenna vertical pattern variation is considered, the four methodologies would yield comparable results. The following discussion provides several specific examples showing this to be the case.

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46 Reply comments of Fantasma Networks Inc., *In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, ET 98-1-53 (Nov. 1, 2000).

47 *See* Single and Aggregate Models, *supra* note 43, at Section 4.

48 Struzak, Ryzard, *Noise Interference in Radiocommunication Networks: Shannon's Formula Revisited*, EMC 2000 International Wroclaw Symposium on EMC (June 2000).

For this comparison, the following hypothetical parameters are used:

TABLE 5-2
Hypothetical Parameters Used for Aggregate Model Comparison

Parameter	Example 1	Example 2	Example 3	Example 4
Frequency (GHz)	1	5	3	4
UWB EIRP (dBm per MHz (RMS)	-41.3	-41.3	-41.3	-41.3
UWB Antenna Height (m)	2	2	2	2
UWB Density (active emitters per km^2 plus active emitters per m^2)	100 [0.0001]	10 [0.00001]	1000 [0.001]	100 [0.0001]
Receiver Height (m)	3	30	300	3000
Receiver Main Beam Antenna Gain (dBi)	0	30	0	3
Receiver Horizontal Antenna Beamwidth[1] (degrees)	360	5	360	360
Receiver Average Antenna Gain (dBi)	0	11.5	0	3
Propagation Model	Smooth Earth	Smooth Earth	Free Space	Free Space
Minimum Radius (m)	15	50	0	0
Maximum Radius (km)	13	28	20	Maximum Visibility

Note: Antenna modeled for purposes here as a two-dimensional pattern (i.e., no vertical variation) with the indicated main beam gain and beamwidth, and -10 dBi gain outside of the main beam.

UWBRings Method

The resulting values for these four examples using the deterministic model described above are as follows:

Example 1: I_{agg} = -96.6 dBm/MHz average (RMS)
Example 2: I_{agg} = -109.3 dBm/MHz average (RMS)
Example 3: I_{agg} = -99.1 dBm/MHz average (RMS)
Example 4: I_{agg} = -108.6 dBm/MHz average (RMS)

ITS Statistical Method

The ITS Report describes a statistical model of aggregate interference. From that report, (Equation 4.10), the aggregate power can be written in semi-closed form as follows:

$$I_{agg} = W_{eirp} + P + \Gamma_r + \Gamma_b \qquad (5\text{-}1)$$

where I_{agg} = aggregate received power in dBm per unit bandwidth (average, RMS)
W_{eirp} = UWB average EIRP spectral density in dBm per unit bandwidth (average RMS)
P = 10 * Log_{10} (ρ) in dB
ρ = UWB density in active emitters per m^2
Γ_r = average receiver antenna gain in azimuthal direction in dBi
Γ_b = area gain in dB m^2 (values from the ITS Report given in table below)

In this method, the term called area gain is a weighted average propagation loss over the geographic area of interest derived from the Irregular Terrain Model in the Area Prediction Mode[49] using iterative methods. TABLE 5-3 below are representative values derived from the methods described in the ITS Report.

TABLE 5-3
Values of Area Gain*

Frequency (MHz)	Rcvr Ht = 3 m	Rcvr Ht = 30 m	Rcvr Ht = 300 m	Rcvr Ht = 3000 m
1000	-16.8 dB	-17.5 dB	-17.1 dB	-18.1 dB
2000	-22.3 dB	-23.0 dB	-23.1 dB	-24.2 dB
3000	-25.6 dB	-26.5 dB	-26.6 dB	-27.7 dB
4000	-27.9 dB	-28.7 dB	-29.1 dB	-30.2 dB
5000	-29.7 dB	-30.5 dB	-31.1 dB	-32.1 dB

* For Δ h = 0 and UWB emitter height = 2m

For the four examples described above, the results are:

Example 1: I_{agg} = -41.3 + 10 * Log_{10}(0.0001) + 0 + (-16.8)
= -98.1 dBm/MHz

Example 2: I_{agg} = -41.3 + 10*Log_{10}(0.00001) + 11.5 + (-30.5)
= -110.3 dBm/MHz

Example 3: I_{agg} = -41.3 + 10*Log_{10}(0.001) + 0 + (-26.6)
= -97.9 dBm/MHz

Example 4: I_{agg} = -41.3 + 10*Log_{10}(0.0001) + 3 + (-30.2)
= -108.5 dBm/MHz

Fantasma Statistical Method

The methodology described by Fantasma assumes a receiver in the midst of a densely populated metropolitan area defined by minimum and maximum calculation radii,

[49] *See* ITM Report, *supra* note 31.

using free space propagation. As described in the reference (Equation 9), for the case of free space propagation, a closed form expression is derived for the level of interference from an average density of UWB emitters as follows:[50]

$$A = 2\,\alpha\,\eta\,\rho\,\pi\,\ln(R/R_o) \qquad (5\text{-}2)$$

where
- A = Average aggregate interference in Watts per unit bandwidth
- α = Constant dependent on UWB power, antennas, and frequency
- η = Fraction of time each emitter is transmitting ("activity factor") assumed to be unity for the examples given herein
- ρ = Average density of UWB emitters (emitters per meter^2)
- R = Maximum radius of calculations in meters
- R_o = Minimum radius of calculation in meters

The Fantasma paper did not explicitly define the factors included in the constant term, α. However, for the case of omnidirectional UWB emissions and free space propagation, it is simple to conclude that α is given by:[51]

$$\alpha = W_{eirp}\,(\lambda/4\pi)^2\,g_r \qquad (5\text{-}3)$$

where
- W_{eirp} = Average UWB device EIRP in Watts per unit bandwidth
- λ = Wavelength at center of receiver bandpass in meters
- g_r = Receiver antenna in the horizontal plane

While the Fantasma paper did not consider a receiver antenna having directional characteristics, a logical extension to the method could include the effects of a directional receive antenna by simply replacing the fixed receiver gain with an average receiver gain in the horizontal plane. Consolidating the above factors, Equation 5-2 can be written in logarithmic terms as follows:

$$I_{agg} = W_{eirp} + P + \Gamma_r + \Gamma_b \qquad (5\text{-}4)$$

where
- I_{agg}, P_{eirp}, P, Γ_r are defined as above
- $\Gamma_b = 10{*}\mathrm{Log}_{10}(\lambda^2 / (8\,\pi) * \ln(R/R_o))$ (5-5)
- R, R_o = Maximum and minimum calculation distances in meters

Noting the similar form between Equations 5-1 and 5-4, one could conclude that the last term in the two equations have a similar basis and physical interpretation as an area

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50 It is noted that the Fantasma paper takes a further step to compare this calculated aggregate UWB interference level to the level from a single UWB emitter located at a reference distance from the receiving antenna. For the extreme case described in the paper of a trillion emitters in a metropolitan size area (e.g., 25 kilometer radius), the single emitter reference distance to the receiver antenna implied by the study is 5 millimeters. NTIA views this comparison as irrelevant to any real-world situation leading to an erroneous conclusion that aggregate interference never exceeds a single emitter level. If, for example, the aggregate to single emitter comparison is made using a more realistic distance of, say, 15 meters (typical radius enclosed by a physical security fence) the Fantasma-derived results change by 70 dB!

51 Since the Fantasma paper defined α by $I_{single} = \alpha / r^2$ and under free space conditions $I_{single} = P_{eirp}\, g_r\, (\lambda / 4\pi r)^2$.

gain, the first based on multiple iterations using a smooth Earth propagation model and the second on free space propagation. As shown in the following table, the two equations yield remarkably close results, despite the difference in propagation models.

TABLE 5-4
Values of Area Gain (Equation 5-5)*

Frequency (MHz)	**Rcvr Ht = 3 m Min Dist = 15 m Max Dist = 13 km**	**Rcvr Ht = 30 m Min Dist = 50 m Max Dist = 28 km**	**Rcvr Ht = 300 m Min Dist = 0 m Max Dist = 20 km**	**Rcvr Ht = 3000 m Min Dist = 0 m Max Dist = LOS**
1000	-15.6	-16.3	NA**	NA
2000	-21.7	-22.4	NA	NA
3000	-25.2	-25.9	NA	NA
4000	-27.7	-28.8	NA	NA
5000	-29.6	-30.3	NA	NA

* For UWB emitter height = 2m
** Model cannot address cases where minimum horizontal distance is zero (i.e., where UWB emitter is directly under an airborne receiver antenna).

Applying these results to the four examples yields:

Example 1: I_{agg} = -41.3 + 10 * Log_{10}(0.0001) + 0 + (-15.6)
= -96.9 dBm/MHz

Example 2: I_{agg} = -41.3 + 10*Log_{10}(0.00001) + 11.5 + (-30.3)
= -110.1 dBm/MHz

Example 3: Not applicable

Example 4: Not applicable

NTIA Airborne Aggregate Model

As described in NTIA Report TM-89-139, a closed form expression was derived for the case of aggregate interference to an airborne receiver from multiple emitters spread uniformly over the Earth's surface out to a radius R.[52] From that reference

$$A = \alpha \rho \pi r_e / (r_e + h) \ln ((2 (r_e + h) H + h^2) / h^2) \qquad (5\text{-}6)$$

where α, ρ, R are defined as above
r_e = effective Earth radius

[52] *See* Single and Aggregate Models, *supra* note 43, at Section 4.

h = aircraft altitude in meters
H = r_e [1 - cos (R / r_e)]

Since aircraft altitudes are small compared with the Earth radius, this expression can be simplified as follows:

$$A \approx \alpha \rho \pi \ln((R/h)^2 + 1) \quad (5\text{-}7)$$

Rewriting this equation in logarithmic form using the same terminology as Equation 5-4 yields:

$$I_{agg} \approx W_{eirp} + P + \Gamma_r + \Gamma_b \quad (5\text{-}8)$$

where I_{agg}, W_{eirp}, P, Γ_r are defined as above

$$\Gamma_b = 10*\text{Log}_{10}(\lambda^2 / (16\pi) * \ln((R/h)^2 + 1) \quad (5\text{-}9)$$

Although this method was derived on the basis of an airborne receiver within line-of-sight of all emitters, it was found to yield very similar results to the previous examples even when applied at very low heights above ground as follows:

TABLE 5-5
Values of Area Gain (Equation 5-9)*

Frequency (MHz)	Rcvr Ht = 3 m** Min Dist = 15 m Max Dist = 13 km	Rcvr Ht = 30 m** Min Dist = 50 m Max Dist = 28 km	Rcvr Ht = 300 m Min Dist = 0 m Max Dist = 20 km	Rcvr Ht = 3000 m Min Dist = 0 m Max Dist = LOS
1000	-14.7	-16.1	-18.2	-18.1
2000	-20.7	-22.1	-24.2	-24.1
3000	-24.2	-25.6	-27.8	-27.6
4000	-26.7	-28.1	-30.3	-30.1
5000	-28.7	-30.0	-32.2	-32.1

* For UWB emitter height = 2m
** Although the model was not defined based on a surface-based receiver, these calculations were included for comparison purposes.

Applying these results to the four examples yields:

Example 1: I_{agg} = -41.3 + 10 * Log_{10}(0.0001) + 0 + (-14.7)
= -96.0 dBm/MHz

Example 2: I_{agg} = -41.3 + 10*Log_{10}(0.00001) + 11.5 + (-30.0)
= -109.8 dBm/MHz

Example 3: I_{agg} = $-41.3 + 10*Log_{10}(0.001) + 0 + (-27.8)$
= -99.1 dBm/MHz

Example 4: I_{agg} = $-41.3 + 10*Log_{10}(0.0001) + 3 + (-30.1)$
= -108.4 dBm/MHz

EMC Symposium Method

This method developed a result identical in form to Equations 5-8 and 5-9 above thus yielding identical results.

Summary

TABLE 5-6 below summarizes these calculated results for each of the five methodologies discussed above. As seen, for these simplified cases, all five model results agree quite closely within 2 dB. Further examination of these results show that the only significant contributors to the overall level of aggregate interference were from UWB devices located within free-space, line-of-sight of the receiver. Overall, the basic concepts and methodology used in this study appears sound and consistent. The UWBRings deterministic approach is used hereinafter for this overall study because of its degree of automation and its greater flexibility in considering, among other things, various propagation models and three-dimensional antenna patterns.

TABLE 5-6
Summary of Comparison of Models

Example	Aggregate Received Power (dBm/MHz)			
	NTIA UWBRings Model	NTIA Statistical Model	Fantasma Model	NTIA Airborne & EMC Symposium Models
1	-96.6	-98.1	-96.9	-96.0
2	-109.3	-110.3	-110.1	-109.8
3	-99.1	-97.9	NA	-99.1
4	-108.6	-108.5	NA	-108.4

5.5 RESULTS OF AGGREGATE ANALYSES

Summary of Aggregate Analysis

Using the UWBRings model described above, the single emitter analyses were extended to include multiple interferers. The results are plotted as a function of emitter density (simultaneously active emitters per square kilometer, uniformly distributed) for generally the same conditions and parameters used for the single emitter analysis. The exception is that the interference protection criteria used is based on average (RMS) interference for all cases. The plots shown in Figures 5.5-1 through 5.5-15 below indicate the UWB EIRP level (average, RMS) in dBm per MHz where the receiver system interference criteria is exceeded as a function of active emitters per square kilometer.

Each figure has a title bar describing parameters used in the simulation. Each title begins with the center frequency of the receiver. This is followed by path loss information. Each of these figures used the ITM model at 50 percent time, 50 percent location, and 50 percent confidence as described in the end of Section B.2.2. Next is listed receive antenna parameters including antenna pointing, pattern type, main beam gain, and associated beamwidths. This is followed by the minimum and maximum radii used in the distribution. Next the noise figure, Smin,[53] and system losses used are listed, as well as UWB antenna height,[54] and the criterion and threshold used for the simulation. “Iagg+Isngl” appears in each of these figures because this worst case algorithm, as described in Section B.2.4, was used to graphically display the additional EIRP limitation required beyond that indicated in Section 4 to meet the specified criterion threshold. A final point about each figure is that all curves represent a receive antenna height as listed in the legend to the right. This height, h, is above the local terrain elevation and is always listed in kilometers.

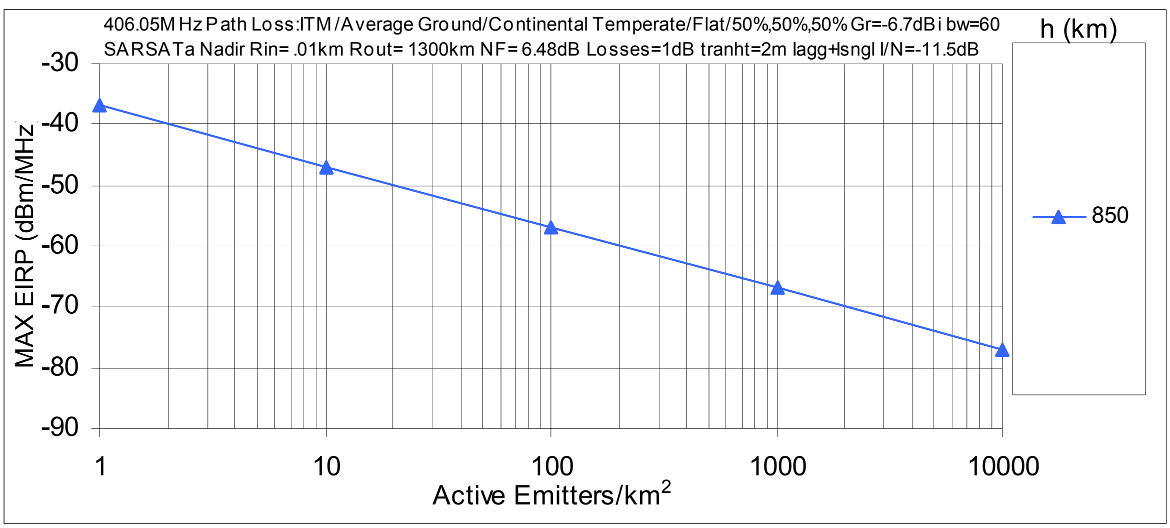

Figure 5.5.1 SARSAT Uplink

53 Noise figure and Smin are described in Section B.2.4. Smin is converted to dBm/MHz for use by the program.

54 In every figure the UWB emitters were fixed at 2 meters above the local terrain elevation.

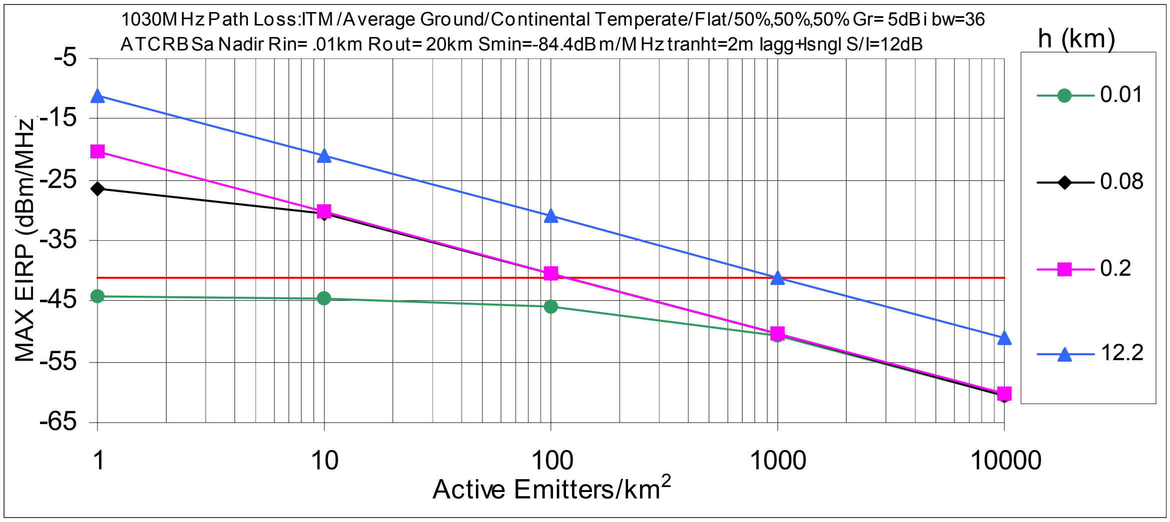

Figure 5.5.2 ATCRBS (Airborne Transponder)

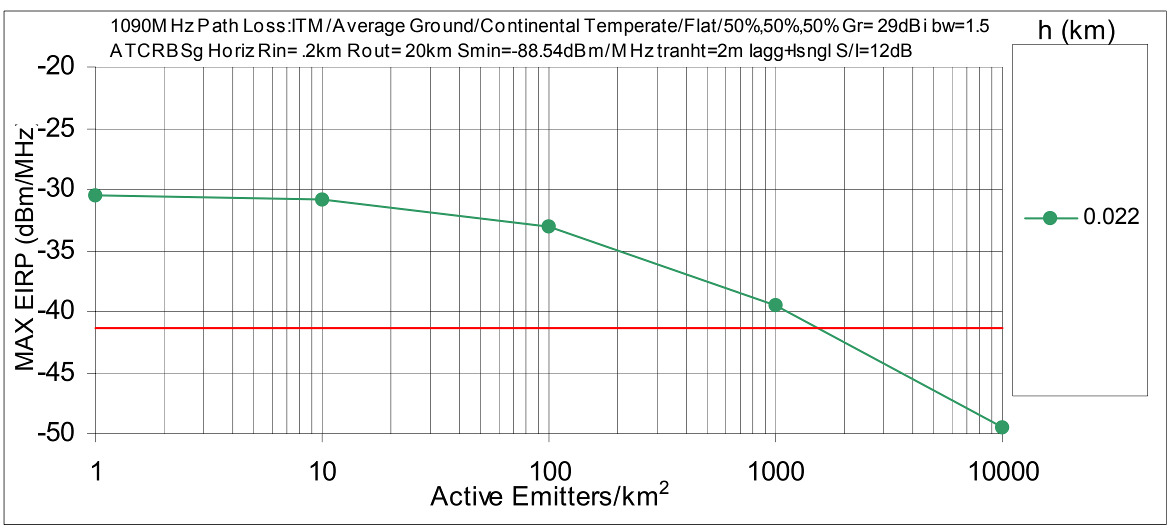

Figure 5.5.3 ATCRBS (Ground Interrogator)

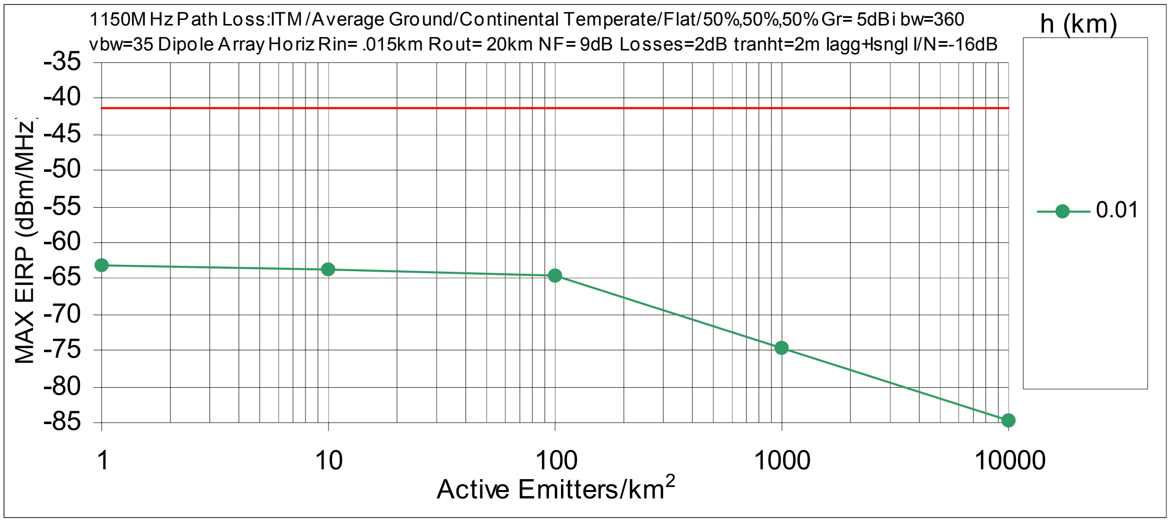

Figure 5.5.4 DME (Ground Transponder)

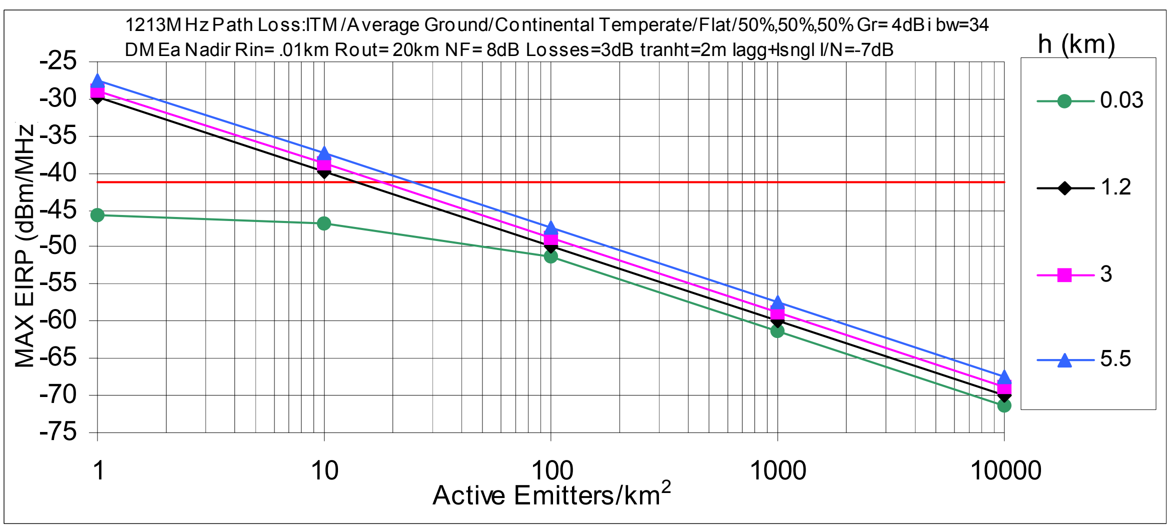

Figure 5.5.5 DME (Airborne Interrogator)

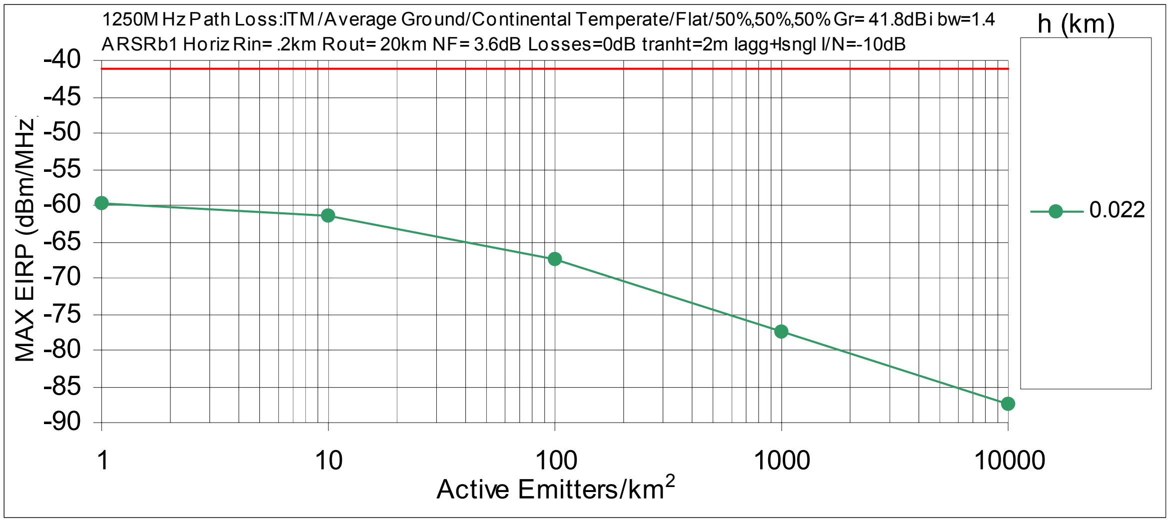

Figure 5.5.6 ARSR-4

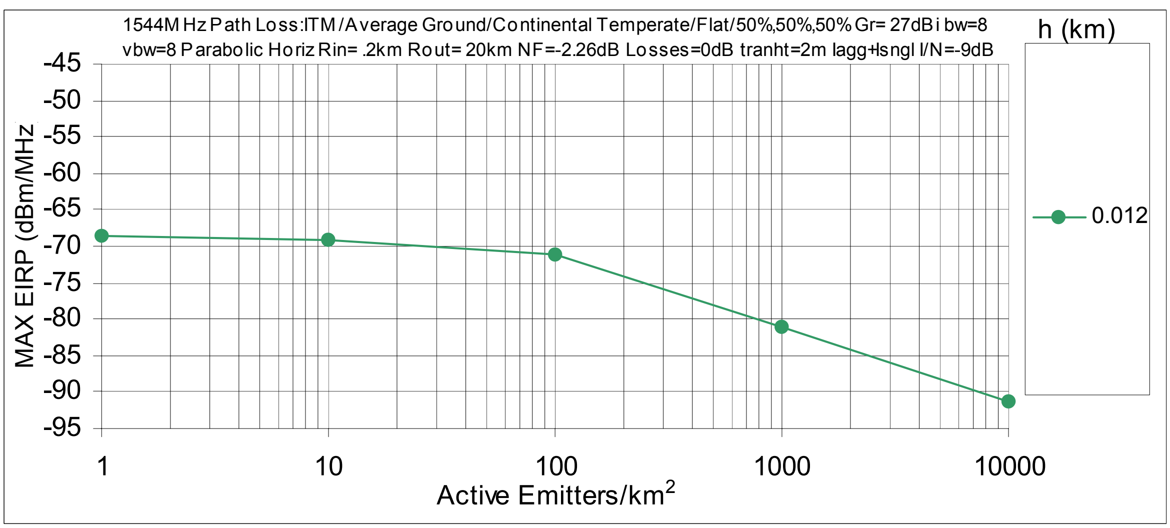

Figure 5.5.7 SARSAT LUT Downlink

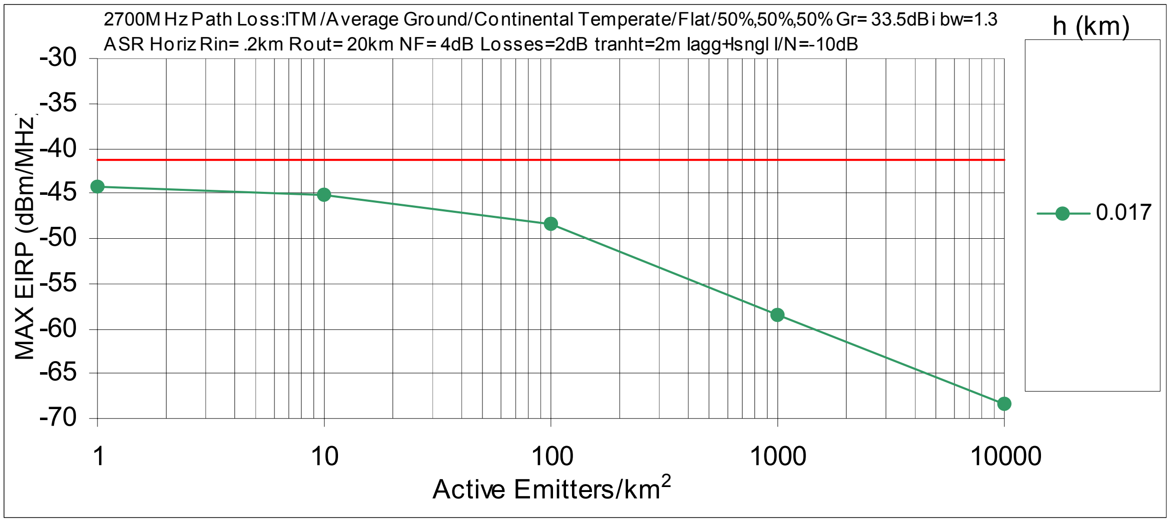

Figure 5.5.8 ASR-9

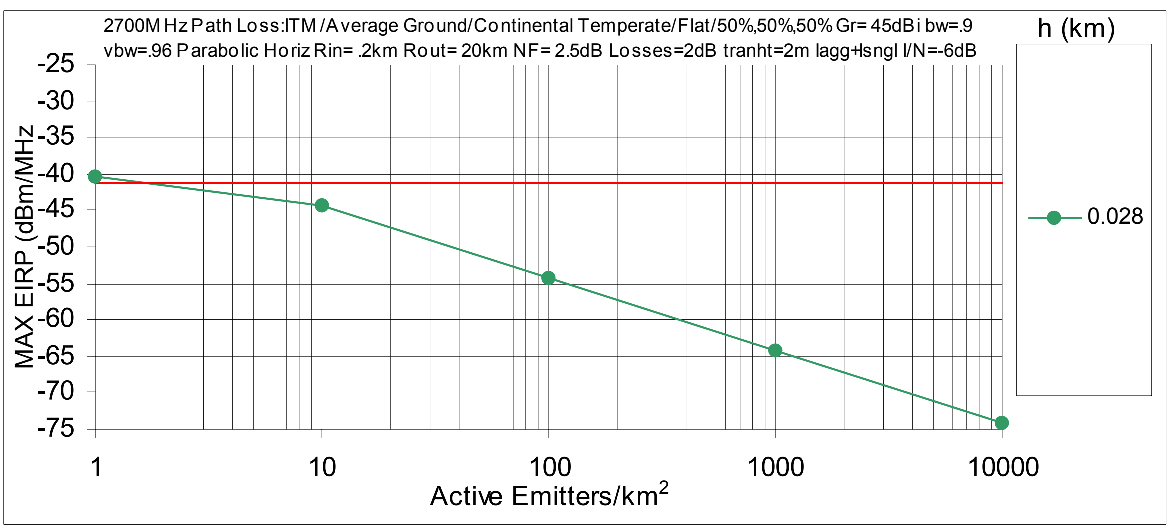

Figure 5.5.9 NEXRAD

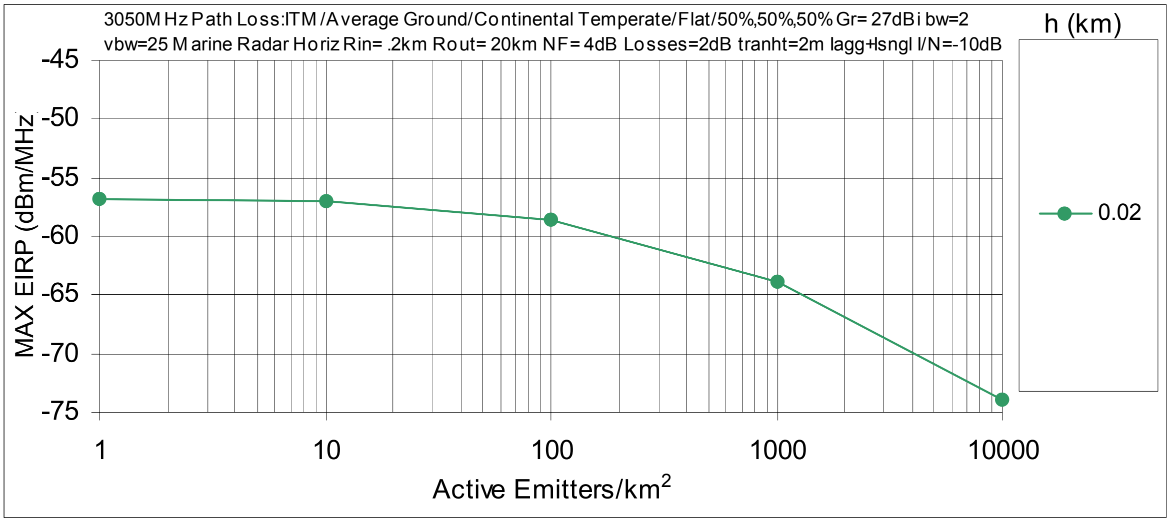

Figure 5.5.10 Marine Radar

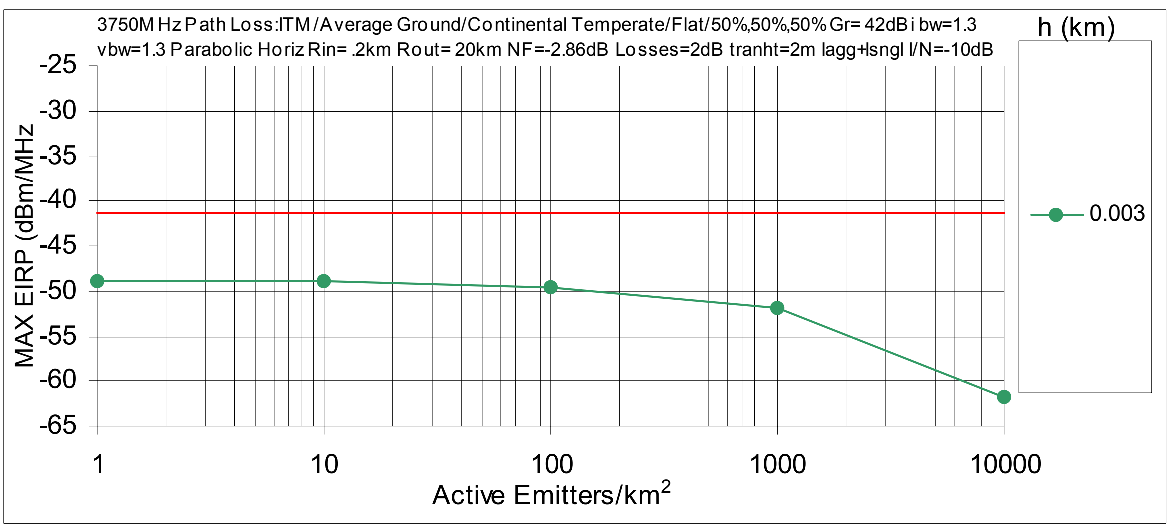

Figure 5.5.11 Fixed Satellite Earth Station (5° elevation tilt).

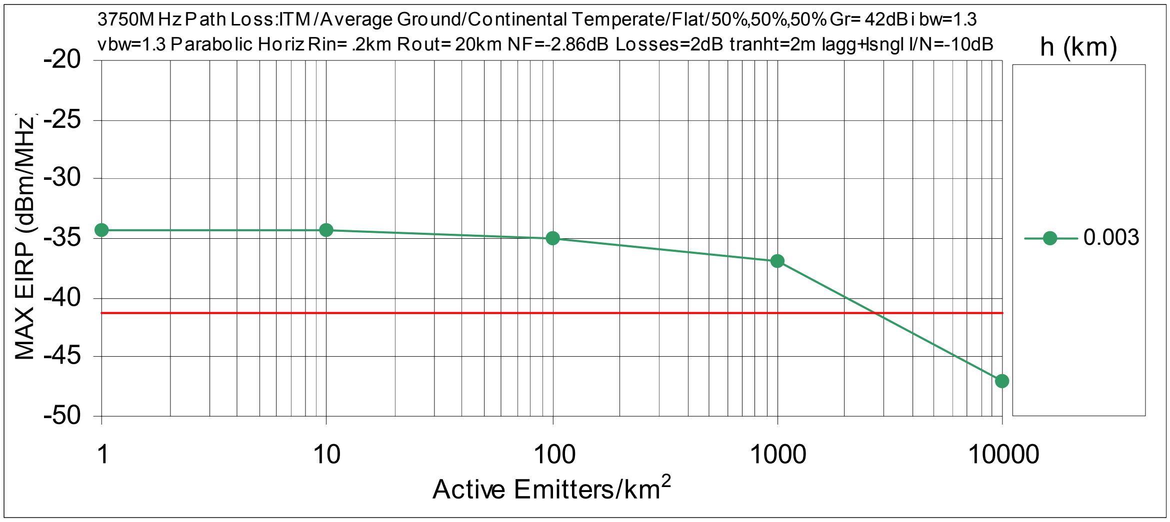

Figure 5.5.12 Fixed Satellite Earth Station (20° elevation tilt).

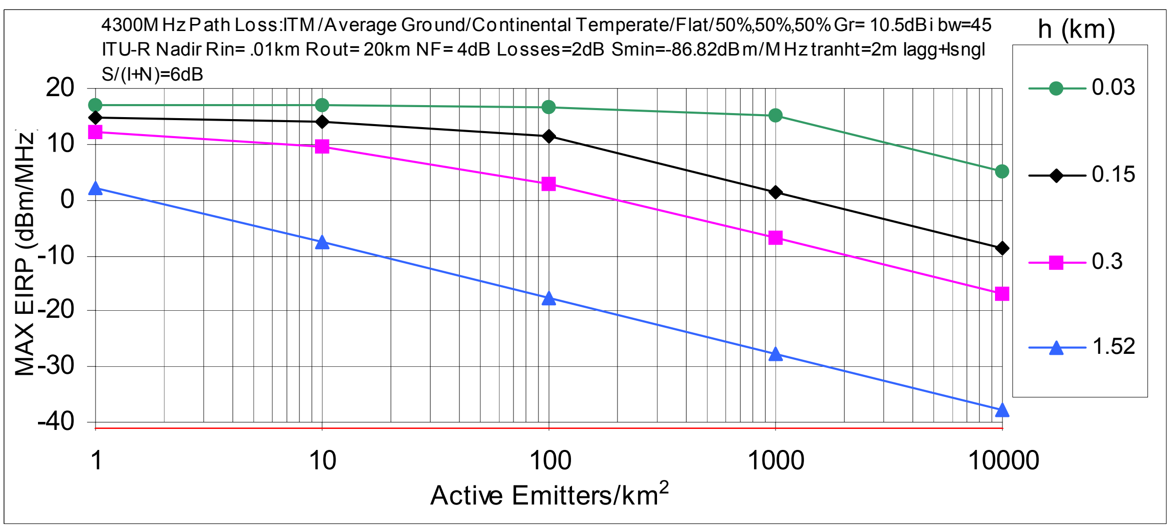

Figure 5.5.13 Radar Altimeter (Pulsed).

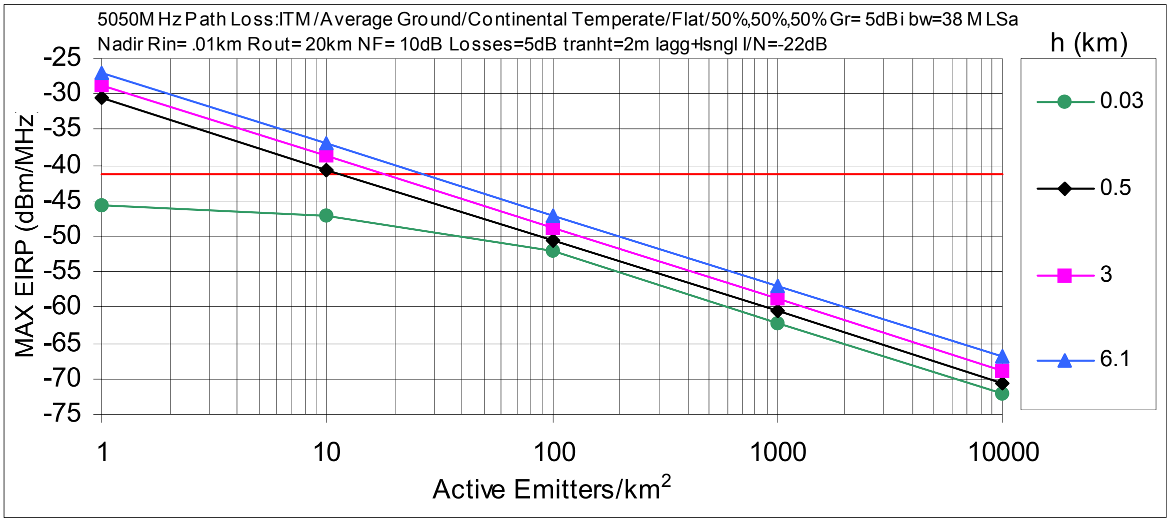

Figure 5.5.14 Microwave Landing System (Airborne)

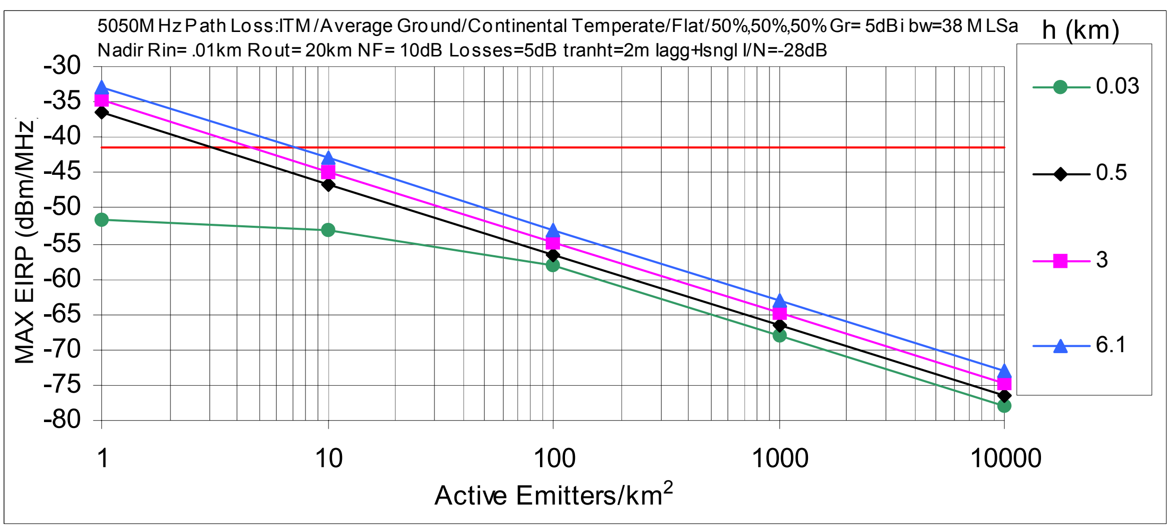

Figure 5.5.15 Microwave Landing System (Airborne).

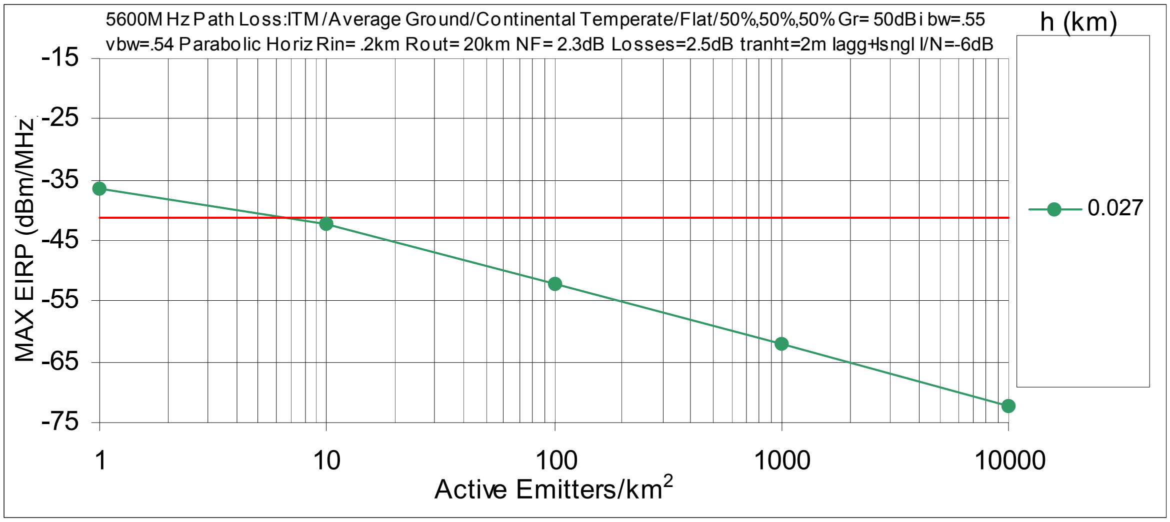

Figure 5.5.16. TDWR

With the exception of Figure 5.5.1, the only satellite receiver analyzed in this report and the only system operating at less than 1 GHz, all figures show[55] an additional curve which is the -41.3 dBm/MHz (RMS) reference line already described and used in Section 4.

Figure 5.5.1 shows a maximum distribution radius of 1,300 km, while the terrestrial and airborne systems in the remaining figures use only 20 km.[56] This radius was chosen to describe the largest circle in the eastern continental United States which touches the coastline yet avoids any significant water masses such as the Gulf of Mexico and the Great Lakes. This land mass is significant because it can represent the highest population density within the continental United States.

When interpreting the significance of Maximum Allowable EIRP vs Active Emitter Density curves of satellite receivers, it is important to note that the emitter density in the footprint will not likely be uniform. In such cases it may be helpful to estimate total emitters in the satellite footprint and use (B1) of Appendix B to calculate a corresponding density to use in the curve.

There is an additional note about the Earth terminals in Figures 5.5.7 and 5.5.11. The title bars for these figures list a negative NF. The spreadsheet calculates all noise as $N = 10\log(KT_0B) + NF$. When a system noise temperature (T) is specified, it is entered in the NF cell as $10\log(T/T_0)$. So the negative noise figures are not really noise figures, but an equivalent way to represent a system noise temperature.

[55] Assuming the ordinate scale permits

[56] To estimate a nominal city size.

From these results, several overall conclusions can be drawn. Most fundamental is the fact that, given the assumption of uniform distribution of identical UWB emitters, the aggregate interference from UWB emitters increases linearly with UWB power and emitter density. Thus, for a ten-fold increase in emitter density, the received aggregate power will increase by ten dB, and for a hundred-fold increase by 20 dB. This conclusion is borne out from the statistical analysis described in the ITS Report as well as other researchers.

The results were derived as a function of density of simultaneously active emitters. This, in turn, is a product of the density of actual emitters and the average fraction of time that each emitter is actively transmitting. This latter term is sometimes called an activity factor. It follows directly that the aggregate interference level also increases linearly with UWB activity factor.

From the above curves, it is possible to show for each system the emitter density where the permitted UWB EIRP level (dBm/MHz) equals:

1) The reference level of -41.3 dBm/MHz and

2) The permitted UWB EIRP level equals that for the worst case single emitter. This information is summarized in TABLE 5-7.

5.6 ADDITIONAL CONSIDERATIONS

5.6.1 Introduction

The results above clearly indicate that under the somewhat ideal conditions used for these aggregate interference analyses, aggregate interference can indeed result in levels that exceed the established interference protection criteria. It is recognized that in most cases such ideal conditions will not exist, resulting in lower realized values of aggregate interference. Several additional considerations are discussed below.

5.6.2 Radio Propagation

The model used in the above analyses of both single entry and aggregate interference to the various radiocommunications systems uses a radio propagation model based on the assumption that the Earth is represented by a smooth sphere, with no natural or man-made obstructions, a so-called smooth Earth model. For this model, emitters that are close to the receiver are subject to free space propagation mode, which smoothly transitions to a diffraction propagation mode beyond the radio horizon.

TABLE 5-7
Summary of Aggregate Interference Calculations (2 meter UWB height)

Receiving System	Receive Frequency (MHz)	UWB Emitter Density Where Aggregate Equals Single Entry* (units/km^2)	UWB Emitter Density Where Permitted EIRP Equals -41.3* dBm/MHz RMS (units/km^2)
SARSAT Uplink	406-406.1	<1	NA
DME (Airborne Interrogator) 30m	960-1215	30	10
DME (Ground Transponder)	1025-1150	<1	<1
ATCRBS (Abn Transponder) 10m	1030	200	100+
ATCRBS (Gnd Interrogator)	1090	100+	1,000+
Enroute Radar (ARSR-4)	1240-1370	15	<1
SARSAT Downlink	1544-1545	50+	<1
Airport Radar (ASR-9)	2700-2900	30+	20
Weather Radar (NEXRAD)	2700-3000	3	5
Maritime Radionavigation (Marine) Radar	2900-3100	200	6
Fixed Satellite Earth Station (5° elevation tilt angle)	3700-4200	500	90
Fixed Satellite Earth Station (20° elevation tilt angle)	3700-4200	500	2500
Radio Altimeters (1.52 km)	4200-4400	4	10,000+
MLS (Airborne) 30m	5030-5091	20	2
Weather Radar (TDWR)	5600-5650	1+	8

*The values in these columns come from additional simulations in which the Iagg+Isngl checkbox is deselected. Thus, it is possible for worst case single emitter interference to exceed aggregate at low emitter densities.

In most realistic environments, smooth Earth propagation models underestimate the actual propagation losses that would occur because of the presence of various natural and man-made obstructions. For calculations involving simple one-on-one interference as discussed in Section 3, it is reasonable to base analyses on a worst case smooth Earth assumption, since one cannot assure that any particular obstruction may be present. However, for aggregate interference calculations it becomes somewhat unrealistic to assume that each UWB emitter is located such that optimal radio propagation conditions result. The following paragraphs discuss four radio propagation factors that are relevant to aggregate interference calculations.

Foliage. In most areas of the United States outside of the Great Plains and dessert areas, additional propagation losses typically occur as a result of natural foliage, predominately trees. This factor is especially significant when one end of the interference path, e.g., the UWB emitters, is at very low heights above the ground such as personal and automobile UWB applications. One reported measurement of excess propagation loss at 869 MHz through a single tree canopy was 10 dB, which increases significantly for more generally forested areas and with increasing frequency.[57] While this factor was not investigated to any depth for this study, it is clear that in even light to moderate forestation, inclusion of the effects of foliage losses will significantly reduce the potential effects of UWB aggregate interference.

Irregular Terrain. Very few places in the United States, even in the Great Plains, include terrain that is effectively smooth. For a given propagation path, the magnitude of typical terrain irregularities can be quantified by a factor, Δh, using digitized terrain elevation data bases, which represents the difference between the upper and lower decile in terrain elevation along the path. Studies have shown that average radio propagation loss values increase as Δh increases.

Expanding on the methodology described in ITS report Section 4,[58] it is possible to plot the additional propagation losses that would occur as the Δh varies from zero (smooth Earth), through 30 meters (typical of the Great Plains), to 90 meters (typical of the rolling hills of the eastern United States). TABLE 5-8 shows additional propagation losses that would occur under various rough Earth conditions as compared to smooth Earth. For the range 1 to 5 GHz, the additional losses are only weakly dependent on frequency and are more pronounced for low antenna heights and larger values of Δh.

TABLE 5-8
Additional Propagation Losses Due to Terrain Irregularities*
(Compared with Smooth Earth Propagation, Δh = 0)

Frequency (GHz)	Receiver Ht = 3 m Δh = 30 m	Receiver Ht = 3 m Δh = 90 m	Receiver Ht = 30 m Δh = 30 m	Receiver Ht = 30 m Δh = 90 m
1	10.6 dB	22.3 dB	2.0 dB	13.5 dB
2	12.6	24.2	4.5	15.0
3	13.0	25.7	3.0	16.0
4	13.1	26.9		
5	13.1	27.8	1.0	16.0

* UWB height = 2m

[57] Henry L. Bertoni, Radio Propagation for Modern Wireless Systems, (Prentice Hall 2000).

[58] *See* ITM Report, *supra* note 31.

Urban Propagation. With the great popularity of wireless telephones, extensive studies have been conducted investigating radio propagation in suburban and urban areas, especially at frequencies near 900 and 1900 MHz. The Okumura-Hata propagation model has been well accepted to represent radio propagation losses in urban/suburban areas for frequency bands in the range 30 MHz to 1.5 GHz.[59] It is in such urban/suburban areas where one might expect to find the highest densities of UWB devices. This suggests that aggregate interference analyses of UWB devices operating below 2 GHz, especially where high emitter densities are being addressed, should include consideration of this model. However, in addition to the frequency range limit, other key limitations of the model include its applicability to only distances beyond one km and certain antenna height limitations. A comparison between predicted aggregate interference levels using the ITM smooth Earth propagation model and the Okumura-Hata model is shown in TABLE 5-9. Two examples are shown, the first where the receiver antenna is omnidirectional and the second where it is highly directional, typical of the ARSR-4 radar.

One immediate observation is that, in the range of applicability beyond 1 km, use of the Okumura-Hata model reduces predicted levels of interference by nearly 30 dB for suburban environments and nearly 40 dB for urban environments, virtually eliminating any aggregate interference from UWB devices beyond one km. For the omnidirectional antenna, this would have only a small effect on the overall predicted interference, since a significant portion of the total interference is due to emitters closer than one km. However, for the highly directional antenna it would result in at least a 10 dB reduction in overall aggregate interference.

TABLE 5-9
Example Aggregate Interference Levels in Urban/Suburban Areas

Freq	Propagation Model	Distance (km)	Receiver Antenna	Predicted Aggregate Interference (dBm)	Difference (dB) (compared with ITM 1-20 km)
1 GHz	ITM (Δh=0)	0.2–1	Omni (0 dBi)	-103.5	
	ITM (Δh=0)	1–20	Omni	-104.8	
	ITM (Δh=0)	0.2–20	Omni	-100.9	
	O–H (Suburban)	1–20	Omni	-132.2	27.4
	O–H (Small-urban)	1–20	Omni	-142.4	37.6
	O–H (Large-urban)	1–20	Omni	-142.7	37.9
	ITM (Δh=0)	0.2–1	ARSR-4	-102.8	
	ITM (Δh=0)	1–20	ARSR-4	-93.8	
	ITM (Δh=0)	0.2–20	ARSR-4	-93.3	

[59] For example, *see* Telecommunications Industry Association, *Interference Criteria for Microwave Systems, Telecommunications Systems Bulletin*, TSB-10-F (Washington, DC, 1994).

TABLE 5-9
Example Aggregate Interference Levels in Urban/Suburban Areas

Freq	Propagation Model	Distance (km)	Receiver Antenna	Predicted Aggregate Interference (dBm)	Difference (dB) (compared with ITM 1-20 km)
	O–H (Suburban	1–20	ARSR-4	-121.6	27.8
	O–H (Small-urban)	1–20	ARSR-4	-131.8	38.0
	O–H (Large-urban)	1–20	ARSR-4	-132.1	38.3
1.5 GHz	ITM (Δh=0)	0.2–1	Omni (0 dBi)	-107	
	ITM (Δh=0)	1–20	Omni	-107	
	ITM (Δh=0)	0.2–20	Omni	-103.9	
	O–H (Suburban	1–20	Omni	-135.5	28.5
	O–H (Small-urban)	1–20	Omni	-146.9	39.9
	O–H (Large-urban)	1–20	Omni	-147.3	40.3
	ITM (Δh=0)	0.2–1	ARSR-4	-106.4	
	ITM (Δh=0)	1–20	ARSR-4	-95.5	
	ITM (Δh=0)	0.2–20	ARSR-4	-95.2	
	O–H (Suburban)	1–20	ARSR-4	-124.9	29.4
	O–H (Small-urban)	1–20	ARSR-4	-136.3	40.8
	O–H (Large-urban)	1–20	ARSR-4	-136.7	41.2

Analysis Parameters: Tx EIRP=41.3 dBm/MHz, Emitters/km^2=100, Ht = 2m, Rx Ht = 25 m, Losses=0 dB

While one would expect that for distances of less than one km, a smooth transition would occur between the propagation losses predicted by Okumura-Hata and smooth Earth, no data are available regarding the nature of such a transition. Further examination of several possible transition trends for distances below one km indicates that aggregate interference from uniformly distributed emitters at distances of less than 1 km would decrease by at least 15 dB in suburban areas and 20 dB in urban areas, as compared with a smooth Earth propagation loss. While the Okumura-Hata model is only applicable for frequencies below 1.5 GHz, the trends shown in TABLE 5-9, clearly show the additional suburban/urban losses increase at higher frequencies. Of course, these results are applicable for surface-to-surface paths only and not to airborne paths. TABLE 5-10 generalizes these results.

5.6.3 Building Penetration Losses in 1.0–6.0 GHz Frequency Band

The aggregate analyses described in this section were based on UWB devices located outdoors. If restrictions were placed on the use of UWB devices in certain frequency bands to indoor use only, it is reasonable to include the additional propagation losses that would be encountered as a result of the signal penetration through the walls of the buildings. The following paragraphs discuss the results of measurements completed by several researchers for building penetration losses in the 1 to 6 GHz region.

There are many different ways of defining building penetration or entry loss. According to the International Telecommunication Union Radiocommunication Sector (ITU-R) Study Group 3 on Propagation, the building entry loss is defined as the excess loss due to the presence of a building wall including windows and other features. It may be determined by comparing signal levels outside and inside the building at the same height. Typically the dominant propagation mode is one in which signals enter a building approximately horizontally through the wall surface including windows. A large number of studies and measurements of building attenuation have been reported in open literature as well as in ITU-R Study Group 3 Recommendations and other documents. Many of the earlier measurements were either for UHF cellular communications or for Earth satellite links. There are genuine differences in the types of buildings, e.g., high rise, medium commercial, residential, etc. Also the penetration loss depends on the type of materials used for construction, number and size of windows, relative difference in heights of the transmitter and receiver, etc. For example, the over all excess path loss from a large number of RLANs deployed randomly in a large variety of buildings will have a continuous average variation with elevation angle.

TABLE 5-10
Expected Reductions in Aggregate Interference in Urban/Suburban Areas
(Based on Okumura-Hata Propagation Model)

Frequency (MHz)	Suburban		Small City		Large City		Airborne
	Low Gain Antenna	High Gain Antenna	Low Gain Antenna	High Gain Antenna	Low Gain Antenna	High Gain Antenna	
960-1610	15 dB	25 dB	20 dB	30 dB	20 dB	30 dB	NA
> 1610	>15 dB	>25 dB	>20 dB	>30 dB	>20 dB	>30 dB	NA

Loew et al of ITS conducted building penetration measurements at 912, 1920 and 5990 MHz.[60] The CW measurement system used a fixed outdoor transmitter and a mobile indoor receiver. Measurements were done at eleven different buildings representing typical residential and high rise office buildings. Mean penetration loss at 912 MHz were

[60] National Telecommunications and Information Administration, U.S. Dept. of Commerce, Building Penetration Measurements from Low-height Base Stations at 912, 1920, and 5990 MHz, NTIA Report 95-325 (Sept. 1995).

6.4 dB, 11.2 dB and 8.2 dB for residential, high rise and all combined respectively. At 1920 MHz, the losses were 8.4 dB, 11.9 dB and 9.8 dB respectively. Corresponding losses for 5990 MHz were 11.7 dB, 20.0 dB and 14.1 dB respectively. Siwiak reports that the penetration loss into a residential building decreases with increasing frequency up to the 1-3 GHz range, where the loss is about 7-8 dB range.[61] Measurements by others indicate that the penetration losses increase with frequency above that range. Davidson and Hill of Motorola reported measurement results for medium buildings at 900 and 1500 MHz.[62] The mean penetration loss in lower enclosed floors at or near the ground level was found to be 10.8 dB with a standard deviation of 5.8 dB at 900 MHz and 10.2 dB with a standard deviation of 5.6 dB at 1500 MHz. Durgin, Rappaport and Xu presented measured data and empirical models for 5.85 GHz radio propagation path loss in and around residential areas.[63] Their results show that the average penetration loss is 14 dB at 5.85 GHz. In a recently revised recommendation ITU-R P.1411, mean measured building entry loss at 5.2 GHz through an external building wall made of brick and concrete with glass windows was reported to be 12 dB with a standard deviation of 5 dB.[64] The wall thickness was 60 cm and the window-to-wall ratio was about 2:1.

Since different researchers have derived somewhat different results, it is not possible to determine for this study a definitive value for building penetration losses for a generic building type. Nevertheless, enough consistency is shown among the various results to allow selecting reasonable values for these studies. For purposes of these aggregate interference study, the following average values for building penetration loss will be used.

960–3000 MHz	9 dB
3000–5650 MHz	12 dB
5650–7250 MHz	14 dB

Thus, if UWB devices are limited to indoor use only in any of these frequency bands, the indicated dB values would be subtracted from any predicted aggregate interference values based on outdoor use.

5.6.4 UWB Antenna Directivity

All of the analyses in this report assume a worst case situation wherein the maximum radiation from the UWB device is always pointing at the victim receiver. For a

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61 K. Siwiak, Radio Wave Propagation and Antennas for Personal Communications, Artech House (1995).

62 A. Davidson and C. Hill, *Measurement of Building Penetration into Medium Buildings at 900 and 1500 MHz*, IEEE Transactions on Vehicular Technology, Vol.46, No. 1, at 161-168 (February 1997).

63 G. Durgin, T. S. Rappaport and H. Xu, *Measurements and Models for Radio Path Loss In and Around Homes and Trees at 5.85 GHz,* IEEE Transactions on Communications, Vol. 46, No. 11, at 1484-1496 (Nov. 1998).

64 ITU-R Draft Revision of Recommendation P. 1411, Propagation Data and Prediction Methods for the Planning of Short-Range Outdoor Radiocommunication Systems and Radio Local Area Networks in the Frequency Range 300 MHz to 100 GHz, Document 3/BL/5-E, (Oct. 6 2000).

UWB device with a near omnidirectional radiation pattern, this results in little error. However, some UWB devices have been found to have significant directivity. An assumption that in the aggregate all such devices are simultaneously pointing at the victim receiver, will result in significant overestimation of the aggregate interference levels. One such measured UWB antenna pattern is shown in Figure 5.6-1. This example pattern results in an average antenna gain of approximately 7 dB below the peak value. This would have the effect of reducing the predicted aggregate interference power by this same amount. For UWB devices having significant directivity, it is reasonable therefore to reduce the predicted aggregate interference level by the average antenna gain (i.e., average gain relative to peak value).

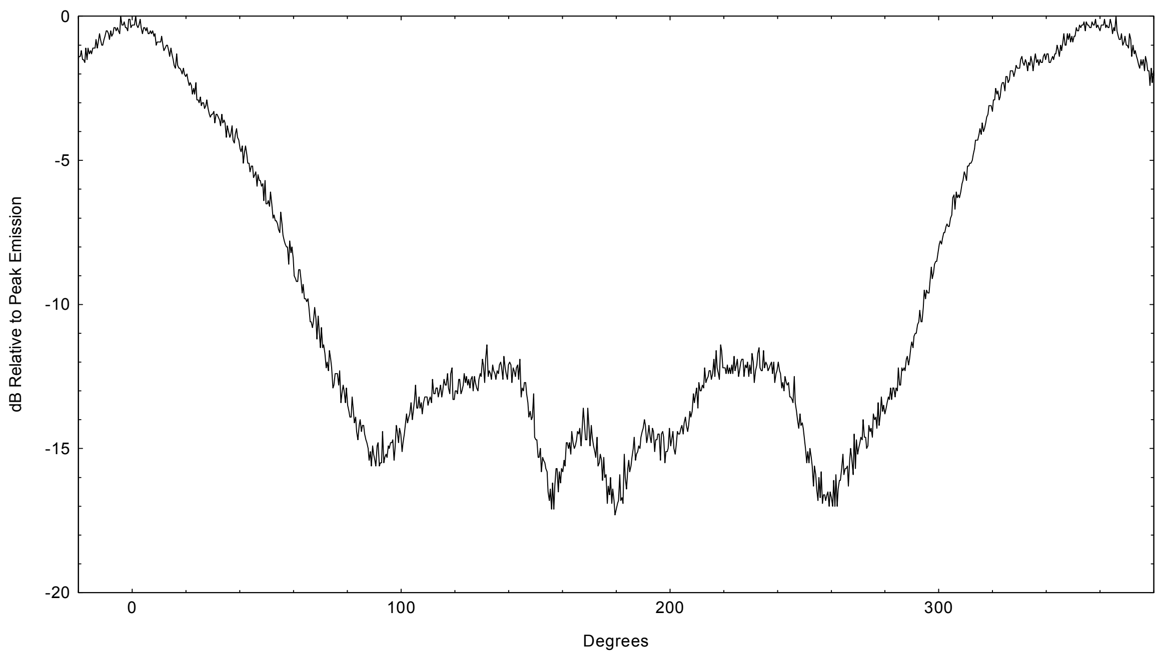

Figure 5-6-1. Example of Directional UWB Antenna Pattern

5.6.5 Transmitter Activity Factor

The results derived above for aggregate interference levels showed values as a function of active emitters per square kilometer and were not shown as an explicit function of transmitter activity factor.[65] However, the average number of active emitters is simply the product of the actual emitters per square kilometer and the transmitter activity factor. It is expected that some applications of UWB devices have inherently low activity factors such as those that are manually activated with a trigger or "deadman" switch, while others

[65] Transmitter activity factor is herein defined as the fraction of time that a typical UWB emitter is actively transmitting. While this is sometimes referred to as duty cycle, it is not to be confused with the duty cycle of a pulsed transmitter which is pulse width times the PRF.

would likely have high activity factors such as a radio local area network or automotive applications. It was not possible for this study to estimate practical values of UWB activity factors for various applications.

5.6.6 UWB Emitter Density

It is clear that under the assumption of uniform distribution of emitters, the density of emitters is a key factor affecting the significance of aggregate interference. As with activity factor, it was not possible for this study to estimate practical values of UWB emitter densities. However, one could define broad categories of densities such as low (e.g., emitter density less than 1 per km^2), medium (e.g., emitter densities of 1 to 100 per km^2) and high (e.g., emitter densities greater than 100 per km^2).

5.6.7 Characterizing UWB Applications

The above discussion describes various factors that may under certain conditions mitigate the levels of predicted aggregate interference from UWB devices. TABLE 5-11 shown below illustrates a methodology for characterizing various potential UWB applications and the possible applicability of various mitigating factors for aggregate interference studies. It is noted that this table is illustrative only and is neither intended to be comprehensive nor definitive.

TABLE 5-11
Characterizing UWB Devices*

Application	UWB Density	Activity Factor	Location	Indoors/ Outdoors	Antenna	Possible Aggregate Interference Mitigating Factors
Automotive Applications	High	High	Any	Outdoors	Directional	! UWB antenna directivity
RLANS	High	High	Urban/ Suburban	Indoors	Non-directional	! Urban/suburban propagation losses ! Building penetration losses
Ground Penetrating Radars	Low	Low	Any	Outdoors	Non-directional	! Low emitter density and activity factor
Wall Imaging Devices for Public Safety Applications	Low	Low	Urban/ Suburban	Indoors	Directional	! Low emitter density and activity factor ! Urban/suburban propagation losses ! Building penetration losses ! UWB antenna directivity
Security Systems	High	High?	Urban/ Suburban	Indoors	Non-directional	! Urban/suburban propagation losses ! Building penetration losses
Manually-Operated Radars	Low	Low	Any	Outdoors	Directional	! Low emitter density and activity factor ! UWB antenna directivity
Consumer Applications	High	High	Urban/ Suburban	Indoors	Non-directional	! Urban/suburban propagation losses ! Building penetration losses

* The values given in this table are intended to demonstrate a possible methodology for characterizing various potential UWB applications for aggregate interference studies and are neither intended to be comprehensive nor definitive.

SECTION 6
CONCLUSIONS

6.1 INTRODUCTION

This report contains a study of the potential impact from emissions of UWB devices to the performance of critical Federal telecommunication systems (except for the GPS). NTIA, in coordination with the Federal agencies, has the responsibility of assessing the potential impact of UWB devices on Federal telecommunication systems, as well as identifying solutions which will ensure compatibility.

The following is a summary of conclusions based on findings contained in this report.

6.2 GENERAL CONCLUSIONS

1. Since UWB devices may be unlicenced, and because of their potential ubiquitous operations, EIRP limits rather than required distance separations may have to be established to ensure compatibility between UWB devices and some Federal telecommunications systems.

2. The spectrum analyzer detector function is key in establishing permitted EIRP levels for UWB devices. Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, NTIA measurements and analyses indicates that the RMS detector function better quantifies the potential interference affects of UWB signals than the current average-logarithmic detector function used for Part 15 compliance.[66]

3. Further measurements and analysis are required to determine the effects of UWB signal duty cycle on the performance of the SARSAT and FSS Earth stations which have digital signal processing. This information would assist in establishing the UWB signal peak power limit in a 50 MHz bandwidth relative to the average (RMS) power in a 1 MHz bandwidth needed to protect digital modulated systems. Analysis has shown that limiting the peak power in a 50 MHz bandwidth to 30 dB would result in limiting the PRF of non-dithered UWB signals to greater than 3.5 MHz, and the PRF of dithered UWB signals to greater than 12.5 MHz.

4. For receiving systems with high gain antennas, the antenna vertical gain pattern, antenna height, antenna tilt angle and UWB device antenna height can significantly affect the level of UWB device emissions coupled into the receiver.

[66] *See* ITS Report, supra note 14, at Section § 8.4 (Items 5, 6, 7).

6.3 ASSESSMENT OF COMPATIBILITY FOR A SINGLE UWB DEVICE

The summary results described below were based on calculations using smooth Earth radio propagation (i.e., with no man-made or natural obstructions), typical antenna heights for the receiving systems, and a UWB height above ground of 2 meters. Results will change with significant departures from these key parameters. See Tables 4-56 and 4-57 in Section 4 for a detailed summary of these findings. The results are summarized in four broad bands of frequencies as discussed below.

Below 960 MHz. The SARSAT system was the only system analyzed which operates below 960 MHz. Since this is an satellite uplink analysis, compatibility with a single UWB device is not relevant. See Section 6.4 for conclusions related to potential aggregate interference to the SARSAT.

960–1610 MHz. Six types of receiving systems operating in the 960–1610 MHz frequency band were investigated by NTIA. A seventh system, GPS, is also being investigated and results will be reported separately. Analysis shows that for three of these systems, DME ground interrogators, ARSRs, and SARSAT LUTs, a significant reduction (in the order of 20 dB) in UWB device emission levels below the current levels permitted by Part 15 would be required to meet the receiver protection criteria. Further studies are needed to quantify the performance degradation to these systems to assess the feasibility of adjusting the EIRP limits contained in this report.

1610–3100 MHz. Three types of receiving systems operating in the 1610–3100 MHz frequency band, all radar systems, were investigated by NTIA. Analysis showed that, of these, maritime radars would be the most sensitive to UWB emissions and may require limiting UWB EIRP to below the current Part 15 limit to meet the receiver interference protection criteria for ship targets and shorelines close to the maritime radar. However, further studies of the relative levels of noise, interference, and clutter signals may reveal that relaxation of current receiver protection criteria for close-in targets is possible.

3100–5650 MHz. Of the five types of systems NTIA investigated that operate between 3100 and 5650 MHz, analysis shows that two system types, FSS Earth stations and MLS, would be the most sensitive to UWB emissions.

A. For FSS systems, the worst case situation would occur for receivers located at ground level with a low antenna elevation angle of 5 degrees. For FSS systems located on top of buildings and/or with higher elevation angles, much lower levels of interference would result. However, at this time uncertainty exists as to the effects of UWB signal duty cycle on the performance of the FSS Earth stations which have digital signal processing. This information would assist in establishing the UWB signal peak power limit; NTIA study is continuing on this important consideration.

B. MLS were found to be most sensitive to non-dithered UWB emissions. If UWB systems were required to be dithered in this frequency range, thus avoiding narrow line spectra, then UWB effects are greatly reduced. Nevertheless, operation at the current levels allowed under Part 15 may exceed the receiver interference protection criteria, depending upon the degree of safety margin required. Further analysis/measurements are needed.

The discussion for the three frequency band segments above was based on UWB emitters located close to the ground, specifically at a height of 2 meters. For most systems studied by NTIA, UWB emitters located outdoors at much higher heights - 30 meters was evaluated in this study - the potential interference effects increased and would require significant reduction in UWB EIRP levels to meet the receiver protection criteria. This results from the fact that the UWB emitters would be closer to, or even directly in, the high main beam antenna gain of the receivers. Thus, UWB emitters located on top of buildings or mounted on poles/towers would significantly exceed receiver protection criteria for a wide variety of authorized radiocommunications systems.

6.4 AGGREGATE ANALYSIS

The examination of the potential for aggregate interference effects from UWB devices resulted in a number of key findings. The following are conclusions related to potential performance degradation to Federal radiocommunication systems caused by an aggregate of UWB devices.

1 Both theory and measurements support the view that the average (RMS) power emitted by UWB devices, both total average power as well as average power contained within a narrow bandwidth, is linearly additive in a receiver.

2. Using a uniform distribution of UWB devices, either statistical or deterministic, is a reasonable and practical method to examine the potential aggregate interference effects of UWB devices.

3. Five different aggregate modeling approaches, one deterministic and four statistical, were examined and found to yield nearly identical results within 2 dB for a variety of hypothetical situations.

4. The UWBRings model, developed by NTIA for this study, was found to effectively calculate aggregate interference in a receiver under a variety of conditions and assumptions, and has the ability to easily consider measured 3-dimensional receiver antenna patterns and various radio propagation models.

5. Results of these studies show, *inter alia*, that the received aggregate interference (RMS) from a uniform distribution of identical UWB emitters varies directly with UWB EIRP, UWB emitter density, and UWB transmitter activity factor.

6. All other factors being fixed, there will exist some UWB emitter density where aggregate interference will exceed that from a single UWB emitter. Other published studies which claim that aggregate UWB interference can never exceed that from a single UWB emitter typically used an unrealistic very close-in reference distance for the single UWB emitter, thus leading to misleading conclusions.

7. Results of the NTIA studies show that under ideal radio propagation conditions, with no man-made or natural obstructions, aggregate interference levels from UWB devices can exceed that from a single emitter at densities as low as a few emitters per square kilometer to greater than 1,000 active emitters per square kilometer. TABLE 5-7 summarizes these results.

8. Additional factors that can play a significant role in aggregate interference studies include obstructions due to foliage, natural terrain irregularities, urban/suburban environments, and building penetration losses, as well as UWB antenna directivity. TABLE 5-11 illustrates a possible methodology for applying these factors.

9. Potential UWB interference into a SARSAT uplink was only investigated based on aggregate interference, since a single UWB emitter will not affect the satellite. Results show that if UWB devices operating in the region of 400 MHz were limited to ground penetration radar (GPR) type of devices operating at the current emission levels permitted by Part 15, aggregate interference would be below the receiver protection criteria, for anticipated densities of GPRs.

6.5 INTERFERENCE MEASUREMENTS

Measurements were made on two Telecommunication system, an ARSR-4 and an ASR-8, for the purpose of assessing the adequacy of the EMC analysis procedure and the analytical model discussed in Section 3. The following are conclusions resulting from the measurements.

1. The measurements indicated that the potential for interference to ARSRs and ASRs from UWB devices can occur in an annular ring around each radar. The distance to the angular ring and the diameter of the angular ring depends on the antenna height, antenna gain elevation pattern and the antenna vertical tilt angle. The antenna gain elevation pattern is key in performing an EMC analysis.

2. A comparison of measured maximum permitted EIRP limits with the analytical model indicates that for the ARSR-4 and ASR-8 systems, the analytical model and

the measurements are within a few dB. The EIRP limits determined by measurements were generally lower. This difference may be due to several factors:

A. The analytical model does not take consideration exact terrain variations, and

B. The radar antenna elevation pattern used in the analytical model may not accurately represent the antenna gain in the direction of the UWB device.

APPENDIX A

CHARACTERISTICS OF SELECTED GOVERNMENT EQUIPMENT

A.1 INTRODUCTION

The systems analyzed for this report were the NEXRAD, ARSR-4, ASR-9, RF Altimeters, ATCRBS, DME, MLS, SARSAT LUT and satellite receiver, TDWR, 4 GHz Earth station Receiver, and a shipboard marine radar.

A description of these systems, tables of receiver characteristics, and receiver protection criteria for single entry and aggregate UWB interference are provided in this Appendix. The tables also provide the nominal approach distance for each system which, due to system operational constraints and/or security measures, represents the closest distance to the system receiver that a UWB device would be expected to operate. However, the maximum UWB interference power in the victim receiver may not occur at that distance due to the geometry of the interference scenario.

A.2 NEXT GENERATION WEATHER RADAR (NEXRAD)

System Description

The NEXRAD weather radar provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information with higher spatial and temporal resolutions than previous weather radar systems. NEXRAD radars are operated throughout the United States by the National Weather Service and the DoD at the locations shown in Figure A-1.

The major difference between meteorological radars and other radars operated in the radiodetermination service is in the nature of their targets. Meteorological targets are distributed in space and occupy a large fraction of the spatial resolution cells observed by the radar. Moreover quantitative measurements of the received signals characteristics must be made in order to estimate such parameters as precipitation rate, precipitation type, air motion, turbulence, and wind shear. While many radar applications call for discrimination of relatively few targets from a clutter background, meteorological radars focus on making accurate estimates on the nature of the *weather clutter* itself.[67] In typical clear air operations the NEXRAD antenna rotates 360 degrees in the horizontal plane at 0.5 rpm and uses six successive elevation angles of 0.5, 4.5, 8.5, 12.5, 16.5, and 20.5 degrees. The radar operator can vary NEXRAD antenna's scan mode to monitor specific meteorological events. Detailed NEXRAD system characteristics are shown below in TABLE A-1.

Protection Criteria

The desensitization effect on meteorological radars from other services that generate CW or noise-like interference is related to the intensity of the interference. In any azimuth sectors in which such interference arrives, its power spectral density (PSD) can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 1 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.26, or an I/N ratio of about -6 dB.

Therefore, the protection criteria for NEXRAD radars from UWB devices is an I/N ratio of -6 dB for aggregate interference and for a single interferer. This criteria is contained in ITU-R. Recommendation 1464, "*Characteristics of and Protection Criteria for Radionavigation and Meteorological Radars Operating in the Frequency Band 2700-2900 MHz*."

The NEXRAD receiver noise power was calculated to be -114 dBm. The permissible aggregate and single entry interference power, using the I/N protection criteria of -6 dB, is calculated to be -120 dBm.

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[67] Robert J. Serafin, *Meteorological Radars*, Radar Handbook, at 23.2 (Merrill I. Skolnik ed., 2d ed. 1990).

TABLE A-1
NEXRAD System Characteristics

Equipment Parameter	Value
Tuning Range	2.7–3.0 GHz
Channelization	NA
Pulse Width and Rate	1.64–4.73 μs with a PRF of 320–1300 pps
3 dB RF Bandwidth	15 MHz
3 dB IF Bandwidth	550 kHz
Noise Figure	2.5 dB
Receiver Noise Power	-114.1 dBm
System Loss (typical value)	2 dB
Antenna Type	Parabolic with center feed, pencil beam pattern
Polarization	Circular
Scan Rate	Vertical 20 Deg/5 min, horizontal 0.5 to 3.4 rpm
Antenna Elevation Angle	-1.0 to 90 degrees, typical installation 0.5 degrees
Main Beam Gain	45 dBi
3 dB Beamwidth	0.9 Degrees horizontal and vertical
Analysis parameter	**Value**
Antenna Height	28 m (average)
Nominal Approach Distance	170 meters
Receiver Protection Criteria	I/N=-6 dB for single entry and aggregate

NEXRAD Antenna Pattern

The NEXRAD vertical antenna pattern is shown below in Figure A-2. The pattern is based on measured data and is symmetrical about the vertical axis.

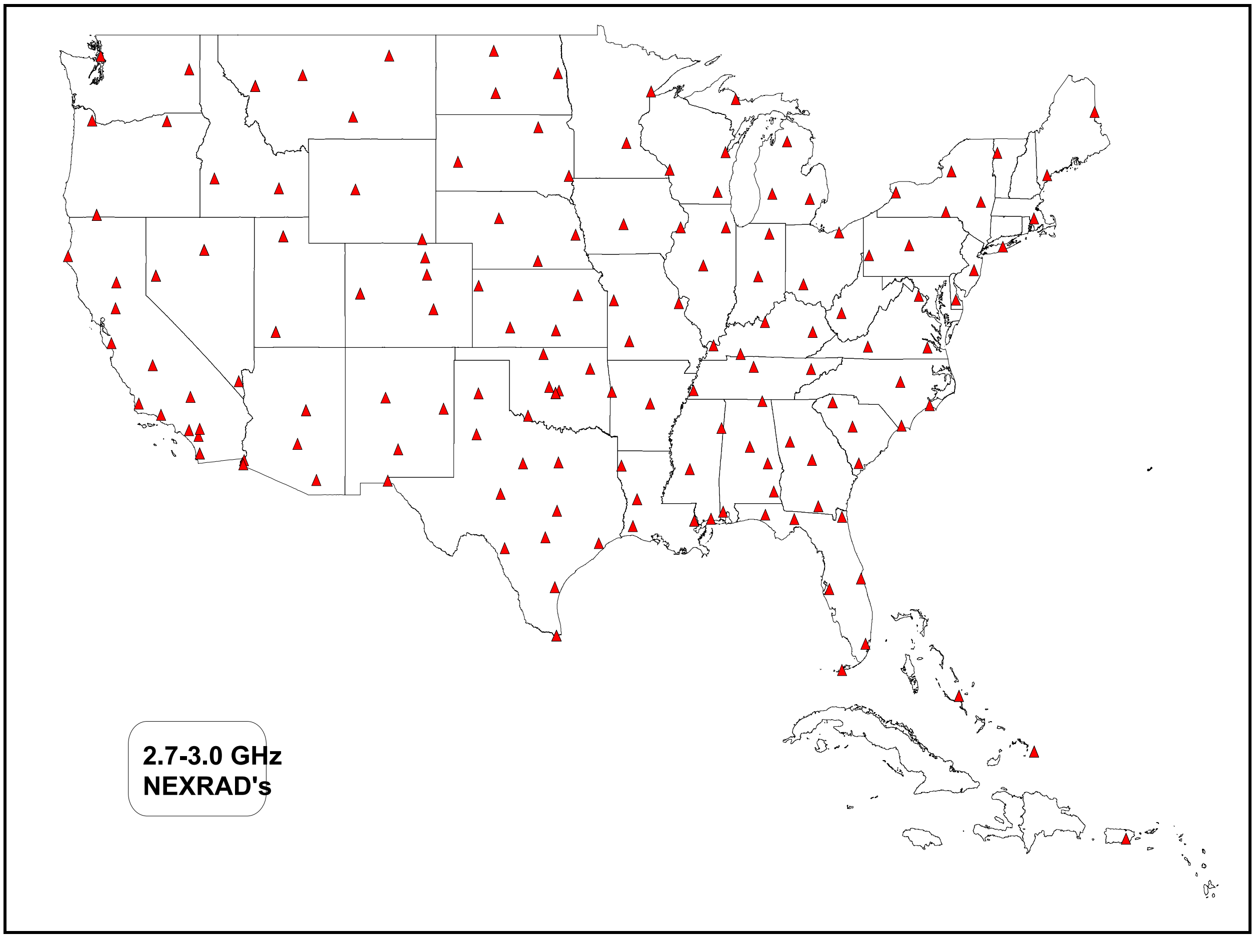

Figure A-1. NEXRAD Radar Locations.

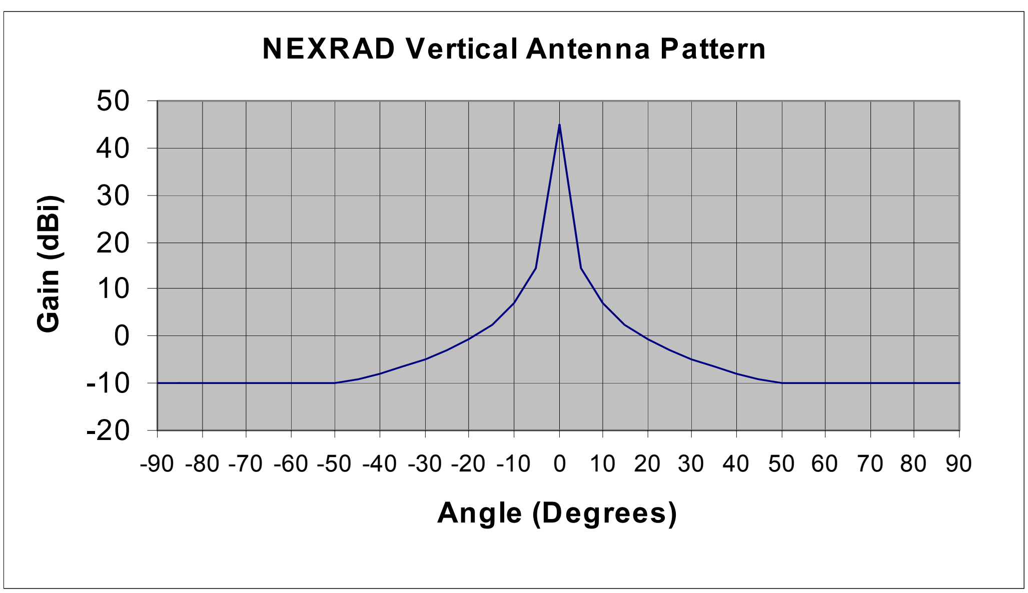

Figure A-2. NEXRAD Vertical Antenna Pattern.

The NEXRAD radars are sited to provide overlapping coverage in most of the United States, especially in areas of severe weather events (tornados, thunderstorms, etc.) like the mid-west and northeast. In addition to the National Weather Service, the FAA and DoD also rely on NEXRAD for weather observations with each agency having its own requirements for range and spatial resolution.

A.3 AIR ROUTE SURVEILLANCE RADAR (ARSR-4)

System Description

The ARSR-4 radar is used by the FAA and DoD to monitor aircraft during enroute flight. It is a pulsed radar with a parabolic reflector and a phased array feedhorn. The range of the radar is 5 to 250 nautical miles up to 100,000 feet. The FAA range requirement is 200 nautical miles and a probability of detection (Pd) of 0.8 or greater for clear air with a target cross section of 2.2 m^2. The DoD range requirement is beyond 200 nautical miles. The range and Pd requirements for ARSR-4 coverage over water, wooded hills and mountains, and during weather events is described in FAA directive FAA-E-2763B. In general, the range requirement for these events and/or terrain conditions is less than the clear air requirements. However, the Pd remains at a minimum of 0.8 for all conditions.

Detailed ARSR-4 system characteristics are shown below in TABLE A-2. The information for these parameters was obtained from the FAA ARSR-4 program office. The locations of the ARSR-4 radars are shown in Figure A-3. Note that the FAA, in addition to the ARSR-4, uses other ARSR radars for enroute aircraft surveillance which would also be located across the country.

Receiver Protection Criteria

The desensitization effect on radiolocation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. An I/N ratio of -10 dB for radiolocation radars will be proposed by the United States in a revision to ITU-R M.1463 in ITU-R Study Group 8B for radars operating in the 1200-1400 MHz frequency band.

Therefore, the protection criteria for the ARSR-4 radars to interference from UWB devices is an I/N ratio of -10 dB for aggregate and single entry interference power. Using the I/N ratio of -10 dB, the maximum permissible interference level for the ARSR-4 is -123 dBm. For the ARSR-4 analysis, an average (RMS) UWB power level was used because the receiver's adaptive threshold algorithm establishes a constant false alarm rate (CFAR) level by taking the average signal level over several range bins. Therefore, the average (RMS) level of the UWB signal will have a bearing in determining a change in the CFAR level.

ARSR-4 Antenna Pattern

The ARSR-4 uses a system of nine narrow receive beams stacked in elevation. The nine receive beams are divided into two groups called the receive high stack and the receive low stack. To provide overlap between the two stacks, beam five is used as the highest receive beam in the low stack and the lowest beam in the high stack The result is that there are five beams in each stack. A tenth beam, the lookdown beam, is available for sites with high installations (such as ridges and mountaintops) where the lookdown capability is used. The elevation angle of the lookdown beam is 7 degrees below the horizontal. Figure A-4 shows the vertical antenna pattern of the ARSR-4 antenna. The pattern was obtained from measured data.

TABLE A-2
ARSR-4 System Characteristics

Parameter	Value
Tuning Range	1215-1400 MHz
Channelization	44 frequency pairs
Pulse Width and Rate	88.8 and 58.8 μs, 291.5 or 312.5 pps
3 dB RF Bandwidth	58 MHz
3 dB IF Bandwidth	690 kHz
Noise Figure	3.6 dB
Receiver Noise Power	-113 dBm
System Loss	0 dB
Antenna Type	Parabolic reflector with phased array feedhorn
Polarization	Vertical, horizontal, RHCP, LHCP
Horizontal Scan Rate	5 rpm
Main Beam Gain	41.8 dBi
Beam One 3 dB Beamwidth	Vertical 2.0, horizontal 1.4 degrees
Analysis Parameters	**Value**
Antenna height	22 m (average)
Nominal Approach Distance[1]	15 m
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

[1] Typical distance for public access to radar site

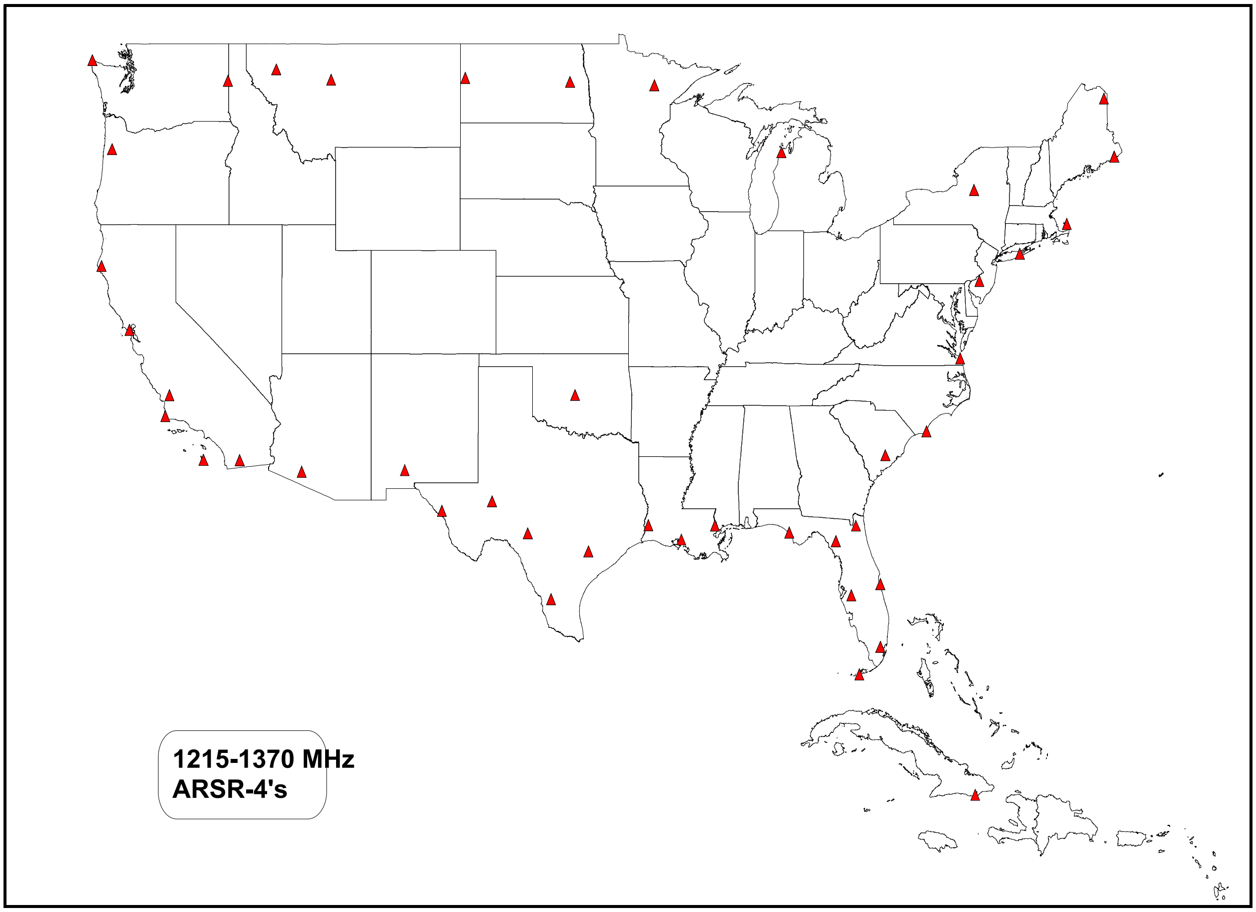

Figure A-3. ARSR-4 Radar Locations.

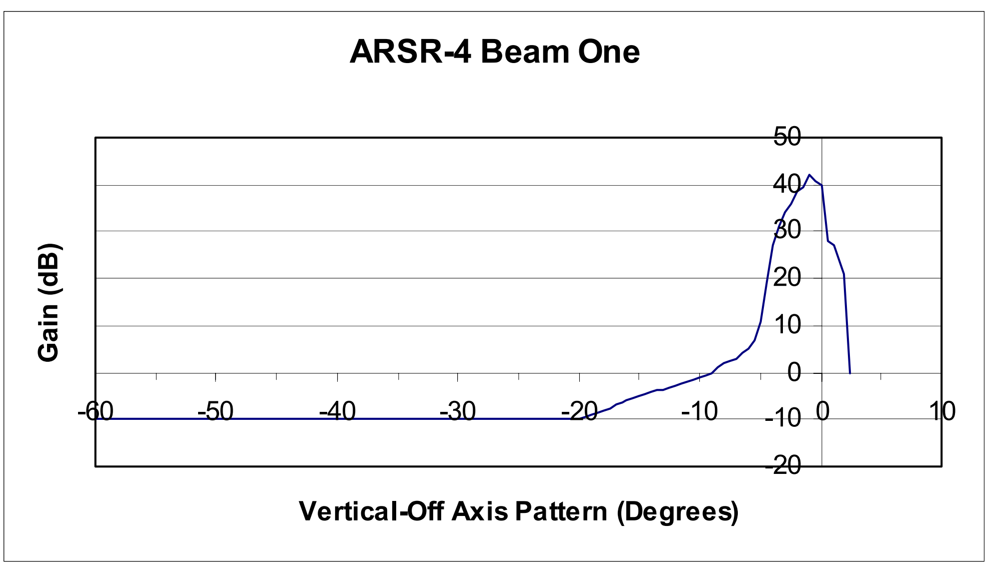

Figure A-4. ARSR-4 Beam One Vertical Antenna Pattern.

A.4 AIRPORT SURVEILLANCE RADAR (ASR-9)

System Description

The ASR-9 radar is used by the FAA and DoD to monitor aircraft in the airspace in and around airports. The FAA has a requirement of a range of 110 km for this radar. Detailed ASR-9 system characteristics are shown below in TABLE A-3. The information for these parameters was obtained from ASR-9 program offices of the FAA. The locations of the ASR-9 radars are shown in Figure A-5. Note that the FAA, in addition to the ASR-9, uses other ASR radars for aircraft surveillance in and around airports. They would also be located across the country.

TABLE A-3
ASR-9 System Characteristics

Parameter	Value
Tuning Range	2700-2900 MHz
Channelization	200 channels, fixed crystal
Pulse Width and Rate	1.08 μs with a PRF of 928 and 1193 up to 1027 and 1321pps
3 dB RF Bandwidth	10 MHz
3 dB IF Bandwidth	653 kHz
Noise Figure	4 dB
Receiver Noise Power	-112 dBm
System Loss (typical value)	2 dB
Antenna Type	Parabolic reflector
Polarization	Right hand circular or linear
Horizontal Scan Rate	12.5 rpm
Main Beam Gain	33.5 dBi
3 dB Beamwidth	1.3 degrees horizontal, 4.8 degrees vertical
Analysis Parameters	**Value**
Antenna Height	17 m (average)
Nominal Approach Distance[1]	15 m
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

[1] Typical distance for public access to radar site.

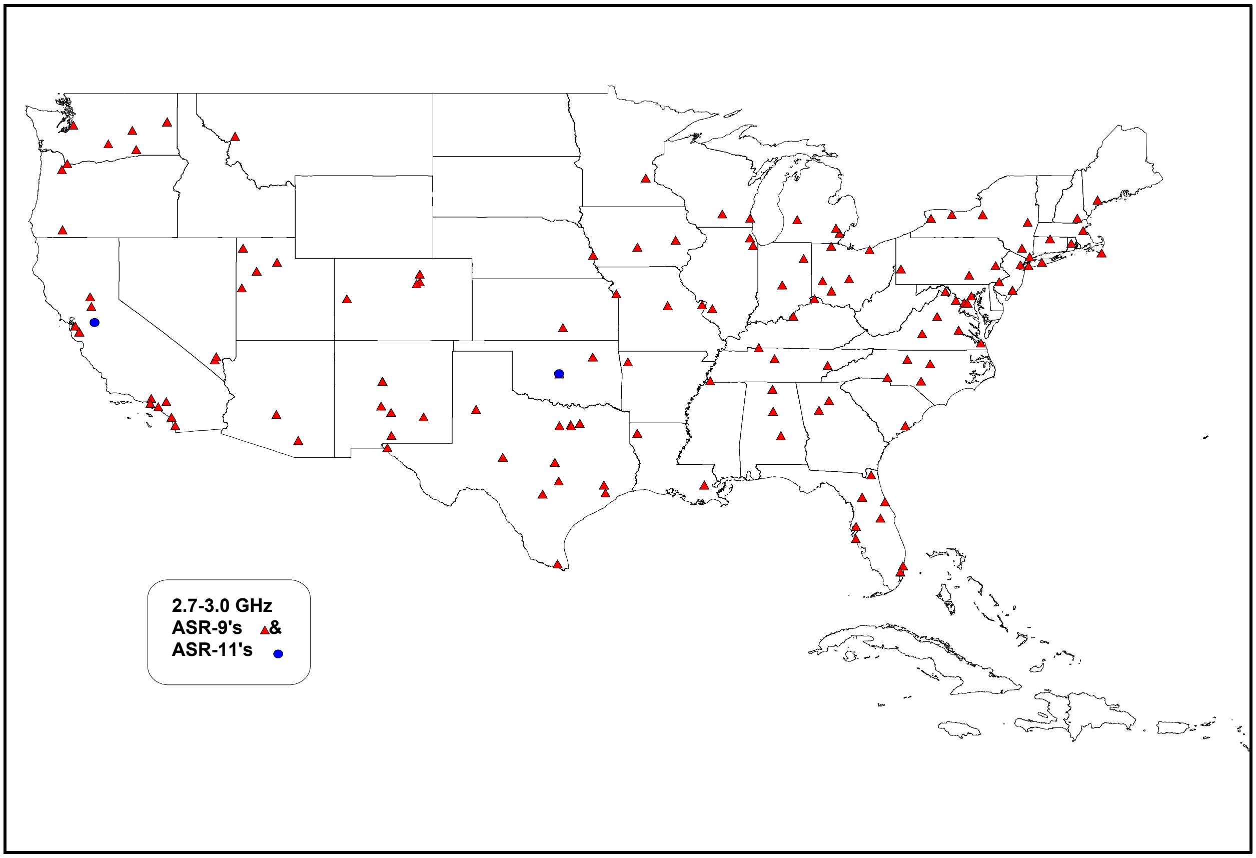

Figure A-5. ASR-9 Locations.

Receiver Protection Criteria

The desensitization effect on radionavigation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. The I/N ratio of -10 dB is contained in a proposed revision to ITU-R M.1464 under consideration by ITU-R Study Group 8.

Therefore, the protection criteria for an ASR-9 radar from UWB devices is an I/N ratio of -10 dB for aggregate interference power and for a single interferer. Using the I/N ratio of -10 dB, the maximum permissible aggregate and single entry interference power is -122 dBm for the ASR-9. For the ASR-9 analysis, an average (RMS) UWB power level was used because the receiver's adaptive threshold algorithm establishes a CFAR level by taking the average signal level over several range bins. Therefore, the average

(RMS) level of the UWB signal will have a bearing in determining a change in the CFAR level.

ASR-9 Antenna Pattern

The vertical antenna pattern for the ASR-9 is shown in Figure A-6. The pattern was obtained from measured data. Negative angles on the X-axis in Figure A-6 are towards the ground.

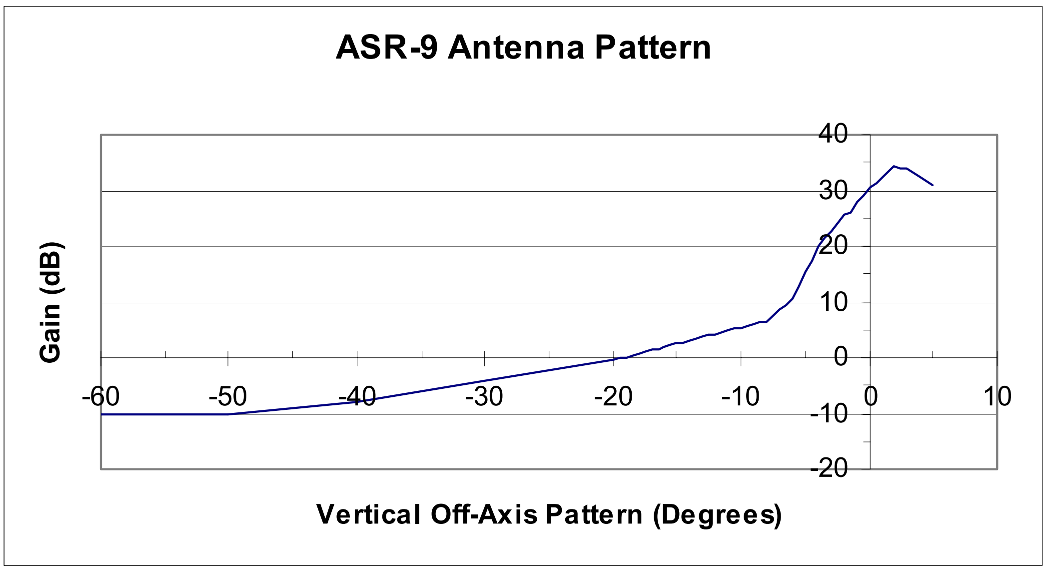

Figure A-6. ASR-9 Vertical Antenna Pattern.

A.5 ALTIMETERS

System Description

Radar altimeters determine and display aircraft height AGL to pilots. They are used in commercial and private aviation as well as in military aircraft. Altimeters that operate in the 4200-4400 MHz frequency band are either pulsed or frequency modulated continuous wave (FMCW) systems. In the FMCW systems the linearly modulated emitted signal is reflected by the terrain and detected by the altimeter receiver. If part of the signal currently being transmitted is mixed with the reflected signal, the result is a difference or beat frequency. The beat frequency is directly proportional to the altimeter altitude and is processed to determine and display altitude. It is also possible to maintain a fixed beat frequency, using a tracking loop, by varying the FM deviation according to the altitude. In this case, variations in deviation are processed to determine the altitude. In pulsed altimeter systems, the time between the pulsed emission and the terrain reflected return is directly proportional to the altimeter altitude.

The system characteristics of typical FMCW and pulsed radar altimeters are shown below in TABLE A-4. The characteristics of the FMCW radar shown in TABLE A-4 are representative of the type used by commercial aviation while the characteristics of the pulsed radar is representative of the type used by the DoD.

Interference Criteria

The UWB and altimeter EMC analysis was performed using a S/(I+N) method by calculating the power of the desired signal (S) from 100 feet to the maximum operating ceiling of the altimeter. The UWB interference in the altimeter receivers was assumed to be noise like and add to its own internal noise. The required S/(I+N) for the pulsed altimeter was 6 dB and for the FMCW it was 12 dB. Since the altimeter's antennas face downward towards the Earth, main beam gain was used in the analysis when calculating the single entry UWB interference to it. The altimeter vertical antenna patterns are shown below in Figure A-7.

TABLE A-4
Altimeter System Characteristics

Parameter	Value	
	Pulsed Type System	**FMCW Type System**
Transmitter Power	5 Watts	0.5 Watts
3 dB Baseband Bandwidth	NA	90 kHz
3 dB IF Bandwidth	30 MHz	NA
Noise Figure	4 dB	4 dB
Receiver Noise Power	-95 dBm	-120
Sensitivity	-83 dBm	-88 dBm
Antenna Gain	10.5 dBi	11 dBi
Antenna 3 dB Beamwidth	45 degrees	60 degrees
Analysis Parameters	**Value**	
Receiver Protection Criteria	S/(N+I)= 6 dB	S/(N+I)= 12 dB
Altitude Measurement Range	100 to 5,000 feet AGL	100 to 2500 feet AGL

NA: Not applicable

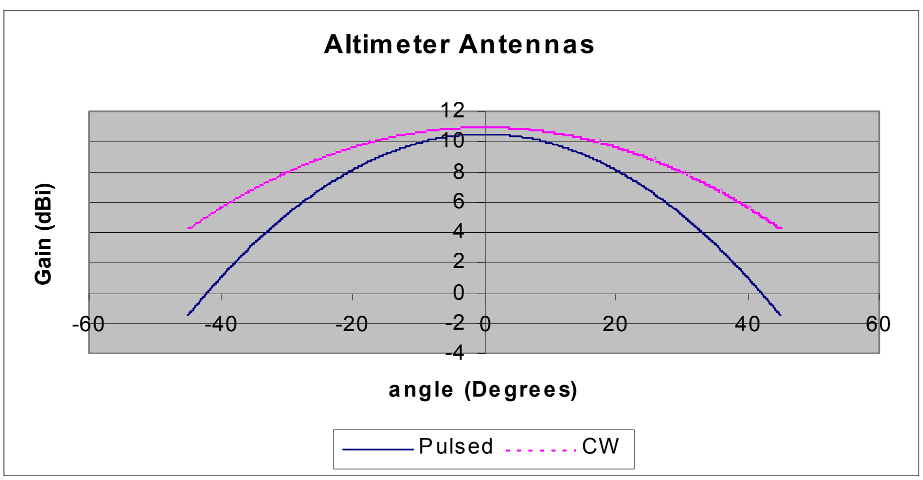

Figure A-7. Altimeter Vertical Antenna Patterns.

A.6 AIR TRAFFIC CONTROL RADIO BEACON SYSTEM (ATCRBS)

System Description

The ATCRBS is used by the FAA and DoD to monitor and identify suitability equipped aircraft in both civil and military aviation applications. The system uses two frequencies, 1030 and 1090 MHz. The aircraft transmits a coded pulse train reply at 1090 MHz in response to interrogations at 1030 MHz from the ground-based station that identifies the aircraft and its altitude. ATCRBS has different modes of operation, defined as modes A, B, C, D, and S. The FAA uses ATCRBS in conjunction with the ASR and ARSR radars to monitor and track aircraft during enroute and approach phases of flight. ATCRBS is also used to monitor aircraft on the ground as they traverse taxiways around the airport. The nominal maximum range for the system is 370 km when used in conjunction with an ARSR radar and about 110 km when used in conjunction with an ASR radar.

The system characteristics and receiver protection criteria of the ATCRBS ground interrogator are shown in TABLE A-5 and the system characteristics and receiver protection criteria of an aircraft ATCRBS transponder are shown below in TABLE A-6. Figures A-3 and A-6 can be used to identify the location of ATCRBS ground stations.

Interference Criteria

The interference criterion of the aircraft transponder is dependent on the ability of its receiver to demodulate and decode requests for the aircraft's identification code and altitude that were transmitted from the ground-based interrogator. The minimum triggering level (MTL) in TABLE A-5 is defined as the minimum input power level referred to the sensor RF port that results in a 90 percent reply ratio if the interrogation signal has all nominal pulse spacings and widths and if the replies are the correct replies assigned to the interrogation format. The criterion is that the transponder receiver be able to demodulate and decode 90 percent of the interrogations that are transmitted in its direction with a signal-to-interference (S/I) ratio of 12 dB.[68]

The interference criterion of the interrogator is dependent on the ability of its receiver to demodulate and decode replies that contain the aircraft's identification code and altitude that were transmitted from the aircraft's transponder. The MTL in TABLE A-6 is defined as the minimum input power level referred to the sensor RF port that results in a 90 percent reply detection probability. The criterion is that the interrogator receiver be able to demodulate and decode 90 percent of the aircrafts replies with an S/I ratio of 12 dB.[69]

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[68] Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/MODE S) Airborne Equipment, Radio Technical Commission for Aeronautics, RTCA DO-181A, at 2.2.8.1 (Jan. 1992) .

[69] Federal Aviation Administration, U.S. Dept. of Transportation, Specification for Mode Select Beacon System (Mode s) Sensor, Amendment 2, FAA-E-2716 (March 1983).

TABLE A-5
ATCRBS Interrogator Characteristics

Parameter	Value
Transmit Frequency	1030 MHz
Transmit Power	59 dBm
Receive Frequency	1090 MHz
Pulse Width and Rate	0.7 -0.9 μs with a PRF of 200 -375 pps
3 dB RF Bandwidth	14.7 MHz
3 dB IF Bandwidth	9 MHz
Noise Figure	2.5 dB
Receiver Noise Power	-102 dBm
Minimum Triggering Level	-79 dBm for 90% reply detection probability
System Loss	2 dB
Antenna Type	Parabolic reflector enroute
Polarization	Vertical
Horizontal Scan Rate	Same as ARSR or ASR radar
Antenna Elevation Angle	Same as ARSR or ASR radar
Main Beam Gain	29 dBi for enroute
3 dB Beamwidth	1.5 degrees horizontal, 4.7 degrees vertical for enroute
Analysis Parameters	**Value**
Antenna Height	Same as ARSR or ASR radar
Nominal Approach Distance	15 m
Receiver Protection Criteria	S/I= 12 dB for single entry and aggregate

In determining the maximum allowable UWB interference power in the ATCRBS interrogator receiver (based on the signal-to-interference (S/I) protection criteria), the ATCRBS transponder desired signal power, S, at the interrogator receiver was set to the minimum triggering level in TABLE A-5.

ATCRBS Interrogator Antenna Pattern

The vertical pattern of the ATCRBS antenna used in conjunction with the ARSR-4 is shown in Figure A-8. The pattern was obtained from measured data. Negative angles on the X-axis in Figure A-8 are towards the ground.

TABLE A-6
ATCRBS Transponder Characteristics

Parameter	Value
Transmit Frequency	1090 MHz
Transmit Power	51 dBm
Receive Frequency	1030 MHz
Pulse Width and Rate	0.7–0.9 μs with a PRF of 200–375 pps
3 dB RF Bandwidth	14.7 MHz
3 dB IF Bandwidth	5.5 MHz
Noise Figure	8 dB
Receiver Noise Power	-98 dBm
Minimum Triggering Level	-77 dBm for 90% reply detection probability
System Loss	2 dB
Antenna Type	omnidirectional flush mount, or blade
Polarization	vertical
Main Beam Gain	4 dBi
Analysis Parameters	**Value**
Antenna Height	10 meters
Operational Height	Airport surface to 40,000+ feet
Receiver Protection Criteria	S/I= 12 dB for single entry and aggregate

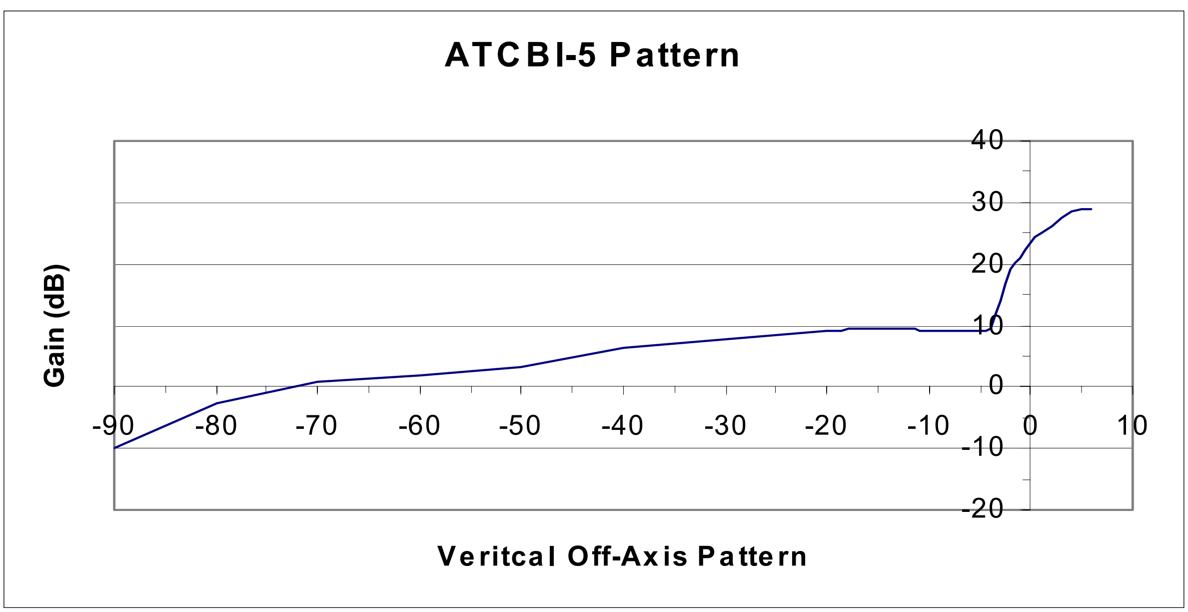

Figure A-8. ATCRBS Interrogator Vertical Antenna Pattern Used in Conjunction with ARSR-4.

ATCRBS Transponder Antenna Pattern

The vertical antenna pattern of the ATCRBS transponder is shown below in Figure A-9. It was based on a measured pattern that was obtained from an avionics antenna manufacturer. The angle 90 degrees is directly under the aircraft.

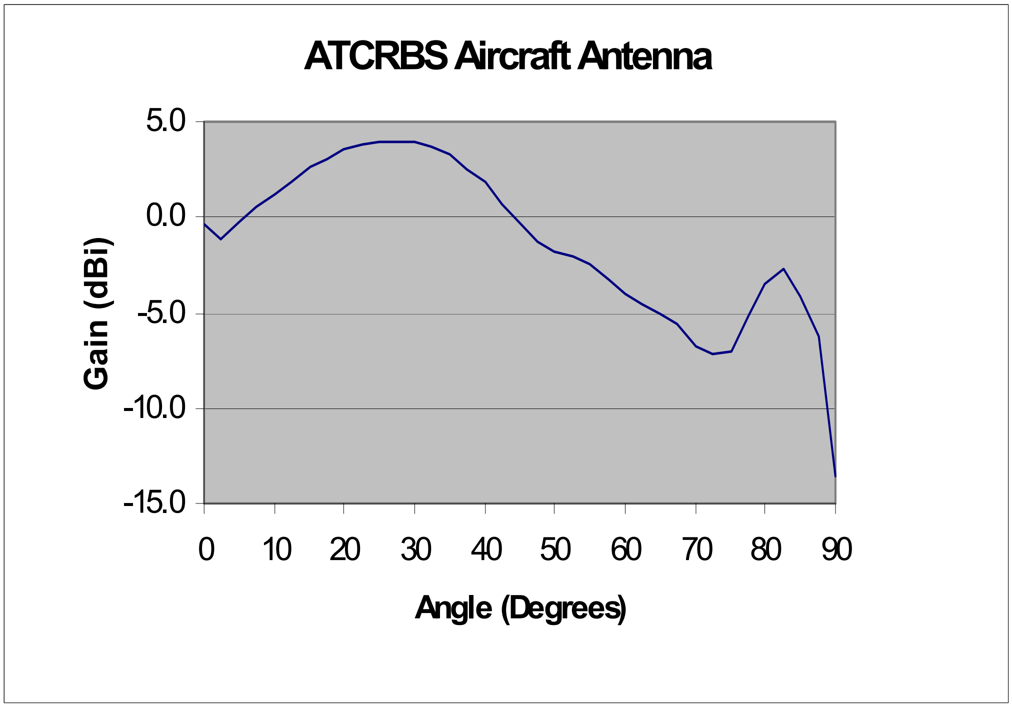

Figure A-9. ATCRBS Transponder Vertical Antenna Pattern.

A.7 MICROWAVE LANDING SYSTEM (MLS)

System Description

The ICAO Standard MLS is an aeronautical radionavigation system used for precision approach and landing of aircraft. It is intended for universal application serving both civil and military users to permit all-weather landings as well as curved or segmented approaches to airports. The MLS is allocated in the frequency band 5000-5150 MHz and currently operates on 200 channels in the frequency band 5030-5091 MHz. The MLS ground station supports navigation and guidance for suitably equipped aircraft out to a range of 43 km and an altitude of 20,000 feet. The characteristics of an airborne MLS receiver are shown in TABLE A-7.

TABLE A-7
MLS Receiver Characteristics

Parameter	Value
Service Range	20,000 feet to 100 feet
Tuning Range	5030–5091 MHz
Channelization	0.3 MHz
Pulse Width and Rate	33.3 μs with a PRF of 3500 pps
3 dB RF Bandwidth	100 MHz
3 dB IF Bandwidth	150 kHz
Noise Figure	10 dB
Receiver Noise Power	-112 dBm
Sensitivity	-103 dBm
System Loss	5 dB
Antenna Type	Quarter wave stub
Polarization	Vertical
Main Beam Gain	5 dBi
Analysis Parameter	**Value**
Protection Criteria	I = -134 dBm for single entry and aggregate
Minimum Altitude	30 meters

Interference Criteria

Radio frequency interference can lead to errors in the estimation of time intervals associated with beam passage of the MLS transmitting station's antenna beam. Depending on the frequency components of the error process and the aircraft flight control system guidance loop bandwidth, this could lead to the physical displacement of the aircraft relative to the desired approach path. The International Civil Aviation Organization (ICAO) has specified the maximum permissible interference power into a MLS receiver to be -130 dBm to prevent this from occurring.[70] Another 4 dB is subtracted from the ICAO threshold to partition the UWB interference into the link budget. Therefore, the maximum permissible UWB interference is -134 dBm.

MLS Antenna Pattern

The vertical antenna pattern of the airborne MLS receiver is shown below in Figure A-10. It is based on a measured pattern that was obtained from a an avionics antenna manufacturer. The angle 90 degrees is directly under the aircraft.

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[70] International Standards and Recommended Practices Annex 10 to the Convention on International Civil Aviation, Volume 1 (Radio Navigation Aids) Fifth Edition, July 1996.

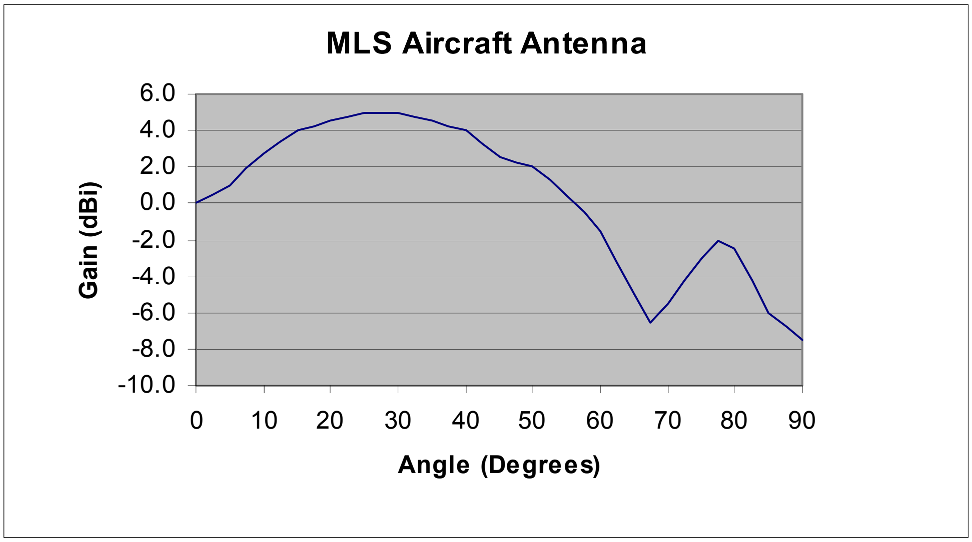

Figure A-10. MLS Antenna Pattern.

A.8 DISTANCE MEASURING EQUIPMENT (DME)

System Description

DME allows aircraft to fly safe, accurate paths during the enroute, terminal, approach, landing, missed approach and departure phases of flight. DME equipment is used across the United States by both civil and military aircraft. DME operates across the 960-1215 MHz frequency band. The DME interrogation and reply frequencies are defined at 1 MHz increments between 962-1213 MHz, leaving 2 MHz guard bands at each end of the band. The system provides user aircraft with range to a ground-based transponder station. In general the ranging systems is air-initiated, with the airborne transmitter interrogating a ground transponder, and calculating range from the time difference between the initiation of the interrogation and receipt of the reply. The maximum range for high altitude service is 240 km with an altitude of 18 km and for low altitude service the distance is 74 km with an altitude of 5.5 km. The maximum range for the standard terminal service is 46 km with an altitude of 3.7 km.[71]

The system characteristics and receiver protection criteria of the transponder are shown in TABLE A-8 and the system characteristics and receiver protection criteria of the interrogator are shown in TABLE A-9.

[71] *See Id.* for a detailed description of the DME service areas.

TABLE A-8
DME Transponder System Characteristics

Parameter	Value
Transmit Power	55 dBm
3 dB RF Bandwidth	22 MHz
3 dB IF Bandwidth	.8 MHz
Noise Figure	9 dB
Receiver Noise Power	-106 dBm
Sensitivity	-94 dBm for 70% reply efficiency
Antenna Type	Dipole array
Polarization	Vertical
Main Beam Gain	5 dBi
3 dB Beamwidth	10 Degrees vertical, 360 degrees horizontal
Analysis Parameters	**Value**
Antenna Height	10 meters
Nominal Approach Distance	15 m
Receiver Protection Criteria	I=-122 dBm for single entry and aggregate

TABLE A-9
DME Interrogator System Characteristics

Parameter	Value
Transmit Power	54 dBm for equipment operating above 18,000 feet 47 dBm for equipment operating below 18,000 feet
3 dB RF Bandwidth	20 MHz
3 dB IF Bandwidth	650 kHz
Noise Figure	8 dB
Receiver Noise Power	-108 dBm
Sensitivity	-83 dBm for 70% reply efficiency
Antenna Type	Quarter wave stub
Polarization	Vertical
Main Beam Gain	4 dBi
3 dB Beamwidth	30 degrees vertical, 360 degrees horizontal
Analysis Parameters	**Value**
Minimum Altitude	30 meters
Receiver Protection Criteria	I = -115 dBm for single entry and aggregate

Interference Criteria

DME interrogators require a 70 percent reply efficiency in the absence of all interfering signals. For DME interrogator equipment intended for dual installations, the receiver shall meet this criteria when a CW signal having a level of -99 dBm is applied on the assigned channel frequency.[72] An additional -10 dB of protection is used to partition the UWB interference into that threshold with an additional 6 dB of protection to account for the aeronautical safety margin. Using this criteria, the maximum permissible UWB interference power in the DME interrogator is -115 dBm.

DME transponders require a 70 percent reply efficiency in the absence of all interfering signals. For DME transponders, the receiver noise floor is -105 dBm. Using a protection criteria of an I/N of -10 dB to partition the UWB interference into the DME link budget and an additional 6 dB for the aeronautical safety margin, the maximum permissible UWB interference power in the transponder receiver is -121 dBm.

A description of the 6 dB aeronautical safety margin and its application is contained in ITU-R Recommendation M.1477.

DME Interrogator Antenna Pattern

The vertical antenna pattern of the airborne DME interrogator is shown below in Figure A-11. It is based on a measured pattern that was obtained from an avionics antenna manufacturer. The angle 90 degrees is directly below the aircraft.

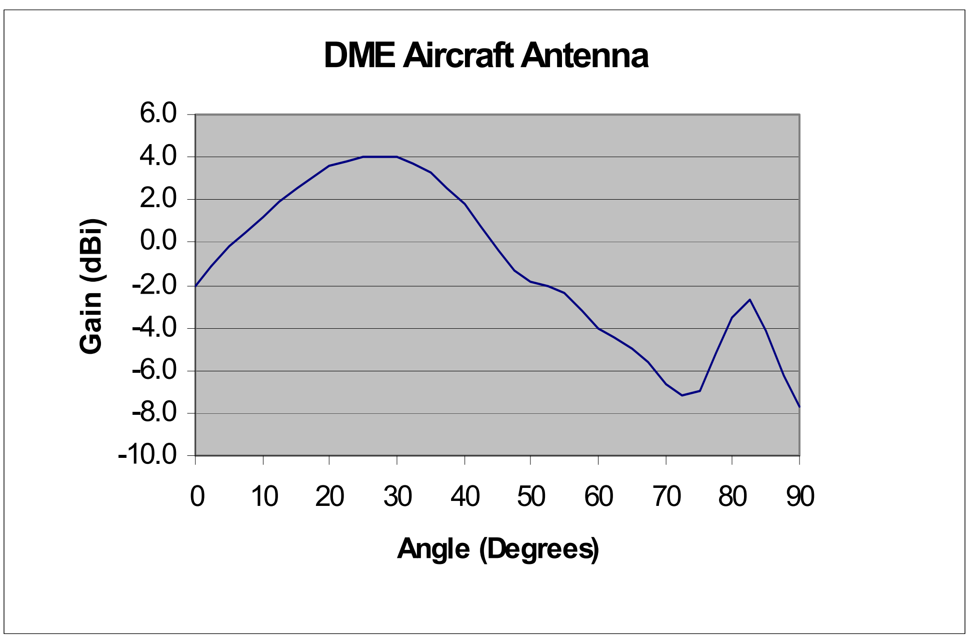

Figure A-11. DME Interrogator Vertical Antenna Pattern.

72 Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating Within The Radio Frequency Range of 960-1215 Megahertz, Radio Technical Commission for Aeronautics, RTCA DO-189, at 2.2.11 (Sept. 1985) .

A.9 4 GHz EARTH STATION

System Description

The 4 GHz Earth stations are used to receive downlink transmissions from geosynchronous satellites for a variety of applications, including voice, data, and video services for Federal agencies. The system characteristics and receiver protection criteria of the 4 GHz Earth station receiver is shown in TABLE A-10. The system noise temperature is a typical value and includes antenna sky noise and noise due to the Low-Noise amplifier and cabling loss.

TABLE A-10
Earth Station Characteristics

Parameter	Value
Frequency	3750 MHz
3 dB IF Bandwidth	40 MHz
System Noise Temperature	150 K
System Noise Power	-101 dBm
Antenna Type	Parabolic
Vertical Elevation Angle	5 to 20 degrees above horizon
Polarization	Circular
Main Beam Gain	40 dBi
Analysis Parameter	**Value**
Antenna Height	3 m
Receiver Protection Criteria	I/N=-10 dB average and peak power for single entry and aggregate interference[73]

[73] For this study, both peak and average power UWB device signal levels will be used to bound the potential interference level to digital communication systems. Measurements and analysis have shown that the undesired signal level at which bit errors start to occur, interference threshold, in a digital modulated signal are based on the peak power of the undesired signal. For example, assuming no bit error correction and a low duty cycle (0.01 percent) pulsed undesired signal, measured bit errors would start to occur at a certain peak undesired signal level. However, receiver performance degradation is not a simple function of the bit error rate (BER). Error correction and interleaving of bits can make a digital modulated system more robust to the occurrence of the undesired signal exceeding the interference threshold. Also, the relation of digital receiver performance degradation is not directly related to the average BER, bursts of errors can have a catastrophic effect on performance degradation. In summary, once the undesired signal peak power has exceeded the interference threshold, the occurrence of receiver performance degradation is a function of the undesired signal duty cycle. However, there is not a simple undesired signal duty factor relation. Factors such as undesired signal gating, duty cycle during gating period (not overall signal duty cycle), receiver digital modulation type, bit error correction scheme, and interleaving depth need to be considered. This uncertainty in the undesired signal duty cycle which causes receiver performance degradation was bounded by including both the peak and average interference signal levels in the analysis.

Earth Station Antenna Pattern

The antenna pattern that was used in the Earth station analysis is shown below in Figure A-12. It is based on a FCC model.

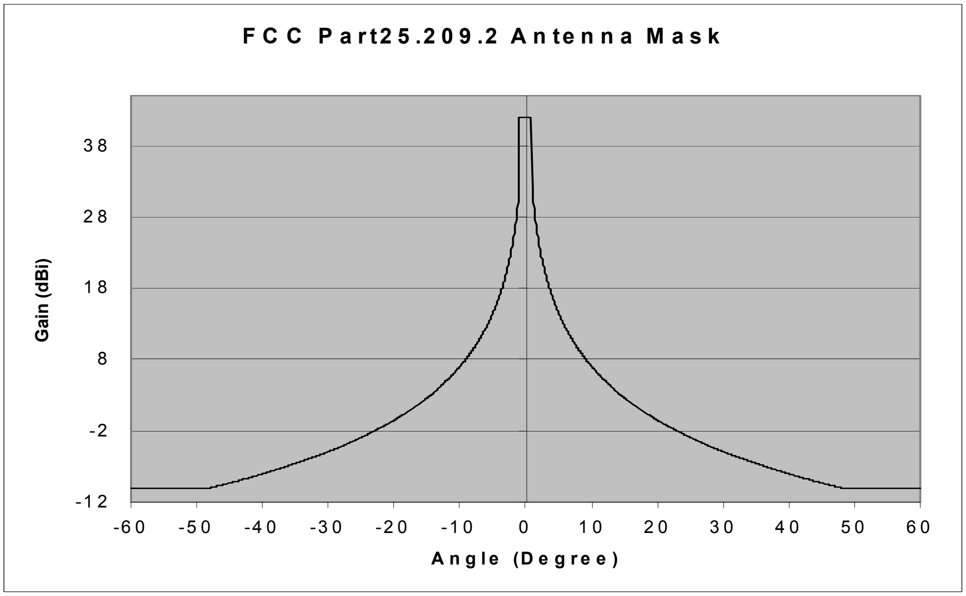

Figure A-12. Earth Station Antenna Pattern.

A.10 SARSAT

System Description

The National Oceanic and Atmospheric Administration (NOAA) operates polar orbiting and geostationary satellites that carry SARSAT payloads that provide distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress. Russia operates very similar instruments known as Cosmicheskaya Systyema Poiska Avariynich Sudov (COSPAS) aboard satellites that are part of a navigation system. Both are being used in an international cooperative search and rescue effort titled COSPAS-SARSAT.

COSPAS-SARSAT consists of a network of satellites, ground stations, mission control centers, and rescue coordination centers. When an emergency beacon is activated, the signal is received by satellite and relayed to the nearest available ground station. The ground station is called a LUT. The LUTs receive information from satellites in the 1544-1545 MHz frequency band. NOAA has 14 LUTs at 7 locations and they are shown below in TABLE A-11. This provides total system redundancy and allows maximization of satellite tracking. The characteristics of the LUTs are shown below in TABLE A-12.

Interference Criteria

The protection criteria for a SARSAT LUT is an I/N ratio of -9 dB. The LUT ground station receiver noise power includes man-made environmental noise, transmission line noise, and internal receiver noise. The total system noise power is the equivalent system noise temperature which is equal to the noise temperature of the antenna plus the noise temperature of the receiver. The antenna noise temperature takes into account both man-made environmental and transmission line noise. The total system noise power of the LUT ground station was found to be -117 dBm. The maximum permissible level of interference is then -126 dBm.

TABLE A-11
SARSAT LUT Locations

LUT Location	Coordinates
Andersen AFB, Guam	13.5784°N 144.9390°E
Vandenberg AFB, CA	34.6624°N 120.5514°W
Sabana Seca USN, PR	18.4317°N 066.1922°W
USCG Station, Wahiawa, HI	21.5260°N 157.9964°W
NASA JSC, Houston, TX	29.5605°N 095.0925°W
Fairbanks, AK	64.9933°N 147.5237°W
Suitland, MD	38.8510°N 076.9310°W

TABLE A-12
SARSAT LUT Characteristics

Parameter	Value
Receiver Locations	See TABLE A-11
Tuning Range	1544-1545 MHz
3 dB IF Bandwidth	800 kHz
System Noise Temp	175.5 K
System Noise Power	-117 dBm
Antenna Type	Parabolic
Antenna Beamwidth	8 degrees
Vertical Elevation Angle	0 degrees
Polarization	Vertical
Analysis Parameter	**Value**
Antenna Height	5 m
Nominal Approach Distance	15 m
Receiver Protection Criteria	I/N=-9 dB for average and peak power for single entry and aggregate[74]

[74] *Id.*

SARSAT LUT Antenna Pattern

The vertical antenna pattern that was used in the SARSAT LUT analysis shown below in Figure A-13. The pattern is symmetrical about the vertical axis.

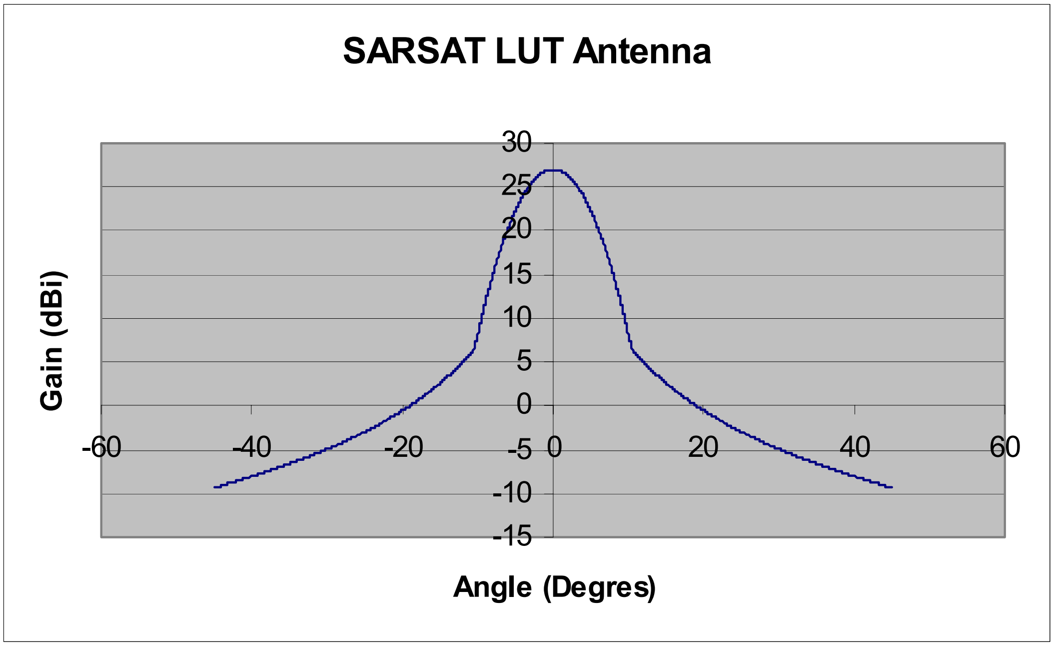

Figure A-13. SARSAT LUT Vertical Antenna Pattern.

A.11 TERMINAL DOPPLER WEATHER RADAR (TDWR)

System Description

TDWR provide quantitative measurements of gust fronts, wind shear, micro bursts, and other weather hazards for improving the safety of operations at major airports in the United States. The radar operates in the 5600-5650 MHz frequency band. An advantage of operating the radar at this frequency is using a small antenna, an important consideration near airports. The system characteristics and receiver protection criteria of the TDWR receiver is shown in TABLE A-13. The vertical antenna pattern of the TDWR is shown in Figure A-14.

The TDWR antenna uses two basic scanning modes. The first is Monitor Mode which is used when no significant weather returns have been detected within 25 nautical miles of the airport. The second is the Hazardous Weather Detection Mode which is used when hazardous weather is has been detected or is expected. The TDWR antenna is designed to operate from a minimum vertical elevation angle of -1° up to a maximum of

60°. In typical operations, the vertical elevation angle is 0.2° for Hazardous Weather Detection Mode and 0.4° for Monitor Mode.

Interference Criteria

The interference protection criteria for the TDWR receiver is an I/N ratio of -6 dB for single entry and aggregate interference. This criteria is contained in an ITU-R draft new recommendation under consideration by ITU-R Study Group 8 titled, "*Characteristics of and Protection Criteria for Radiolocation, Aeronautical Radionavigation, and Meteorological Radars Operating in the Frequency bands Between 5250-5850 MHz*." Using this criteria, the maximum permissible UWB interference noise power is -118.5 dBm.

TABLE A-13
TDWR Characteristics

Parameter	Value
Frequency	5600-5650 MHz
3 dB IF Bandwidth	.910 MHz
Noise Figure	2.3 dB
Receiver Noise Power	-112.5 dBm
Antenna Type	25 foot parabolic reflector
Beamwidth	.55 degrees horizontal and vertical
Vertical Elevation Angle	0.2 degrees for hazardous mode, 0.4 degrees for monitor mode
Polarization	Circular
Main Beam Gain	50 dBi
Analysis Parameter	**Value**
Antenna Height	27 m (average)
Receiver Protection Criteria	I/N=-6 dB for single entry and aggregate

TDWR Antenna Pattern

The vertical antenna pattern that was used in the TDWR analysis shown below in Figure A-14. The pattern is symmetrical about the vertical axis.

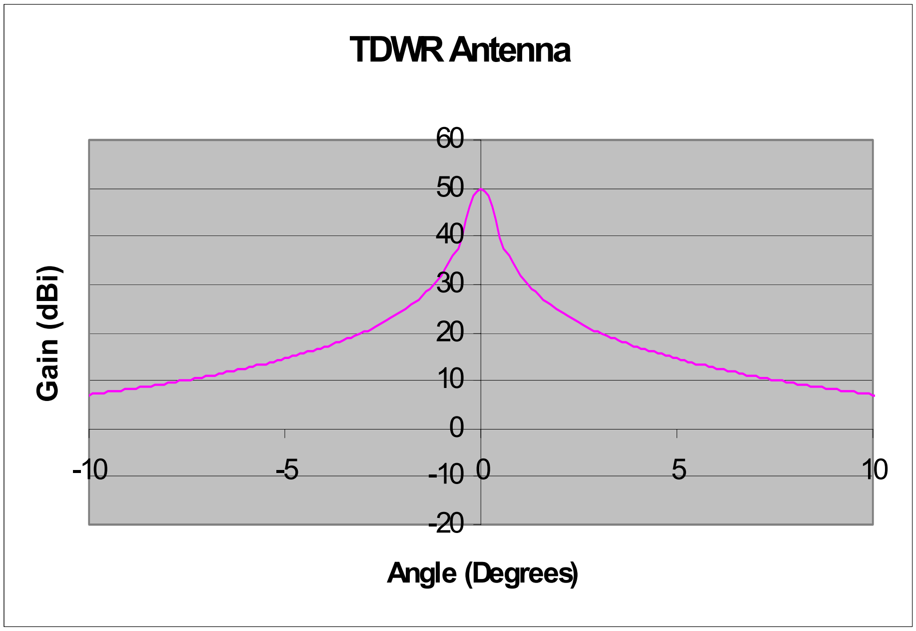

Figure A-14. TDWR Vertical Antenna Pattern.

A.12 S-BAND (10cm) MARINE RADAR

System Description

The S-Band (10cm) marine radar provides ships with surface search, navigation capacities, and tracking services, particularly in foul weather. This radar is used by all categories of commercial and Government vessels, including thousands of foreign and U.S.-flagged cargo, oil tanker and passenger ships operating in U.S. waters, and is a vital sensor for safe navigation of waterways. Vessel traffic services also useS-Band marine radars, and shore-based racons (radar beacons) also operate with marine radars in this band to aid navigation. The marine radar provides indications and data on surface craft, obstructions, buoy markers, and navigation marks to assist in navigation and collision avoidance. S-Band marine radars provide significantly superior target detection in severe weather and can, for example, detect a ship or obstruction at approximately 10 times the range of an X-band (3cm) marine radar during snowfall.

Typical marine radar components include the following; antenna, signal waveguide, transmitter/receiver, and operator display/console. The antenna is a horizontal slotted waveguide array mounted on a pedestal for rotational support. The antenna is typically 12 feet long. The signal waveguide interfaces the antenna with the transmitter/receiver and can be a single shielded cable. Detailed S-Band (10cm) marine radar system characteristics are shown below in TABLE A-14.

TABLE A-14
Marine Radar Characteristics

Parameter	Value
Frequency	2900-3100 MHz
Pule Width and Rate	.08-1.2 us, 500-2200 pps
RF Bandwidth	60 MHz
3 dB IF Bandwidth	4 to 20 MHz
Noise Figure	4 dB
Receiver Noise Power	-104 dBm
Antenna Type	Slotted waveguide array
Beamwidth	2 degrees horizontal, 25 degrees vertical
Vertical Elevation Angle	0 degrees
Horizontal Scan Rate	30 revolutions per minute
Polarization	Horizontal, vertical
Main Beam Gain	27 dBi
Analysis Parameter	**Value**
Antenna Height	20 meters over water line
Nominal Approach Distance	4 meters
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

Receiver Protection Criteria

The desensitization effect on radionavigation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. The I/N ratio of -10 dB is contained in a proposed revision to ITU-R M.1313-1 under consideration by ITU-R Study Group 8 titled ,"*Technical Characteristics of Maritime Radionavigation Radars*".

Therefore, the protection criteria for marine radars from UWB devices is an I/N ratio of -10 dB for aggregate interference power and for a single interferer. Using the I/N ratio of -10 dB, the maximum permissible aggregate and single entry interference power is -114 dBm for the marine radar receiver.

Antenna Pattern

The vertical antenna pattern of the Marine radar receiver is shown below in Figure A-14. It is based on a measured pattern that was obtained from a marine radar manufacturer. Angles from 0 to +90 degrees are towards the sky.

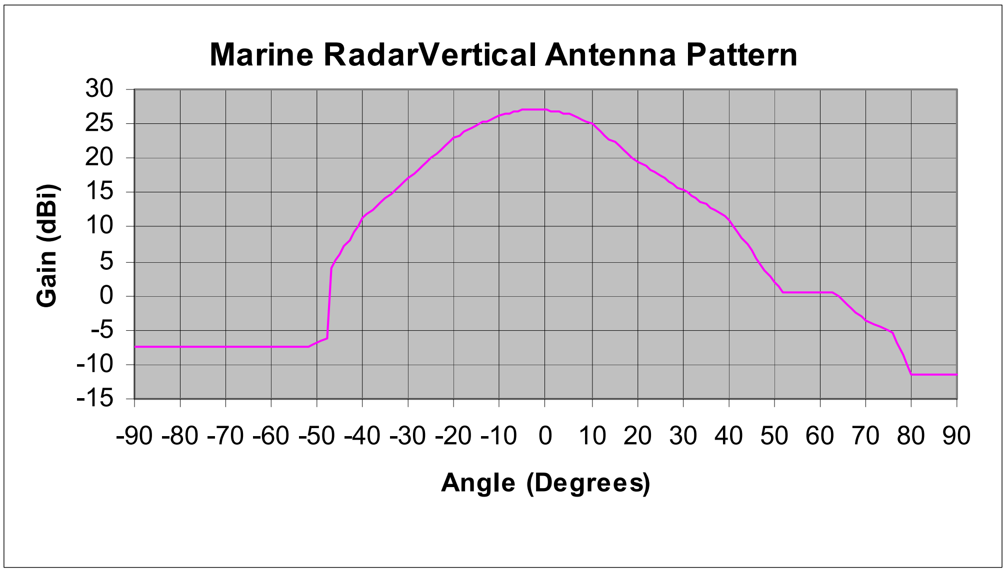

Figure A-14. Marine Radar Vertical Antenna Pattern.

APPENDIX B

DESCRIPTION OF AGGREGATE MODEL

B.1 FORMULATION OF EMITTER DISTRIBUTION

This section will summarize details of the emitter distribution and the equations used in UWBRings. It is based upon NTIA TM-89-139, Section 3, and upon the original RINGS[75] source code. The RINGS concept was already described and illustrated in Section 5.3.

As mentioned in 5.3, multiple emitters with the same emission frequency and emission level are distributed on equally-spaced, concentric, circular rings surrounding the base[76] of the victim receive station. The emitters are distributed in an annular region bounded by a minimum (inner) and maximum (outer) ring radius. After the emitter surface density is specified the model automatically assigns the number of rings, ring separation, and number of emitters per ring, for a symmetric distribution. Figure B-1 shows a top down view of the simplified distribution.

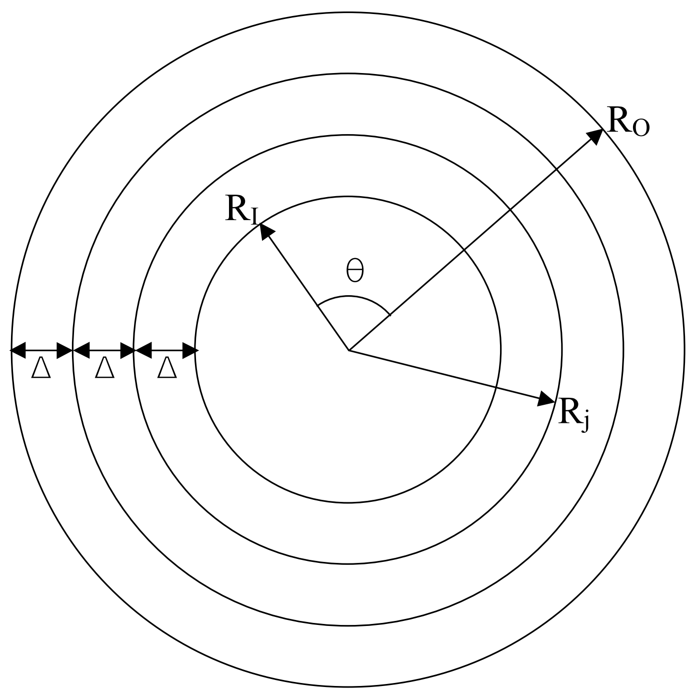

Figure B-1. Example of RINGS Symmetric Distribution of Emitters.

[75] "RINGS" is the proper name of the program described in the documentation.

[76] Could also be a subsatellite point.

As seen in Figure B-1 the distance between all rings is a constant value, Δ, which the program must determine. From this value the number of rings, M, is determined. This leads to the calculation of the radius of the jth ring, $R_{j,}$ for all M rings in the distribution. Given that this radius is taken to be a great circle distance, the line of sight range from the ring can be calculated to find the path loss.

We also must determine the appropriate number of emitters to assign to each ring. These values must be chosen in such a way as to provide symmetry in the emitter distribution, so as to not favor their angular separation within a ring or their radial separation between rings at the expense of each other.

Figure B-1 also shows that the full annulus could be sectioned off through use of a horizontal plane angle θ, which could be the horizontal 3 dB beamwidth. In this case the number of emitters per ring, $N_{j,}$ would have to be modified appropriately.

TABLE B-1 shows a list of all parameters used and their units of measurement:

TABLE B-1

R_I	Inner ring radius	km
R_O	Outer ring radius	km
R_j	The jth ring radius in the distribution	km
θ	Sector angle defined by the antenna horizontal beamwidth	radians
K	Emitter density	#/km^2
T	Total number of emitters in the full annulus	
N	Number of emitters in the sector	
N_j	Number of emitters in the sector in the jth ring	
Δ	Ring separation distance	km
M	Number of rings used	

To begin the derivations the first thing to determine is the total number of emitters in the full annulus. This value is simply the product of emitter density with the area bounded by inner and outer ring radii. It is shown in the following equation:

$$T = K\pi\left(R_O{}^2 - R_I{}^2\right) \tag{B1}$$

Next, to find the total number of emitters in the sector outlined by θ, we scale the total emitters in the annulus by the ratio of sector angle to full annulus. Thus, we arrive at the following equation:

$$N = T\frac{\theta}{2\pi} \tag{B2}$$

N is the actual number of emitters which contribute to the horizontal main beam aggregate in a given scenario. For cases where we are also considering antenna backlobes[77] we apply the backlobe gain to the T minus N remaining emitters.

To find the separation between rings we consider that the area occupied by each emitter is $1/K$. Considering this area as a square seems to work good towards equidistantly spacing the emitters. We could then consider that the ring spacing should be one side of this square. This leads to the following equation:

$$\Delta = \frac{1}{\sqrt{K}} \tag{B3}$$

The determination of the total number of rings for a simulation follows from dividing the distance between innermost and outermost rings by the ring separation. This quotient gives the total number of Δs. If we attach one ring to each we need to add an extra ring to bound the outside of the outermost Δ. This leads to:

$$M = \frac{R_O - R_I}{\Delta} + 1 \tag{B4}$$

In cases where M does not calculate to be an integer the original RINGS program rounded it to the nearest integer. This introduced some error which was deemed to be insignificant. UWBRings adds an improved algorithm which instead rounds M up to the nearest integer and recalculates the value of Δ from (B4). This liberty is taken because (B3) is only an approximation, however, intuitively, M must be an integer. Additionally, this allows for an exact implementation of (B7).

In order to calculate path loss between each ring and the victim receive antenna we need an expression for the radius of the j^{th} ring. This follows from adding the appropriate number of Δs to the radius of the innermost ring. This leads to:

$$R_j = R_I + (j - 1)\Delta, \quad j = 1 \text{ to } M \tag{B5}$$

The last of the core equations to consider is the number of the N emitters of the sector to assign to each ring. As was stated in Section 5.3 the emitter distribution is based on having the ratio of number of emitters on each ring to ring radius to be constant. This leads to the following:

---

77 *See infra* Section B.2.3, at B-16 for discussion on backlobes.

$$\frac{N_j}{R_j} = k \qquad \text{(B6)}$$

To get the value of k we consider that the following equation must also be satisfied:

$$\sum_{j=1}^{M} N_j = N \qquad \text{(B7)}$$

After substitution we arrive at:

$$\sum_{j=1}^{M} k\left[R_I + \left(j-1\right)\Delta\right] = N \qquad \text{(B8)}$$

After rearranging and simplifying we progress through the following two equations:

$$k\left[\sum_{j=1}^{M} R_I + \Delta\sum_{j=1}^{M}\left(j-1\right)\right] = N \qquad \text{(B9)}$$

$$k\left[MR_I + \Delta\sum_{j=1}^{M-1} j\right] = N \qquad \text{(B10)}$$

Using a well known series identity allows us to solve for k:

$$k = \frac{N}{MR_I + \dfrac{\Delta(M-1)M}{2}} \qquad \text{(B11)}$$

This leads directly to the expression for N_j after substitution in (B6):

$$N_j = \frac{2N\left[R_I + (j-1)\Delta\right]}{2MR_I + \Delta(M-1)M} \qquad \text{(B12)}$$

Intuitively N_j should be an integer, however, there are advantages in allowing it to be real. For example, it can happen that the sector geometry and emitter distribution parameters specified by the user could result in no emitters assigned to the first (inner) and other lower rings. A large outer/inner radius ratio and a low emitter density could allocate all emitters to the higher rings, since the number of emitters per ring is proportional to the ring radius. This happens if we round N_j to be an integer, and threatens to distort the results because the closest rings are the most significant in the calculation.

A second reason for allowing N_j to be real is that it frees up the dependency of Δ on K and smooths the distribution toward a more realistic homogeneity. If we make Δ completely independent of K we can significantly improve the accuracy of readings under low emitter density, which would normally predict very large values of Δ. Using a small Δ (e.g., 10 meters) for all K will allow the simulation to better track variations in vertical pattern antenna gain.

These equations provide the foundation for computing the aggregate power level in a RINGS topology. To complete the derivation we extrapolate the single emitter received power into an aggregate received power level. First, the single emitter received power equation:

$$P_R(single) = [EIRP]\frac{G}{L} \tag{B13}$$

Where [EIRP] is the radiated power level of the interfering source; G is the receive antenna gain in the direction of the source; and L is the path loss between source and receive antenna.

This is easily extrapolated to the aggregate case in the following:

$$P_R(aggregate) = [EIRP]\sum_{j=1}^{M}\frac{N_j G_j}{L_j} \tag{B14}$$

Thus, the aggregate function loops through all M rings determining the number of emitters in each ring, the receive antenna gain in the direction of each ring, and the path loss from each ring. After the summation is complete it may then be multiplied by the user-entered interfering radiated power, or it may be used to determine what that EIRP should be to satisfy a user-entered performance criterion.

B.2 DETAILED UWBRINGS PROGRAM DESCRIPTION

Figure B-2 shows the UWBRings user interface. The main feature of the interface is the output chart whose associated data points appear directly beneath the chart. About this chart are various input sections, which from left to right, top to bottom are: the *Transmitter* section, the *Path Loss* section, the *Receive Antenna* section, the *General section* (composed of an assortment of miscellaneous inputs), and the *Radar Altimeter* section.

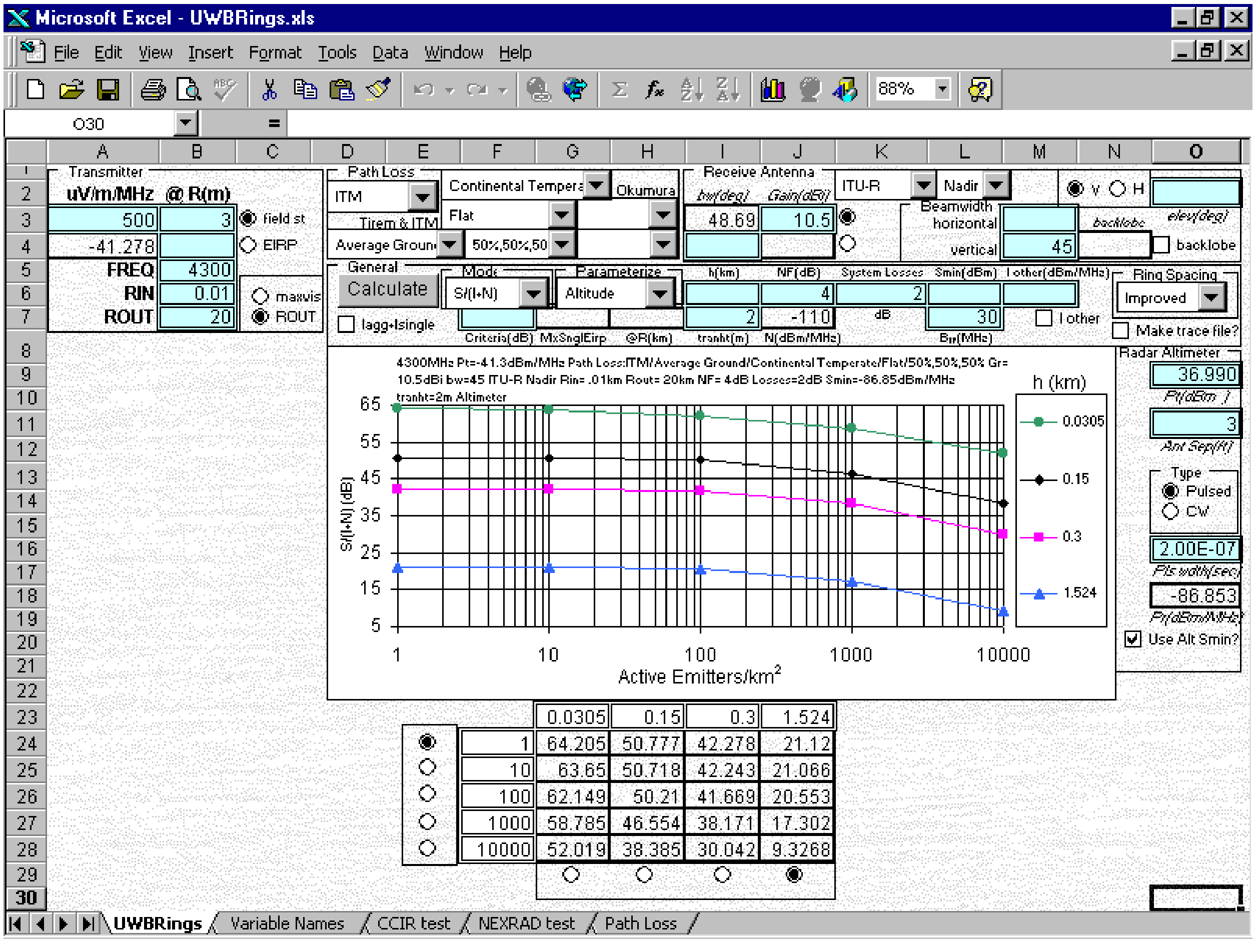

Figure B-2. UWBRings User Interface

The shaded cells in various input sections indicate user typed inputs from which the final program inputs may be derived. Following are descriptions of each of these interface elements.

B.2.1 Transmitter Section [A1:C7][78]

This section allows the user to specify characteristics of the UWB emitters. The EIRP used by each UWB emitter can be specified as either a field strength in microvolts per meter measured in a one MHz bandwidth [A3][79] at so many meters from the emitter [B3], or it can be specified directly in dBm/MHz in [B4]. The radio button pair in [C3:C4], namely, "field st" and "EIRP", allows the user to specify whether to take the input from the field strength cells [A3:B3] or from the EIRP cell [B4]. If the "field st" button is pushed

[78] This notation indicates the location of the section in the spreadsheet. Two cells separated by a colon indicate a range, which is a cell block defined by extremes of the range diagonal. Thus, in this example, cell A1 is at one end of the range diagonal, and cell C7 is at the other.

[79] Cell references are enclosed in square brackets.

UWBRings uses the spreadsheet conversion from field strength to power which appears in [A4]. All power levels used by the program are in dBm, whether they be interference or desired sources, or noise, and are with respect to a 1 MHz reference bandwidth. Desired received signal levels are converted to this reference bandwidth through application of the BWCF (Equation 3-13) of Section 3.

The center frequency of the victim receiver appears in [B5] in units of MHz. Though UWB bandwidths can span hundreds of MHz, the receiver bandwidths under test are all relatively narrow and center on an RF carrier indicated in [B5]. This input probably should have been placed in a Receiver section, but due to lack of space was left where it is.

The inner and outer radii of the emitter distribution are entered in units of kilometers in [B6] and [B7], respectively. The radio buttons appearing in [C6:C7], namely, “maxvis” and “ROUT”, allow the user to select whether to confine the distribution to the outer radius, or to expand it to the radius of maximum visibility[80] depending on receive antenna height. Pushing “ROUT” limits the outer radius to that appearing in [B7] or to the maximum visibility of the receive antenna, whichever is smaller. Pushing “maxvis” always sets the outer ring radius to that determined by the maximum visibility of the receive antenna.

The values selected for RIN and ROUT are, needless to say, crucial to the meaningfulness of the results. RIN should generally be chosen according to a specified minimum separation distance,[81] or a minimum receive antenna far field distance,[82] whichever is greater. However, to facilitate coordination with the single emitter analyses it was determined to simplify by choosing 200 meters for most ground based receivers under study. This simplifying assumption may be underestimating interference for some systems, and allowance should be taken into consideration when forming policy. In cases of airborne receivers RIN was usually chosen to be 10 meters.[83] The best value to choose for ROUT would depend on the emitter densities of interest. If higher densities were deemed significant ROUT should be chosen to represent a city, which is where higher UWB densities would be expected. Lower densities could use a larger outer ring radius, or “maxvis”, corresponding to outlying rural areas.

B.2.2 Path Loss Section [D1:H4]

This section allows the user to specify which path loss algorithm will be used for every link of every aggregate calculation. The main drop down list box for this section is over [D2:E2] and allows selection between the following path loss algorithms:

---

80 This refers to the optical visibility to the horizon assuming a smooth spherical Earth.

81 *See* the Nominal Approach Distance in the system tables of Appendix A.

82 Field strengths in the near field are unpredictable and were not considered in this study.

83 A zero meter radius, which would place the first ring directly under the receiver, would have zero emitters according to Equation B12. Ten meters seemed to be a close enough approximation.

Free Space
TIREM
Okumura
ITM

If free space loss is chosen all other drop down lists in this section are ignored.[84] If TIREM is selected the drop down lists over [D4:E4], [F2:G2], and [F3] are read. The following three tables show the options for each of these list boxes, respectively, and what parameter values they indicate:

TABLE B-2

Surface	Relative Permittivity	Conductivity (Siemens per Meter)
Average Ground	15	0.005
Poor Ground	4	0.001
Good Ground	25	0.020
Fresh Water	81	0.010
Sea Water	81	5.000

TABLE B-3

Radio Climates	Surface Refractivity
Equatorial (Congo)	360
Continental Subtropical (Sudan)	320
Maritime Subtropical (West Coast Africa)	370
Desert (Sahara)	280
Continental Temperate	301
Maritime Temperate, over land (United Kingdom and continental west coasts)	320
Maritime Temperate, over sea	350

[84] Typical Windows© style is to gray the inactive controls thus providing a visual aid to the user; but due to lack of time, and the fact that Excel© does not readily lend itself to this practice, the user must base understanding of inner program workings on the instructions of this appendix.

TABLE B-4

Ground Surface Features	Δh (meters)
Flat (or smooth water)	0
Plains	30
Hills	90
Mountains	200
Rugged Mountains	500

The Δh value of TABLE B-4 is defined to be the total range of path elevations after the highest 10 percent and lowest 10 percent have been removed. It is intended to give the model a feel for the roughness of the terrain. In addition to the refractivity, conductivity, and permittivity of the propagating medium, the TIREM algorithm is also a function of frequency, path length, transmit and receive antenna heights, humidity, and antenna polarization. The humidity refers to the surface humidity at the transmitter site. A nominal value of 10 g/m^3 was chosen for this study.

If Okumura is selected from the main drop down list, the drop down list over [G3:H3] is read. The following shows the options available:

Urban
Suburban
Open

The Okumura model is not intended to be a general purpose model, but rather, is simply a replication of results of path loss studies in particular urban, suburban, and rural areas of Japan. Path loss values predicted by this model are likely to be higher than those anticipated in US&P scenarios, but the model is included in this study to give a potentially closer to accurate feel for the effects of major metropolitan areas.

If Urban is selected, the drop down list over [G4:H4] is read, which gives choice between the following city sizes:

Small/Medium
Large

If ITM is selected from the main drop down list, the drop down lists of TABLEs B-2 through B-4 are read. In addition, the drop down list over [F4] is also read. This list gives choice between a number of combinations of reliability measures for time, location, and confidence, respectively. For example: 10, 50, and 90 percentages indicates that the received field strength of the desired signal will meet or exceed a specified criterion

10 percent of the time, at 50 percent of the intended receive locations, with a 90 percent confidence level.

Generally speaking, for each of these parameters the predicted path loss increases with the percentage of the parameter. The nominal setting would be 50, 50, and 50 percentages, which was selected for the aggregate portion of this study.

B.2.3 Receive Antenna Section [I1:O4]

This section allows the user to specify all pertinent characteristics about the victim receive antenna, except antenna height. This section is further divided and discussed in the following subsections:

Antenna Pointing [L2]

The list box over [L2] allows the user to specify the directional characteristic of the receive antenna. The following choices are available:

Horiz
Nadir
OMNI

"Horiz" (horizontal) and "Nadir" (vertical, downward[85]) antennas are understood to be pointed, with respect to the local horizon plane, either parallel or perpendicular, respectively. Antenna pointing is not precisely defined due to difficulties in dealing with different types of antennas. Figures B-3 through B-15, which will be explained in the next subsection, are offered to illustrate what is meant by horizontal and nadir pointing and to show the pattern orientation with respect to the local horizon. The fundamental difference between horizontal and nadir pointing is that nadir pointing always assumes the horizontal plane pattern is omni-directional.

"OMNI" indicates an omni-directional pattern in the horizontal and vertical planes. If the user selects "OMNI" the program ignores any indicated beamwidths or antenna patterns and applies the indicated main beam gain to all rings of the full annulus.[86]

Antenna Patterns [K2]

The drop down list over [K2] allows the user to specify any one of the following antenna patterns which are listed in TABLE B-5:

---

[85] All cases of vertical pointing are considered to be nadir, as opposed to possibly zenith, because all UWB devices are assumed to be at or near the surface of the Earth.

[86] This is equivalent to setting the horizontal plane beamwidth to 360 degrees and the vertical plane beamwidth to 180 degrees.

TABLE B-5
UWBRings User Interface Antenna Patterns Selections at Cell K2

Antenna	Definition	Remarks
Const	Constant gain	Allows use of 2-level patterns. Multi-purpose
ITU-R[87]	Directional satellite antenna	Used for radar altimeter directional aircraft antenna
SARSATa	SARSAT uplink	This is a measured pattern
DMEa	DME, aircraft	This is a measured pattern
ATCRBSa	ATCRBS, aircraft	This is a measured pattern
MLSa	MLS, aircraft	This is a measured pattern
ASR	ASR, ground	This is a measured pattern
ARSRb1	ARSR beam 1, ground	This is a measured pattern
ARSRld	ARSR look down beam, ground	This is a measured pattern
ATCRBSg	ATCRBS, ground	This is a measured pattern
DMEg	DME, ground	Not available yet
Parabolic	General purpose parabolic	Used for SARSAT downlink, NEXRAD, FSS, and TDWR
Marine Radar	S-band marine radar	This is a measured pattern
Dipole Array	Textbook equation[88]	2 element dipole used to substitute for DMEg

The vertical plane patterns of most[89] of these antennas appear in Figures B-3 through B-15. In some of the patterns 0° is to the right of the plot, in others it is at the bottom. These differences indicate horizontal and nadir pointing, respectively. All horizontally pointed antenna patterns are graphed with elevation angles set to 0°. With the exception of Const, ITU-R, Parabolic, and Dipole Array, all these patterns were taken from measured data.

The horizontal plane pattern associated with these antennas is taken to be omni-directional for all nadir pointing antennas. Horizontally pointed antennas always have a horizontal beamwidth[90] associated with them to define the horizontal pattern. Figure B-3 has a horizontal beamwidth of 360°, though it could be less.

---

87 *See* ITU-R S.672-4 Annex 1. This pattern is typically used to model satellite antennas, but could also be used for directional aircraft antennas.

88 Richard C. Johnson, Antenna Engineering Handbook, at Equation 20-5 (2d ed, 1984).

89 For this study, ARSRld was not used and DMEg was not available to NTIA.

90 *See infra* Section B.2.3, at B-16 for discussion on beamwidth.

The "Const" pattern indicates that the gain level is constant within the indicated beamwidth(s). If the user wants to include the antenna sidelobes and backlobes, these values will all be represented by one constant level as specified in [N4].[91] If backlobes are not used all emitters outside the main beam will be rejected. Thus, "Const" indicates that one or two gain levels will be applied related to the specified main beam. The "Const" pattern applies only to "Horiz" and "Nadir" antenna pointing.

The "ITU-R" pattern is a well known ITU antenna radiation pattern which is a function of antenna main beam gain, beamwidth, and off-axis angle. This pattern is actually intended to model directional satellite antennas but could also be used for aircraft. For this study it is used to represent the aircraft radar altimeter antenna pattern.

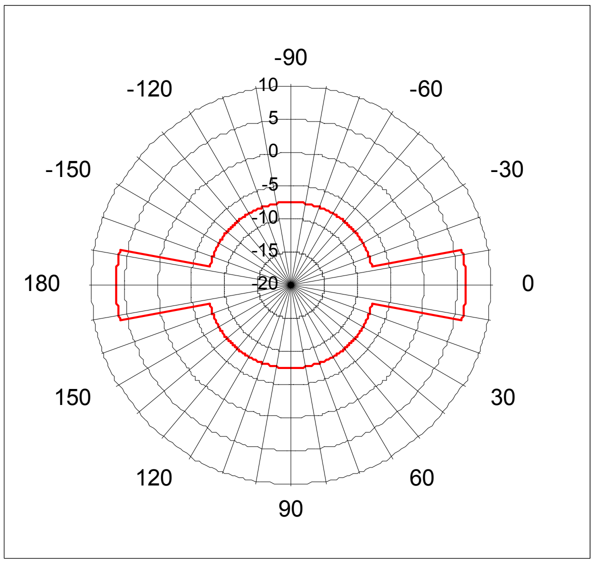

Figure B-3. Const, Horiz, G=6, hbw=360, vbw=25, use backlobe

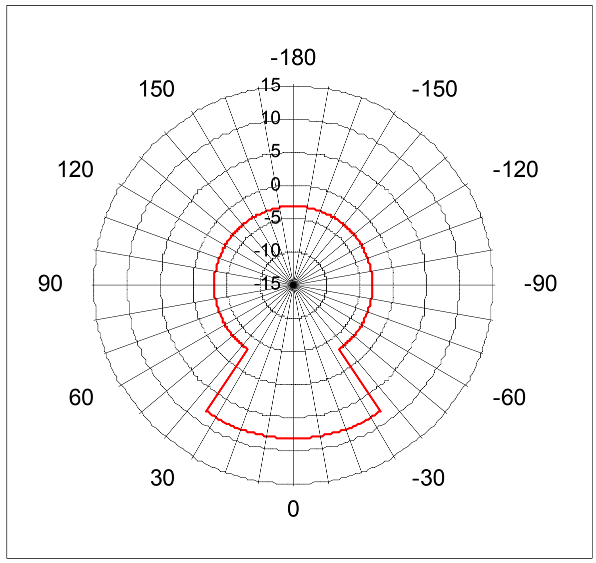

Figure B-4. Const, Nadir, G=8, vbw=70, use backlobe

[91] *See Id.* for discussion on backlobes.

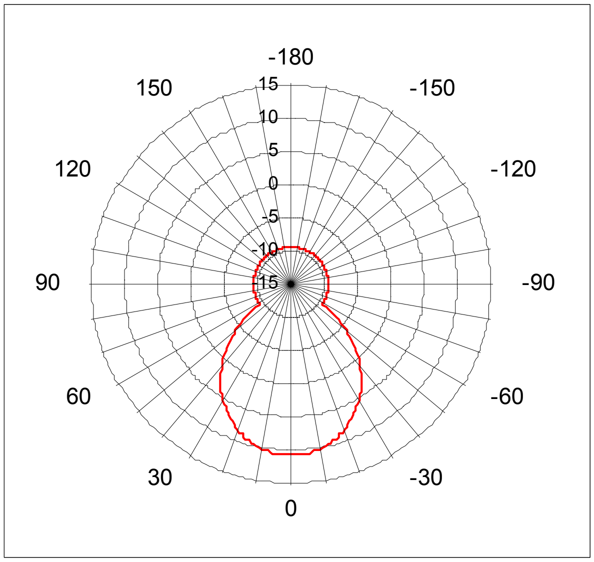

Figure B-5. ITU-R, Altimeter Antenna Pattern.

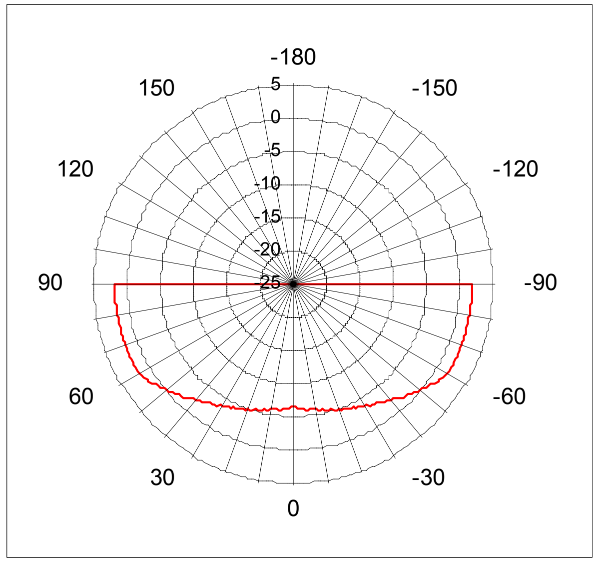

Figure B-6. SARSATa Antenna Pattern.

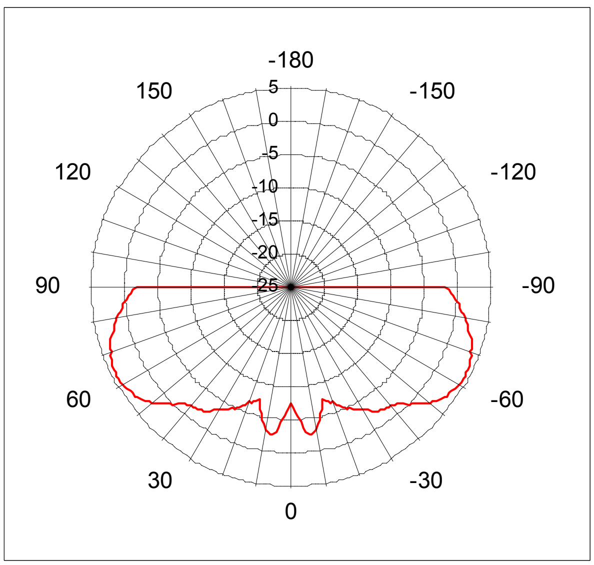

Figure B-7. DMEa Antenna Pattern.

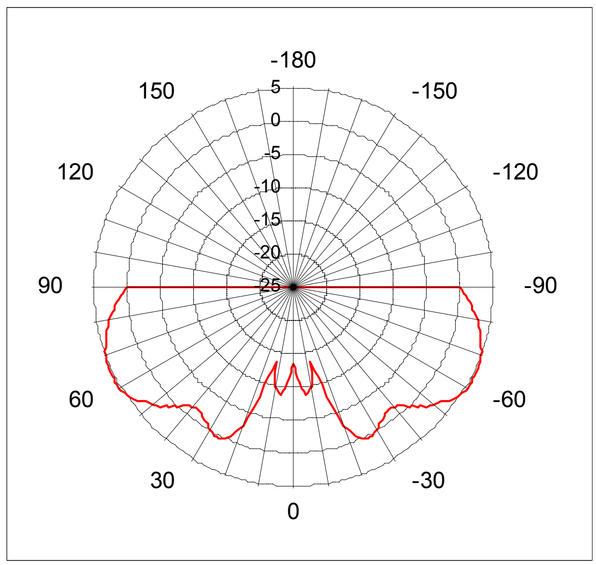

Figure B-8. ATCRBSa Antenna Pattern.

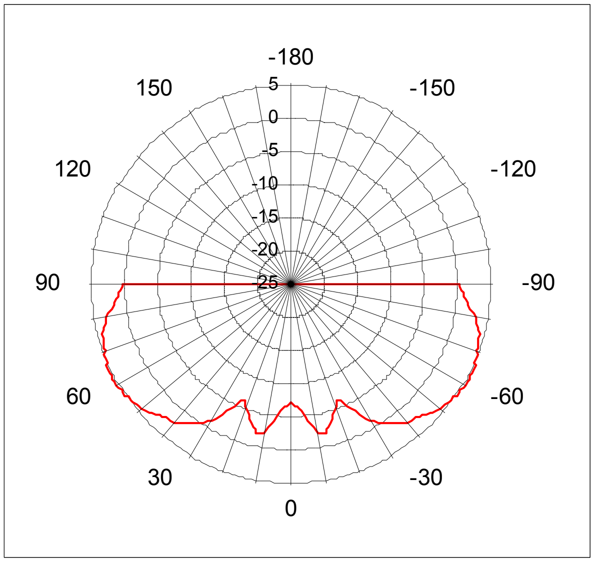

Figure B-9. MLSa Antenna Pattern.

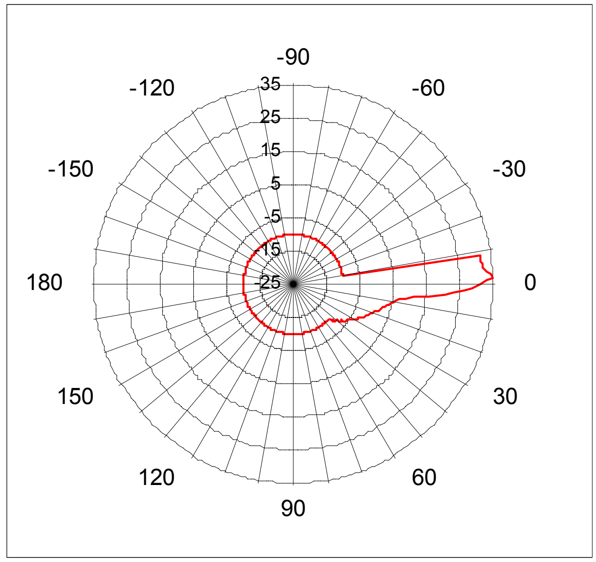

Figure B-10. ASRg Antenna Pattern.

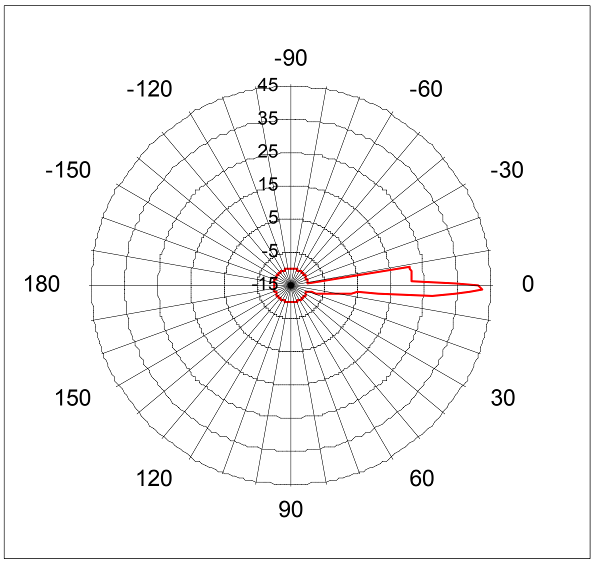

Figure B-11. ARSRb1 Antenna Pattern.

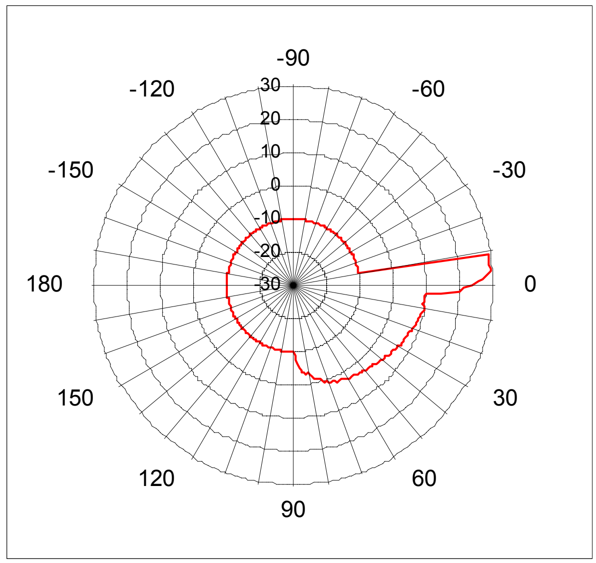

Figure B-12. ATCRBSg Antenna Pattern.

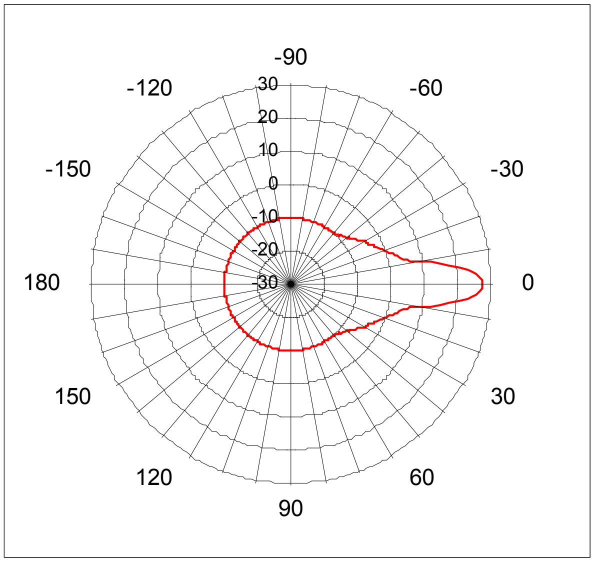

Figure B-13. **Parabolic, SARSAT LUT Antenna Pattern.**

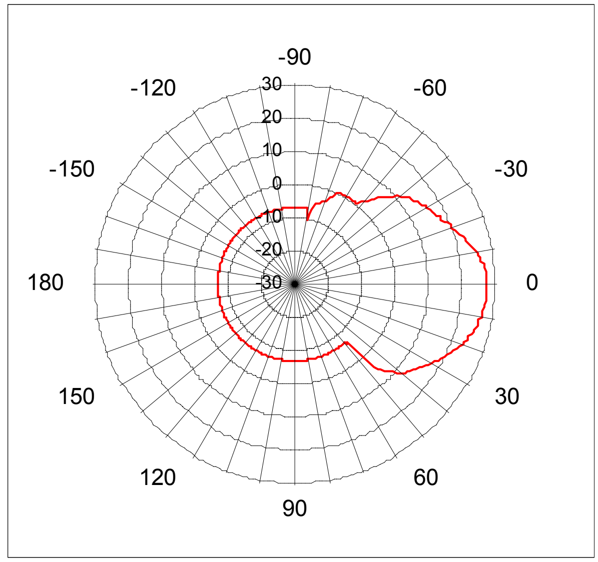

Figure B-14. Marine Radar Antenna Pattern.

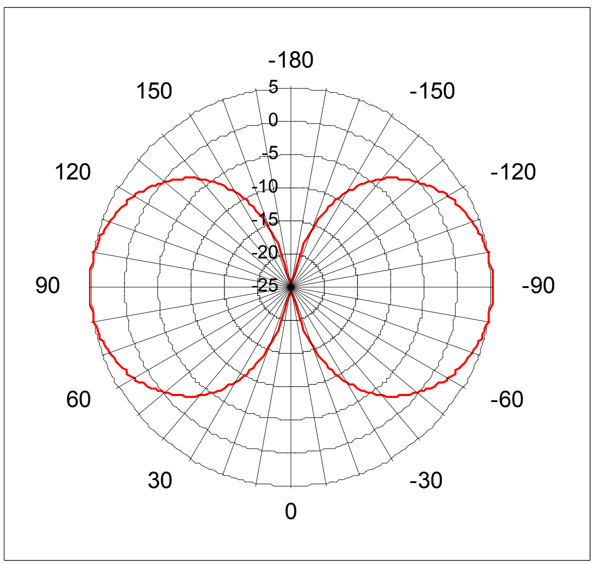

Figure B-15. Dipole Array Antenna Pattern.

Gain [I3:K4]

This subsection is made up of two rows of antenna gains and associated beamwidths. The only purpose of this subsection is to select the main beam gain used by the program. The conversion between gain and beamwidth used in this subsection comes from the original RINGS source code and is offered as a possible aid to the user. The beamwidths which will be used by the program are described in the Beamwidth subsection immediately following.

In the top row [I3:J3] the user specifies the gain [J3] while the spreadsheet calculates a recommended beamwidth [I3]. In the second row the user specifies the beamwidth [I4] while the spreadsheet calculates the recommended gain [J4]. The radio buttons to the right of these rows allow the user to select which gain will be used in the program.

If the user selects one of the measured antenna patterns as described in the Antenna Patterns subsection above, the gain value selected by this subsection is ignored by the program, except that it is used in the titling function of the output chart which is mentioned later in B.2.6.

Beamwidth [L3:M4]

UWBRings uses the concept of both a horizontal plane beamwidth and a vertical plane off-axis angle to describe antenna pattern geometry. The horizontal beamwidth is always used to sector off a portion of the RINGS annulus as described in Section 5.3 and the beginning section of this appendix. This tells the program how many of the emitters implied by the emitter density to include in the aggregate calculation. The program takes this horizontal beamwidth from the user-entered value appearing in [M3], or, in the case of nadir antenna pointing, the program overrides the value in [M3] and assigns a 360° horizontal beamwidth.

In the vertical plane an off-axis angle is used in both "Horiz" and "Nadir" pointing antennas to determine the gain to apply to each ring of the emitter density. That is, an off-axis angle is first determined from the receive antenna to the j^{th} ring. This value is then compared with the selected antenna pattern to find the appropriate gain. For the case of a "Const" pattern this value is compared with the vertical beamwidth indicated in [M4]. For all other antenna patterns this value is input into the computer coded pattern function to produce a gain which is applied to that ring. For the Const, ITU-R, and Parabolic patterns a value is required in [M4]. For all other patterns any value in [M4] is not used except in the output chart titling function.

The way to model an antenna which is omni-directional in the horizontal plane, but has a limited vertical plane beamwidth,[92] is to set the antenna pointing to "Horiz", the antenna pattern to "Const", the horizontal beamwidth in [M3] to 360°, and the vertical beamwidth in [M4] is set as desired (see Figure B-3).

Backlobes [N4:O4]

For a constant gain antenna a conical or a horizontal and vertical beamwidth is used to describe the antenna main beam depending on whether the antenna is pointed at nadir or the horizon, respectively. The only emitters considered to contribute to the aggregate at the victim receiver are those which fall within this main beam. Knowing that a receive antenna actually receives radiation in all directions, the question arises as to whether

[92] As in a VHF repeater.

sidelobe and backlobe contributions could be significant. The purpose for this subsection is to provide a "feel" for the answer.

For simplification this section approximates all gain outside the main beam to a single constant level which is determined according to the following theoretical approach. The first observation made is that although it is most convenient and practical to measure the pattern of an antenna in the receiving mode, it is identical to that of the transmitting mode because of the theorem of reciprocity.[93] Therefore, though the following development considers the transmit mode, it applies equally to the receive pattern.

Consider that the gain of any antenna could be approximated by a piecewise function of power densities over a sphere covering all possible directions of radiation. This approach is depicted by the following equation:

$$\int P_{d1} dS + \int P_{d2} dS + \int P_{d3} dS + \ \ldots \ + \int P_{dn} dS = \eta P \qquad \text{(B15)}$$

There are n power density functions which are each integrated over the portion of the sphere to which they apply. The sum of these integrals must equal the total radiated power of the source except for various losses, which are represented by an antenna efficiency, η.

If we consider that the antenna pattern over the sphere is represented by only two power density functions we arrive at the following equation after substitution.

$$\int \frac{PG_m}{4\pi r^2} dS + \int \frac{PG_b}{4\pi r^2} dS = \eta P \qquad \text{(B16)}$$

In this equation G_m represents the main beam gain, and G_b represents the gain of everything on the sphere outside of the main beam. Since there could be two different descriptions of the main beam depending on whether a conical beam is used, or a horizontal and vertical beamwidth, we consider the following two applications of this equation.

Conical:

$$\int_0^{2\pi} \int_0^{\frac{\phi_3}{2}} \frac{PG_m r^2 \sin\phi}{4\pi r^2} d\phi d\theta + \int_0^{2\pi} \int_{\frac{\phi_3}{2}}^{\pi} \frac{PG_b r^2 \sin\phi}{4\pi r^2} d\phi d\theta = \eta P \qquad \text{(B17)}$$

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[93] Constantine A. Balanis, "Antenna Theory, at 97 (Wiley & Sons 1982).

Horizontal/Vertical:

$$\int_0^{\theta_3}\int_{\frac{-\phi_3}{2}}^{\frac{\phi_3}{2}}\frac{PG_m r^2\cos\phi}{4\pi r^2}d\phi d\theta + \int_0^{\theta_3}\int_{\frac{-\pi}{2}}^{\frac{-\phi_3}{2}}\frac{PG_b r^2\cos\phi}{4\pi r^2}d\phi d\theta +$$

$$\int_0^{\theta_3}\int_{\frac{\phi_3}{2}}^{\frac{\pi}{2}}\frac{PG_b r^2\cos\phi}{4\pi r^2}d\phi d\theta + \int_{\theta_3}^{2\pi}\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}}\frac{PG_b r^2\cos\phi}{4\pi r^2}d\phi d\theta = \eta P \qquad \text{(B18)}$$

In both cases the angle θ is in the horizontal plane and ϕ is in the vertical plane. Correspondingly, θ_3 represents the full horizontal beamwidth and ϕ_3 represents the full beamwidth in the vertical plane.

Since we are considering that G_m and G_b are both independent of position on the sphere, the solution to both of these equations is trivial. Both are modeled in cell [N4] of the spreadsheet (with η set to 100 percent) when Pattern is set to "Const". The equation for Conical is implemented, using the beamwidth in cell [M4], when Ant Pointing is set to "Nadir". The equation for Horizontal/Vertical is implemented, using beamwidth values in both [M3] and [M4], when Ant Pointing is set to "Horiz". The backlobe in [N4] is used in the simulation when the "backlobe" check box over [O4] is checked. A value of "#NUM!" in [N4] indicates an unrealistic beamwidth which is too wide, for the selected gain, to allow any energy in the backlobe.

Antenna Polarization [N2]

This subsection was added when using the TIREM path loss model because it was discovered that the polarization used made a slight difference in calculated aggregate power for receive antenna heights under 100 meters. The only choices offered by TIREM for antenna polarization are vertical and horizontal, which are the "V" and "H" radio buttons, respectively, in this subsection. As it turns out, this is also compatible with ITM, so the selection in this subsection would also apply if the user selects the ITM path loss.

Antenna Elevation Angle [O2]

Any time the program looks for a receive antenna elevation angle, it takes that value from [O2]. UWBRings then takes this value and adds it to the calculated off-axis angle, which is compatible with all the ground-based antenna pattern functions used. Just to note, positive elevation angles are defined by the program to be above the local horizontal. Positive off-axis angles are defined to be below the local horizontal.

B.2.4 General Section [D5:O8]

This section contains several miscellaneous inputs and controls which are described in the following subsections.

Calculate button [D6:E6]

As mentioned previously, the "Calculate" button, which appears over [D6:E6], is the control which activates the Visual Basic© routines used to update the data points in [G24:J28][94] and format the associated chart. It was determined that the best way to structure the program for robustness and clarity was to separate the input gathering and calculations from the output data point calculations. This was due primarily to calculation order errors which occur across a worksheet page each time the spreadsheet recalculates. The idea is to separate the much faster input calculations from the much slower data point calculations. An added bonus to this structure is that the overall program speed is greatly enhanced because now the typically numerous input adjustments will not each trigger recalculation of all data point cells.

Mode drop-down list [F6]

The Mode control allows the user to select either the criteria calculated in the output chart, or the maximum allowable EIRP calculated based on the specified Criteria. List options include the following:

I/N
S/I
S/(I+N)
EIRP[I/N]
EIRP[S/I]
EIRP[S/(I+N)]

Criterion [F7]

If the user selects any of the EIRP modes in the Mode list just described, the program looks in [F7] to find the associated criterion threshold. Thus, if the user selects the EIRP[I/N] mode, the threshold entered in [F7] will be interpreted to be an I/N criterion. The user-entered threshold is understood by the program to be in decibels.

Parameterize drop-down list [G6:H6]

The intention of this list box is to allow the user to plot more than one curve on the output chart at the same time. The additional curves are a function of the parameter which appears in this control. List options include the following:

Altitude
NF
Smin

[94] Described in the Data Points section (B.2.7).

Whichever of these parameters the user chooses to vary, the program looks in the 23rd row starting at the leftmost cell [G23] to find these parameter values. Although in most cases only 4 variations of the parameter are listed (out to [J23]), the program will actually continue reading cells to the right until it finds an empty cell. Thus, the user can calculate the data points of several more curves. They can subsequently be plotted by highlighting the additional data points, making sure to include the associated parameter value in the 23rd row, and dragging and releasing anywhere in the chart area.

Iagg+Isingle check box [D7:E7]

The purpose of this control is to allow the user to ensure a worst case aggregate interference calculation. Under low emitter density and low receive antenna height the RINGS topology may assign less than a single emitter to the innermost ring(s). In such cases it is possible that the entire aggregate power level (Iagg) may be less than the power received by a single emitter placed on the worst case ring [95] (Isingle). Selecting this check box causes the program to check for this condition. If, and only if, it finds this to be the case, the program increases the aggregate power by the worst case single emitter power. Hence the name "Iagg+Isingle".

MxSnglEirp [G7] and @R(km) [H7]

If the user selects any of the EIRP modes and checks the "Iagg+Isingle" check box, the program writes values in these two cells. Into [G7] it writes the maximum allowable EIRP (to keep from exceeding the criterion threshold) for a single emitter calculated from the worst case ring.[96] Into [H7] it writes the value of that worst case ring radius. These values were added to ensure that the aggregate portion of the study agrees with the single emitter portion (Section 4).

h(km) [I6]

The program variable assigned to the victim receive antenna height is "h". In the Parameterize list box this same variable is called "Altitude".[97] In those cases where the user has not elected to vary the altitude parameter, the program takes the receive antenna height from [I6]. The value entered is assumed to be in kilometers.

tranht(m) [I7]

Any time the program looks for a UWB transmitter height it takes it from [I7]. As previously mentioned, all emitters are assumed to be at this same height above average terrain. The user-entered value in [I7] is assumed to be in meters.

NF(dB) [J6]

When the program looks for a system NF it takes it from [J6]. The value is understood to be in decibels. If the system noise is listed as a noise temperature (T_s) it can

---

[95] This is defined to be the ring from which a single UWB emitter produces the highest interfering power level at the receiver.

[96] Due to the use of shaped beam antenna patterns, the worst case ring may not be the innermost one.

[97] Indicating a relative altitude with respect to the average terrain height.

be converted to work in this cell through the use of 10log(T_s/T_o). For example, if the noise temperature is 650 K, enter the following (less the quotation marks) in [J6]:

“=10*log((650)/290)”

N(dBm/MHz) [J7]

This cell contains a formula to convert the NF in [J6] to a noise density in dBm/MHz. It is provided for the user’s information and can be used for such useful things as determining the actual aggregate interference levels calculated in the data point cells. The easiest way to do this is directly on the spreadsheet. Several of the free cells surrounding the data points are available as a sort of “scratch pad” for the user to enter custom formulas. To determine the exact aggregate interference calculated for any data point cell, say [H27], simply perform an I/N analysis, find a free cell and enter the following formula (less the quotation marks):

“=H27+J7"

System Losses [K6]

System losses are only used for I/N and S/(I+N) cases since for the S/I case losses cancel each other. Some call these losses “insertion” losses. The user-entered value placed in [K6] is understood by the program to include losses from immediately after the receive antenna to the receiver input.

Smin [L6]

Smin is the minimum desired received signal level at the receiver stage where S/I or S/(I+N) is determined. The power level entered here should be in dBm/Bif(MHz).

Bif [L7]

Bif is the IF bandwidth (in MHz) of the receiver.

Iother [M6]* and *Iother check box [N6]

NTIA recognizes that it is inappropriate for any one service to feel they have the rights to all the excess of a protected service’s link budget. The excess is defined to be the difference between the calculated criteria using the expected signal levels, and the minimum specified threshold to achieve the standard of reception required. In fact, when a service defines its interference threshold, it intends to include the cumulative affect of all possible interferers. Iother was added to allow the user to get a “feel” for the affects of potential interference from other services. The user enters a value in [M6] in dBm/MHz which is understood to be the Iother signal level immediately after the receive antenna. This value is added to the aggregate power levels calculated only if the Iother check box is checked.

Ring Spacing [O6]

The drop down list over [O6] gives the user the option of choosing amongst different Δ spacings as described earlier in this appendix. Options are the following:

Original
Improved
10 meter

The “Original” rings spacing algorithm is the implementation of (B3) followed by (B4) where M is subsequently rounded to an integer, if necessary. The “Improved” algorithm differs from the Original in that it always rounds M up, and follows by recalculating Δ using $\Delta = (R_O - R_I)/(M - 1)$. The effect of this improved algorithm is that all of the subsequently calculated N_j terms add up to exactly N as specified by (B7). The “10 meter” algorithm acts just like the Improved one except that it always uses K = 1,0000 in (B3).

Make trace file? [N7]

This check box gives the option to create a text file of the variables calculated for each ring in a given aggregate calculation. The radio buttons of the Data Points Section (see B.2.7) are used to select the cell for which the user wished to monitor variable development. This feature is added to ensure the integrity of the program. The file, called “trace.txt”, is saved in the MS Excel© default file location directory. A macro called “ReadTrace” is included to open the file as a spreadsheet, thereby facilitating further data processing at the user’s discretion. This macro can be run through the <Ctrl> + R keystroke combination.

B.2.5 Radar Altimeter Section [N9:O19]

This section contains inputs used to calculate the desired received signal level for a radar altimeter. It was added due to the fact that radar altimeters were chosen as one of NTIA’s target systems for this study, that the FAA lists altimeter protection criteria in terms of the desired received signal level, and that peculiarities of the link based upon the reflection at the Earth’s surface requires implementation of a specialized algorithm to improve accuracy of predicted received signal level at the aircraft. That specialized algorithm is documented in an RTCA publication[98] called “Minimum Performance Standards Airborne Low-Range Radar Altimeters”. This document indicates that desired signal level is a function of the frequency of the emission, whether the altimeter uses CW or pulsed emissions, the pulse width (for pulsed emission type), the transmit power, the transmit and receive antenna gains and beamwidths (assumed to be identical), the distance along the aircraft fuselage between transmit and receive antennas, the aircraft altitude, and the unit scattering radar cross section of the ground.

TABLE B-6 below indicates the final[99] inputs from the user interface where each of these parameters are taken: The scattering radar cross section does not appear in the

98 Radio Technical Commission for Aeronautics Document, RTCA DO-155, prepared by RTCA ICG-2 (Nov. 1974).

99 These input locations are not necessarily user-typed, but could be calculated or determined by another control.

table because the documentation suggests using a constant value of 0.006[100] as a reliable representative of a wide variety of terrain and aircraft pitch and roll maneuvers.

When the "Use Altimeter Smin?" check box over [N20] is checked, the calculated received power appears in cell [O18]. This same value will be used in a S/(I+N) program simulation which varies the NF parameter. Otherwise, if the simulation is varying the receive antenna altitude parameter, this same radar altimeter received signal level function appears in the cells [G22:J22] which are directly above the cells containing the aircraft altitudes they use. If you are performing either a S/I or S(I+N) simulation, the range [G22:J22] is where the Smin values will come from. Though you are varying the altitude parameter, yet because Smin depends on altitude, the simulation will use a different Smin for each altitude curve plotted.

TABLE B-6

Description	Cell Location in UWBRings
Frequency of the emission	[B5]
Is the altimeter CW or pulsed?	[O13:O15] (radio buttons)
Pulse width	[O16]
Transmit power	[O9]
Antenna gain	[J3] or [J4][101]
Antenna beamwidth	[M4]
Distance between antennas	[O11]
Aircraft altitude	[I6] or [G23:J23][102]

B.2.6 Chart Section [D9:M22]

UWBRings was written in MS Excel© because of the built-in charting features. Additionally, the underlying Visual Basic© interface lends itself to automating the creation and formatting of titles[103] and chart legend, as well as the formatting and scaling of chart axes. The chart can be copied and pasted easily into any Windows© compatible program. The legend to the right lists the parameter which is varied to create the multiple curves. In the example shown in Figure B-2 the chart legend shows that the curves differ in "h(km)", which is the receive antenna height.

[100] Valid as long as all distances in the external loop loss equation of the RTCA documentation are in feet.

[101] As described in the Gain subsection of the Receive Antenna section.

[102] See B.2.7 (the Data Points section).

[103] See Section 5.5 for more information on automatic chart titling.

B.2.7 Data Points Section [E23:J29]

The chart takes its emitter density values from the spreadsheet column [F24:F28]. The values span 4 orders of magnitude from a single active emitter per square kilometer because this was thought to be enough to cover all practical ranges of emitter densities. Though it is unlikely that the user would want to use different values than these, it is possible to change them simply by writing over them.

The parametric values for the chart are taken from the row beginning at [G23] and extending to the right. According to the user selection in the Parameterize list (previously described in the General section) the program interprets the values in this row to be either receiver antenna heights (in km), NF (in dB), or desired received signal levels (in dBm/MHz). The chart legend reads these values and displays the points in the data point columns directly beneath as curves on the chart.

The data points upon which the chart curves are based are located in the cell block beginning with [G24]. The other end of the cell block diagonal is usually at [J28], however, provision is made to extend the number of curves plotted per chart by extending the parametric values row up to several cells beyond [J23]. Thus, if the user wanted to plot three additional curves this could be accomplished simply by entering appropriate values in [K23:M23]. After clicking the "Calculate" button, data point values would appear in the cells directly beneath the added parametric values. These values could then be plotted manually by using well known MS Excel© charting techniques.

The radio buttons appearing across [G29:J29], and those over [E24:E28], have no affect at all on the data points. They are added as an aid to the user to control program written values which appear in [G7:H7], the spreadsheet calculated value which appears in [O18], and which data points cell is traced when using "Make trace file?". Specifically, both sets of radio buttons are used to identify a specific cell amongst the data points.[104] The "MxSnglEirp" and "@R(km)" values previously discussed in the General section will be based on the selected cell. Additionally, in the Radar Altimeter section of the spreadsheet, the received signal level which appears in [O18] is based upon the receive antenna height identified by the [G29:J29] row of radio buttons when the corresponding parametric values of [G23:J23] represent antenna heights.

B.3 SAMPLE DATA

This subsection shows how the model was used for two of the systems analyzed in this report. The following two figures show the UWBRings user interface for each of these scenarios. The corresponding parameter tables of Appendix A were used to fill various input cells. To avoid confusion the input cells which were not used in the

[104] Through the intersection of the row identified by the [E24:E28] radio buttons, and the column identified by the [G29:J29] buttons.

scenarios were left blank, although it would not affect the simulation if they had contained stray data.

The first system considered is the ATCRBS Ground Interrogator whose parameters appear in TABLE A-5. Figure B-16 shows how to model this scenario using UWBRings. This receiver uses a fan-type antenna pattern with a narrow horizontal beamwidth (1.5°) and a wider vertical beamwidth (4.7°). The horizontal beamwidth is entered in [M3] and is used by the program to eliminate all but a 1.5° sector of emitters from the aggregate calculation. Thus, the program makes an approximation by not considering any sidelobe contributions in the horizontal plane. In the vertical plane the measured data of the ATCRBSg antenna pattern is used to assign a gain level to each ring of the emitter distribution. In this case it is unnecessary to list a vertical beamwidth in [M4] because this information is built into the gain pattern.

Figure B-16 shows that a 2° antenna elevation tilt angle was used.

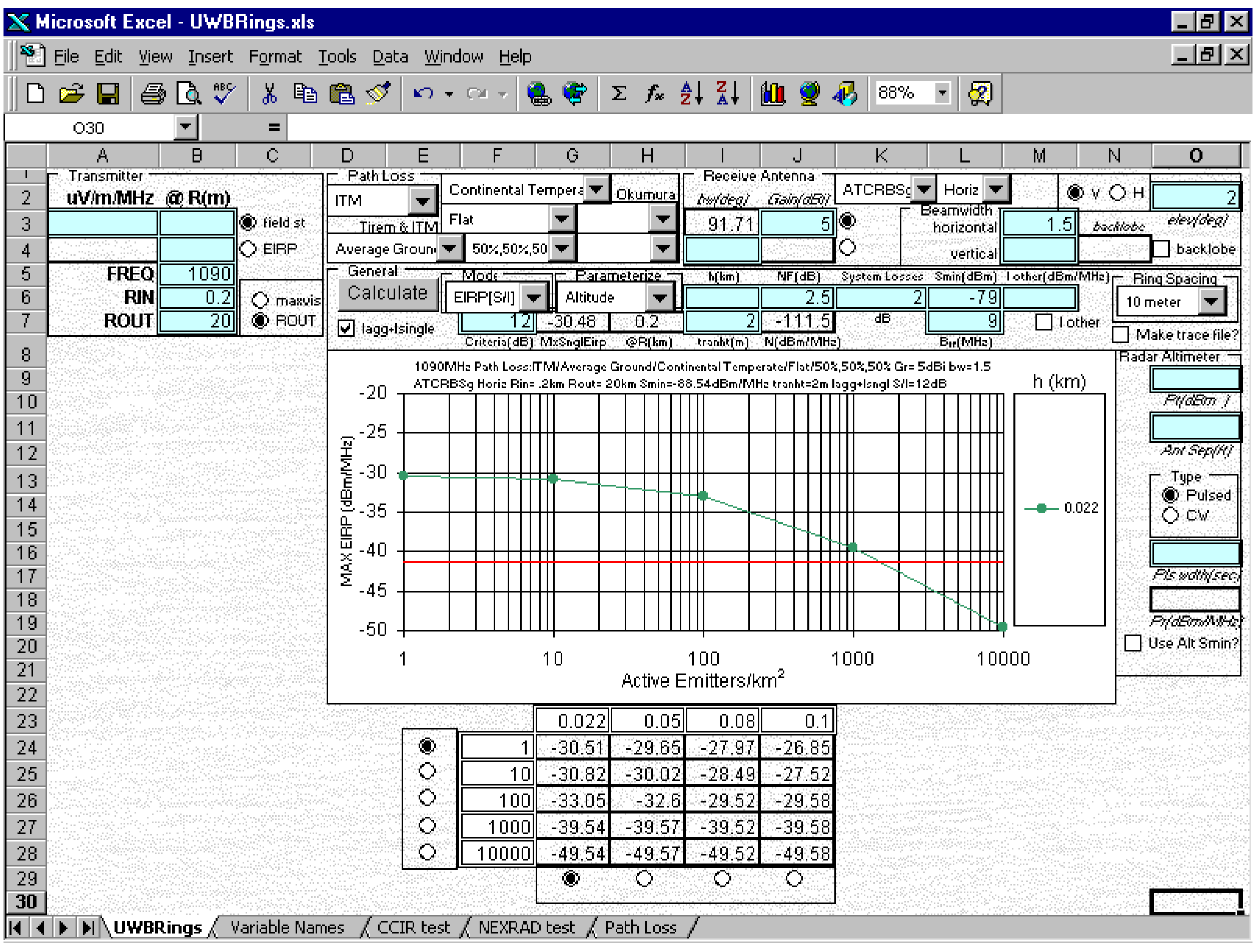


Figure B-16. ATCRBS Ground Interrogator

The Iagg+Isingle check box is selected, which accounts for the fact that the output curve stays relatively flat for the lower emitter densities. This also signals the program to mark the ring from which the strongest interfering signal is received. The EIRP value for a single emitter placed at that ring, which will meet the S/I = 12 dB threshold, appears in [G7]. As expected, the curve value at 1 emitter/km^2, which appears in [G24], is less than the value in [G7]. In this case, because the receive antenna height is small, there is not much difference between [G7] and [G24].

One more point is that the chart title has converted Smin to a PSD with respect to 1 MHz. TABLE A-5 lists Smin as -79 dBm in a 9 MHz bandwidth. Whenever the program uses Smin it always converts to PSD in dBm/MHz to make it compatible with the UWB EIRP reference level.

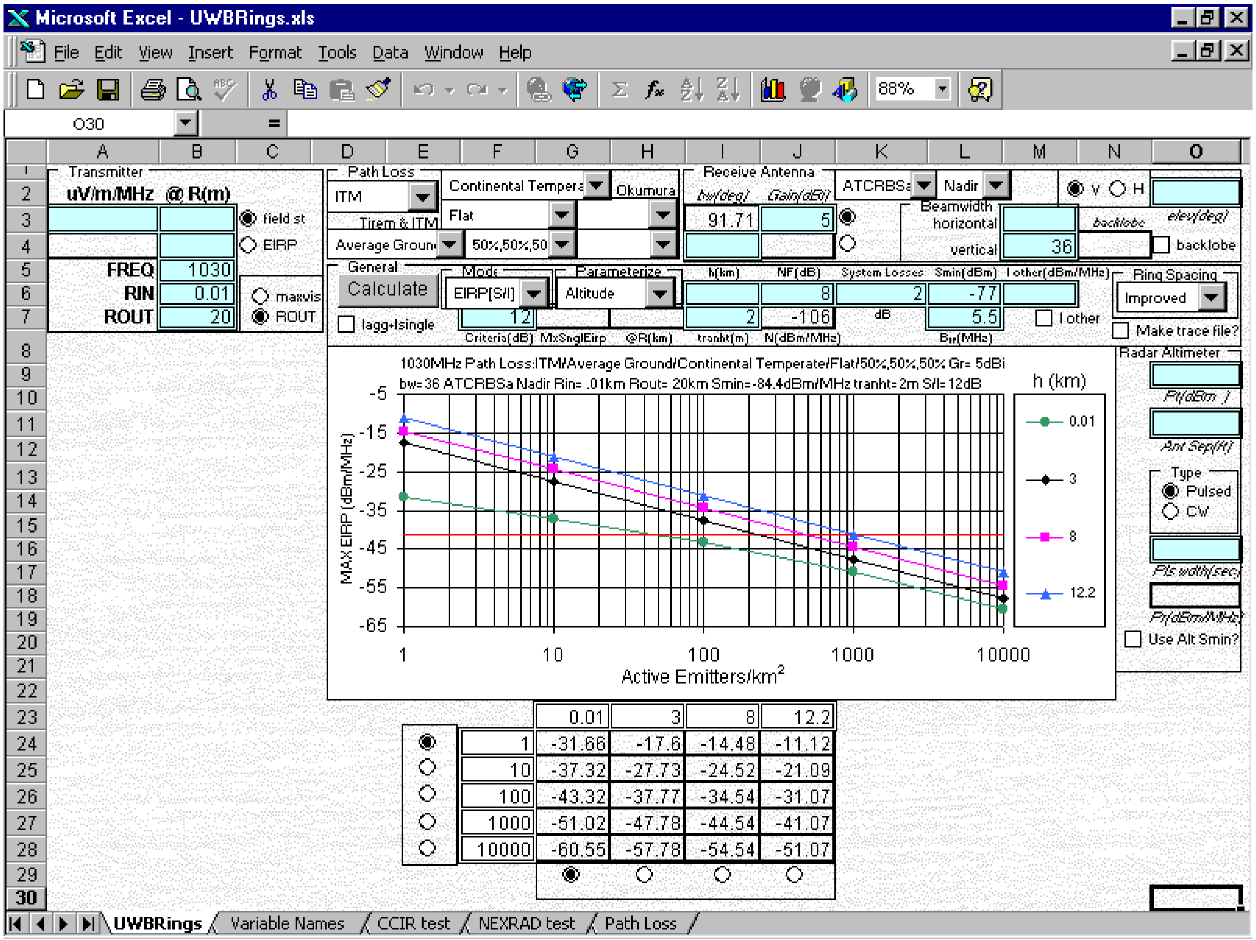
The next system to consider is the ATCRBS airborne transponder, whose parameters appear in TABLE A-6. Figure B-17 shows the corresponding UWBRings scenario. In this case the receive antenna is pointed at nadir. For all nadir pointing antennas the program assumes the horizontal antenna pattern is omni-directional. Thus, all emitters determined using (B1) will be contributing to the aggregate. In the vertical plane the measured data of the ATCRBSa antenna pattern is used to apply a gain to each ring in the distribution. The value appearing in [M4] is the conical vertical plane beamwidth and is used only for the automatic chart titling function. It does not affect the gain calculation in this case because that information is built into the ATCRBSa gain pattern.

Because the Iagg+Isingle check box is deselected it is expected that all curves would follow a -10dB/decade slope. However, it is evident that none of the curves quite comply. One can visibly see that the 10 meter altitude curve veers from the expected slope below 1,000 emitters/km^2. But upon closer examination of the data points in [J24:J28], it is seen that even the 12.2 km[105] curve does not follow a -10dB/decade slope below 100 emitters/km^2. The reason for this discrepancy is a resolution problem that arises when using the Original or Improved Ring Spacing algorithms.[106] These algorithms use a wider ring spacing for lower emitter densities which cannot track the vertical antenna pattern closely enough. This explanation is easily verified by switching to the 10 meter Ring Spacing algorithm, which shows the same values at 10,000 emitters/km^2 and alters values at other densities to provide the expected slope for each curve.

The -41.3 dBm/MHz reference level appears on the output charts of Figures B-16 and B-17.

[105] Equates to 40,000 feet

[106] See the Ring Spacing subsection in B.2.4, as well as the paragraph between (B4) and (B5), and paragraphs between (B12) and (B13), for more information.



	0.01	3	8	12.2
1	-31.66	-17.6	-14.48	-11.12
10	-37.32	-27.73	-24.52	-21.09
100	-43.32	-37.77	-34.54	-31.07
1000	-51.02	-47.78	-44.54	-41.07
10000	-60.55	-57.78	-54.54	-51.07

Figure B-17. ATCRBS Airborne Transponder

APPENDIX C

DISCUSSION OF OKLAHOMA CITY MEASUREMENTS

C.1 INTRODUCTION

This section discusses measurements conducted at the FAA Academy in Oklahoma City, Oklahoma. The objective of these measurements were to:

1) Determine what emission limits are necessary to protect selected Federal radio systems, and
2) Validate the one-on-one interference analysis procedure by determining the minimum distance separation and/or the maximum UWB EIRP to ensure compatibility between UWB devices and selected Federal radionavigation and safety-of-life systems.

Measurements were conducted on three National Airspace Systems equipment: ARSR, ASR, and the ATCRBS. Prior to conducting radiated measurements, preliminary closed system measurements were conducted to determine the receiver noise level and to observe the UWB signal characteristics at the receiver IF output for various UWB signal levels.

C.2 RADIATED MEASUREMENTS

All radiated measurements were conducted with the radar antenna not rotating and pointing at the NTIA Radio Spectrum Measurement System (RSMS) van. The horn antenna on the RSMS van was mounted on the top of the van at a height of 4 meters and pointed at the radar. The RSMS van equipment was set-up as shown in Figure C-1 with the attenuator set to produce an EIRP of -41 dBm, log-average using the video filtering technique (1 MHz RBW, 10 Hz VBW) for each UWB signal radiated.

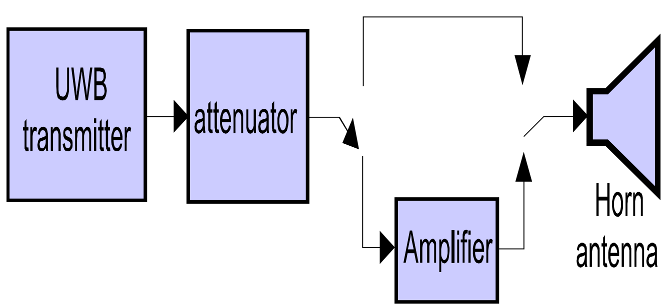


Figure C-1. UWB Pulsar Equipment Configuration.

C.2.1 Air Route Surveillance Radar (ARSR-4)

The following is a summary of the radiated measurements conducted on the ARSR-4.

Receiver Characteristics:

1. IF bandwidth = 1.3 MHz (measured)
2. IF Frequency at J3 = 36.25 MHz (measured)
3. Receiver input noise level = -113 dBm (calculation)
4. Receiver noise level at IF output (J3) = -79 dBm (measured)
5. Antenna low beam gain = 41.86 dBi. (obtained from manual)
6. Antenna height = 100 feet (30.48 meters)
7. Receiver front end losses (L_R), = 0.5 dB (estimated)

Radar Measurement Setup:

1. Receiver Channel A (1241.47 MHz)
2. Monitored Channel 1 (low beam, array rows 6-9) IF output (J3)
3. UWB Signal injected at row 8 of the antenna feed array prior to LNA and before channel beam forming network (cable loss to injection point (L_c) = 26 dB)
4. Transmitter off
5. Test targets off
6. Sensitivity Time Control (STC) set to 5 nm (minimum)
7. AGC frozen (maintains constant AGC during tests. Noise level is sampled during dead time and AGC established based on system noise)
8. Antenna low beam -2.5 dB point set on the horizon (G_r = 38.36 dBi)
9. Location (lat. 35°, 24', 12.8" N /lon. 97°, 37', 44.2" W)

Note: Limited measurements were made observing the affects of CW-like interference to the ARSR-4 radar. It was determined that CW-like interfering signals reduce the receiver gain. A 10 MHz non-dithered signal produced a CW-like signal at the receiver IF output.

Site Selection: Measurement sites were selected by observations from the radar antenna platform and by measuring the signal from the ARSR-4 using the receiver in the RSMS van. The variation in coupling between an FAA ARSR-4 radar at the Oklahoma City Technical Center and a UWB antenna on the RSMS van is shown over a distance of 0.4 to 3.6 kilometers (see Figure C-2). This figure was generated by driving the NTIA RSMS van slowly away from the radar while measuring the power coupled from the radar. The beam rotated past the van every 10 seconds, resulting in the periodic spikes seen in the figure. For the particular measurement shown in Figure 1, the maximum coupling level occurs at 1.25 kilometers, and gradual drop-off in coupling beyond that distance. Similar measurements were performed for ASR-8, and ATCBI-5 antennas at Oklahoma City.

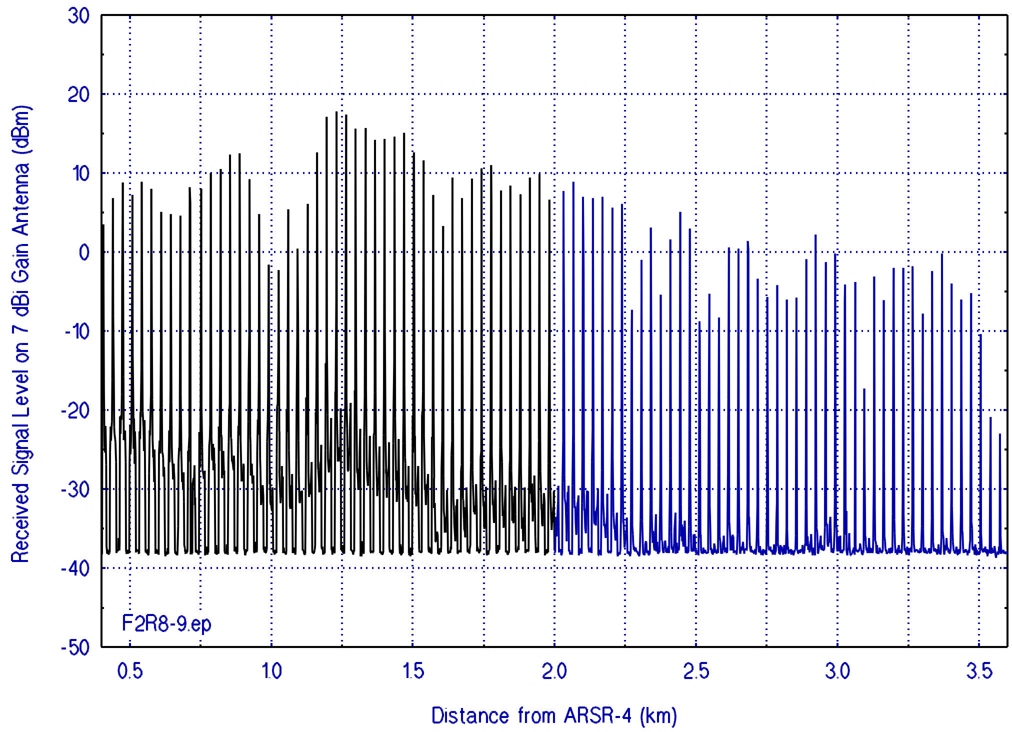


Figure C-2. Received Signal Level as a Function of Distance from the ARSR-4 Radar.

Site Measurements: At each selected measurement site, the distance was measured using a GPS receiver. The following is a summary of the measurement data for each measurement site.

Site #1: The RSMS van was located on Halaby Drive at the TDWR site (Lat.35^0 23' 31.8"/Lon.97^0 37' 41.4"). The site was 1.26 km from the ARSR-4 and a bearing of 179.5^0 on the ARSR-4 bearing indicator. The measured (I+N)/N ratio at the ARSR-4 receiver IF output were:

> The 10 MHz PRF dithered UWB signal produced an (I+N)/N ratio of 9 dB. An (I+N)/N ratio of 9 dB equates to an I/N ratio of 8.4 dB. The measurements showed that it was necessary to attenuate the UWB signal by 15 dB to limit the (I+N)/N ratio to 1 dB, I/N = -6 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 18.4 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -56.9 dBm RMS (-38.5 dBm RMS -18.4 dB).

Site #2: The RSMS van was located on Rockwell Avenue (Lat. 35^0 23' 09"/Lon. 97^0 38' 10.2"). The site was 2.1 km from the ARSR-4 and a bearing of 203^0 on the ARSR-4 bearing indicator. The measured (I+N)/N ratio at the ARSR-4 receiver IF output were:

> The 10 MHz PRF dithered UWB signal produced an (I+N)/N ratio of 11 dB. An (I+N)/N ratio of 11 dB equates to an I/N ratio of 10.6 dB. The measurements showed it was necessary to attenuate the UWB signal by 18 dB to limit the (I+N)/N ratio to 1 dB, I/N = -6 dB. Figures C-3 and C-4 show the ARSR-4 IF output for the baseline noise level (UWB signal off) and with the UWB signal on for peak detector (RBW and VBW = 1 MHz), and the average signal level using video filtering (RBW = 1 MHz and VBW = 10 Hz), respectively. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 20.6 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -59.1 dBm RMS (-38.5 dBm RMS -20.6 dB).

Site #3: The RSMS van was located on North Meridian Avenue just south of Airport Road and north of the grave yard (Lat. 35^0 25" 14.4"/Lon. 97^0 36' 3.1"). The site was 3.1 km from the ARSR-4 and a bearing of 56^0 on the ARSR-4 bearing indicator. The measured (I+N)/N ratio at the ARSR-4 receiver IF output were:

> The 10 MHz PRF dithered UWB signal produced an (I+N)/N ratio of 8 dB. An (I+N)/N ratio of 8 dB equates to an I/N ratio of 7.2 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 17.2 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -55.7 dBm RMS (-38.5 dBm RMS -17.2 dB).

Incidental Radiator Measurements: At each of the measurement sites an electric drill and razor were radiated to see if they could be observed at the ARSR-4 IF output. The electric drill was not detected at any on the measurement sites. The electric razor was observed to produce asynchronous spikes 10-15 dB above system noise at Site #1. However, the average (RMS) noise level at the IF output was observed and there was no increase in the average (RMS) noise level at the IF output due to the electric razor.

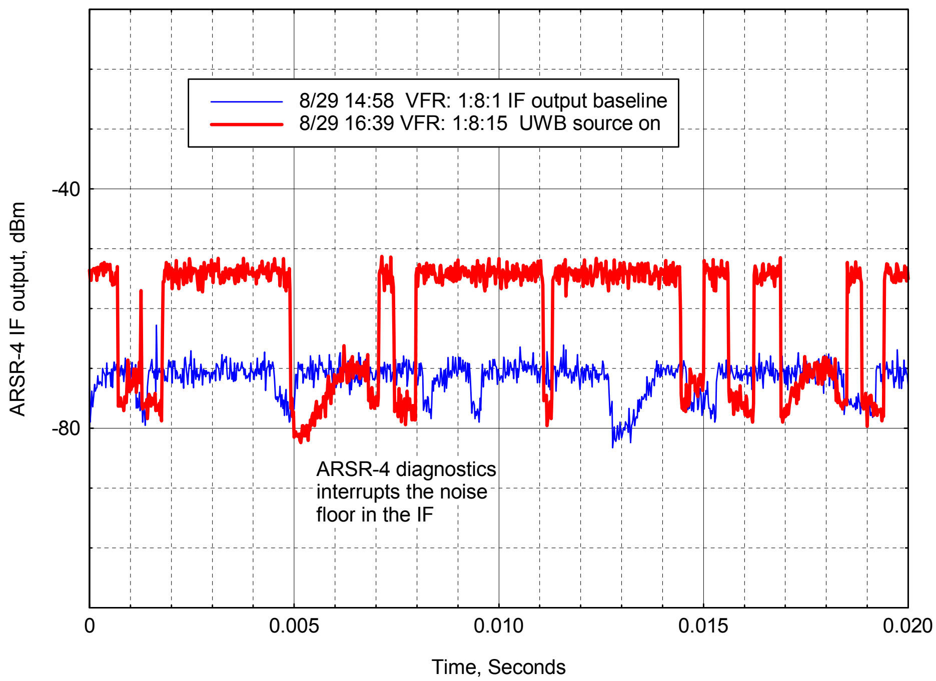


Figure C-3. ARSR-4 IF Output for Baseline Noise Level (UWB Signal off) and UWB Signal on for Site #2 (2.1 km). Peak Detected in 1 MHz Resolution and Video Bandwidth.

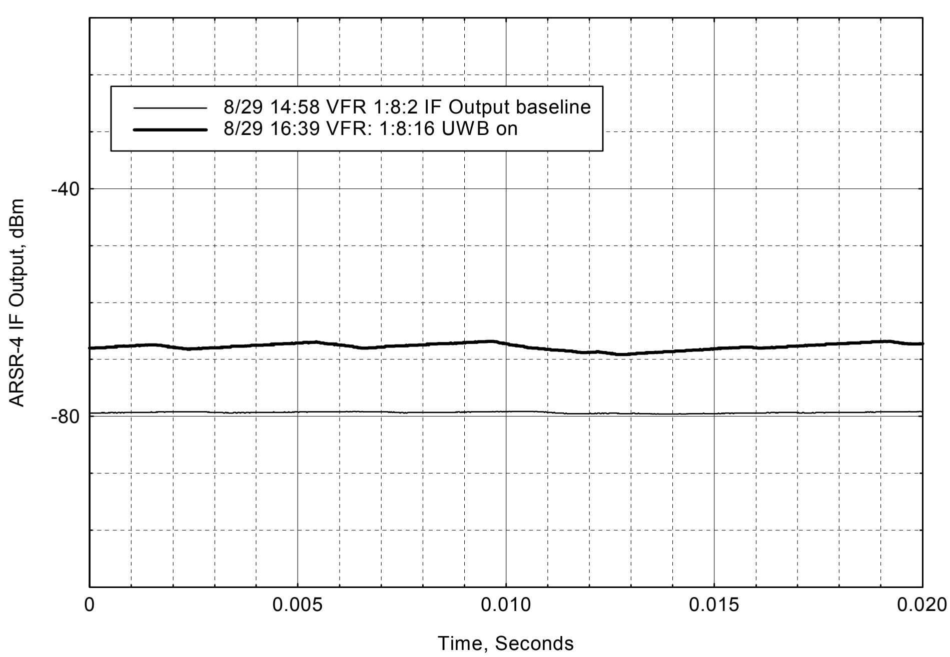


Figure C-4. ARSR-4 IF Output for Baseline Noise Level (UWB signal off) and UWB Signal on for Site # 2 (2.1 km). Peak Detected in 1 MHz Resolution Bandwidth and 10 Hz Video Bandwidth.

C.2.2 Airport Surveillance Radar (ASR-8)

The following is a summary of the closed system and radiated measurements conducted on the ASR-8.

Receiver Characteristics:

1. IF bandwidth = 0.9 MHz (measured)
2. IF Frequency at = 30 MHz (measured)
3. Receiver input noise level = -110 dBm (measured)
4. Receiver noise level at normal channel IF output (TP-9) = -11 dBm (measured)
5. Receiver normal channel saturation level = -80 dBm (measured)
6. Antenna low beam gain = 34 dBi. (obtained from manual)
7. Antenna height = 45 feet (13.71 meters)
8. Antenna tilt angle = 1.5 degrees
9. Receiver front end losses (L_R), = 2.0 dB (estimated)

Radar Measurement Setup:

1. Receiver Channel A (2770 MHz)
2. Monitored normal channel IF output (TP-9)
3. UWB signal injected into low beam (active channel) waveguide. The coupler loss (L_c) = 20 dB (coupler label)
4. Transmitter off
5. Exciter test targets off
6. STC off
7. AGC set to normal
8. Antenna gain on the horizon = 27 dBi (approximate)
9. Location (lat. 35°, 24', 5.2" N /lon. 97°, 37', 17.9", W)

Radiated Measurements:

Site Selection: Measurement sites were selected by observations from the radar antenna platform and by measuring the signal from the ASR-8 using the receiver in the RSMS van. The RSMS van was set up to measure the signal from the ASR-8, and driven in areas around the above estimated distance separations to determined locations where maximum signal levels from the ASR-8 were received. This information was used to select measurement sites to perform radiated measurements using the UWB pulser signal generator. At each selected measurement site the distance was measured using a GPS receiver.

Site Measurements: The radiated measurements were conducted with the radar antenna not rotating, and the antenna pointing at the RSMS van. The RSMS van equipment was set-up as shown in Figure 3, and the attenuator set to produce an EIRP of -41 dBm log-average using the video filtering technique (1 MHz RBW, 10 Hz VBW) for each UWB signal radiated. The following is a summary of the measurement data for each measurement site.

Site #1: The RSMS van was located on Foster Drive (Lat. 35^0 24' 14.2"/Lon. 97^0 37' 26.8"). The site was 0.4 km from the ASR-8 and a bearing of 317^0 on the ASR-8 bearing indicator. The measured UWB signal levels at the ASR-8 receiver IF output were:

A. The 10 MHz PRF dithered UWB signal produced an (I+N)/N ratio of 3.7 dB. An (I+N)/N ratio of 3.7 dB equates to an I/N ratio of 1.2 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 11.2 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -49.7 dBm RMS (-38.5 dBm RMS -11.2 dB).

B. The 10 MHz PRF non-dithered UWB signal produced an (I+N)/N ratio of 4.4 dB. An (I+N)/N ratio of 4.4 dB equates to an I/N ratio of 2.4 dB. Figures C-5 and C-6 show the ASR-8 IF output for the baseline noise level (UWB signal off) and with the UWB signal on for peak detector (RBW and VBW = 1 MHz), and the average signal level using video filtering (RBW = 1 MHz and VBW = 10 Hz), respectively. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 12.4 dB below the EIRP level (-41 dBm RMS -12.4 = -53.4 dBm RMS).

Site #2: The RSMS van was located on MacArthur Boulevard (Lat. 35^0 24' 48.5"/ Lon. 97^0 37' 6.9"). The site was 1.4 km from the ASR-8 at a bearing of 11.5^0 on the ASR-8 bearing indicator. The measured UWB signal levels at the ASR-8 receiver IF output were:

A. The 10 MHz PRF dithered UWB signal produced an (I+N)/N ratio of 1.7 dB. An (I+N)/N ratio of 1.7 dB equates to an I/N ratio of -3.1 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 6.9 dB below the EIRP level. Noting that for a noise-like signal there is a 2.5 dB difference between the log-average and average (RMS) level, the EIRP level is -38.5 dBm RMS. Thus, the EIRP level is -45.4 dBm RMS (-38.5 dBm RMS -6.9 dB).

B. The 10 MHz PRF non-dithered UWB signal produced an (I+N)/N ratio of 2 dB. An (I+N)/N ratio of 2 dB equates to an I/N ratio of -2.3 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 7.7 dB below the EIRP level (-41 dBm RMS - 7.7 dB = -48.7 dBm RMS).

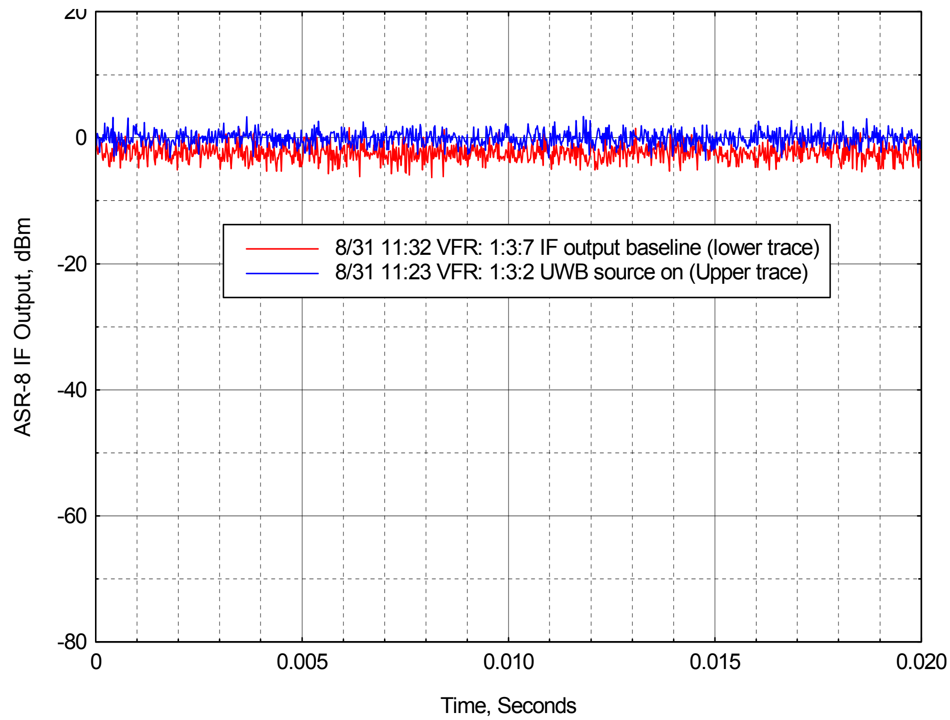


Figure C-5. **ASR-8 IF output for baseline noise level (UWB signal off) and UWB signal on for Site #1 (0.4 km). Peak detected in 1 MHz resolution and video bandwidth.**

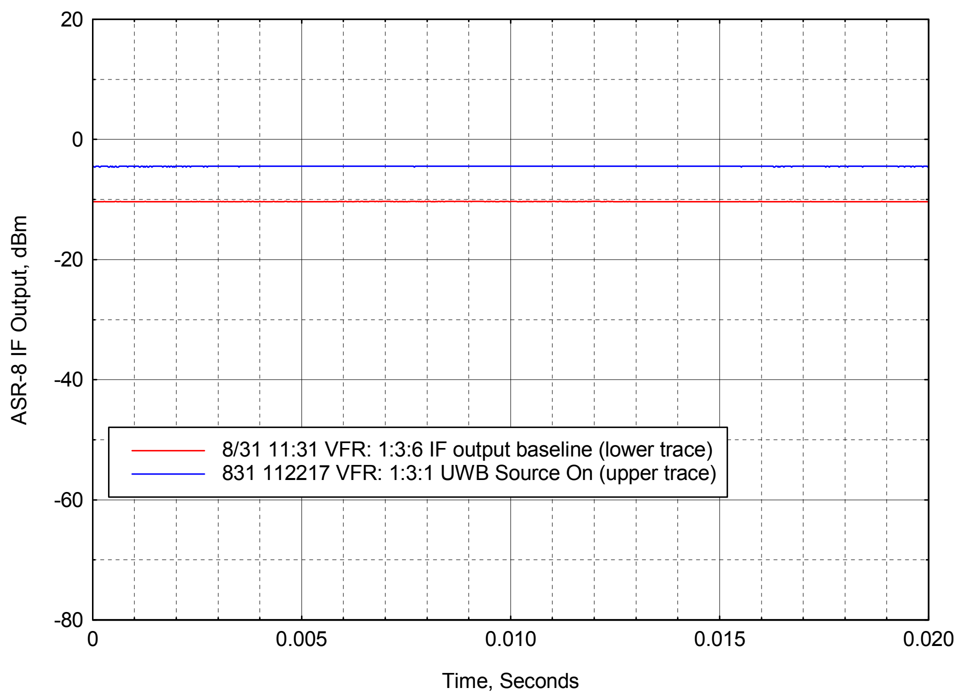


Figure C-6. **ASR-8 IF Output for Baseline Noise Level (UWB Signal Off) and UWB Signal on for Site #1 (0.4 km). Peak Detected with 1 MHz Resolution Bandwidth and 10 Hz Video Bandwidth, RMS Noise Level.**

Incidental Radiator Measurements: At each of the measurement sites an electric drill, electric razor and hair dryer were radiated to see if they could be observed at the ASR-8 IF output. None of the incidental radiators were observed at the radar IF output from Site 1 or 2.

C.2.3 ATCBI-5

The following is a summary of the closed system and radiated measurements conducted on the ATCBI-5 beacon associated with the ARSR-4. It should be noted that these measurement results may not be representative of an ATCBI-5 beacon associated with ASRs since the antenna is a different type.

Receiver Characteristics:
1. IF bandwidth = 8.9 MHz (measured)
2. IF Frequency at TP1 = 60 MHz (measured)
3. Receiver input noise level = -102 dBm (calculated)
4. Receiver noise level at IF output (TP1) = -64.5 dBm (measured)
5. Antenna main beam gain = 26 dBi (obtained from manual)
6. Antenna main beam gain on the horizon = 23 dBi (obtained from manual)
7. Antenna height = 100 feet (30.48 meters)
8. Receiver front end losses (L_R), = 2.0 dB (estimated)

Radar Measurement Setup:
1. Receiver Channels A and B(1090 MHz)
2. Monitored IF output (TP1)
3. UWB Signal injected at receiver input coupler through a filter (coupler loss (L_c) = 30 dB)
4. Transmitter output dumped into a dummy load to stop interrogations
5. Adjustment made to minimize off time (dead time)
8. STC turned off
7. Location (lat. 35°, 24', 12.8" N /lon. 97°, 37', 44.2" W)

Note: Limited measurements were made observing the affects of CW-like interference to the ATCBI-5 radar. It was determined that CW-like interfering signals reduce the receiver gain. A 10 MHz non-dithered signal produced a CW-like signal at the receiver IF output.

Radiated Measurements:

Site #1: The RSMS van was located on Halaby Drive at the TDWR site (Lat.35^0 23' 31.8"/Lon.97^0 37' 41.4"). The site was 1.26 km from the ATCBI-5 and a bearing of [179.5^0] on the ATCBI-5 bearing indicator. The UWB signal was not observed at the ATCBI-5 IF output for either the UWB dithered or undithered signal.

Site #2: The RSMS van was located on Halaby Drive at (Lat.35^0 23' 56.8"/Lon.97^0 37' 42.7"). The site was 0.5 km from the ATCBI-5, and at a bearing of 181^0 on the ARSR-4 bearing indicator. The measured UWB signal levels at the ATCBI-5 receiver IF output were:

A. The 10 MHz PRF dithered UWB signal was not observed at the receiver IF output.

B. The 10 MHz PRF non-dithered UWB signal produced an (I+N)/N ratio of 0.7 dB. An (I+N)/N ratio of 0.7 dB equates to an I/N ratio of -7.6 dB. For a protection criteria of I/N = -10 dB, it would be necessary to limit the emission from UWB devices to 2.4 dB below the FCC Part 15 limit (-43.7 dBm).

Incidental Radiator Measurements: At each of the measurement sites and an additional site, 50 ft. on the ground from the antenna tower, an electric drill and razor were radiated to see if they could be observed at the ATCBI-5 IF output. The electric drill and razor were not detected at any of the measurement sites.

C.3 SUMMARY OF FINDINGS

The following is a summary of the findings from measurements conducted at Oklahoma City, OK. Since the measurements were conducted at a limited number of measurement sites (distances from the radars), specific radar system configurations (antenna height and tilt angle), UWB antenna height and specific local terrain environment, the findings given below should not be taken as representative conditions that will ensure protection of the radar systems.

1. The measurements indicate that the potential for interference to ARSRs and ASRs from UWB devices can occur in an annular ring around each radar. The distance to the angular ring and the diameter of the angular ring depends on the antenna height, antenna pattern and the antenna vertical tilt angle. The antenna gain elevation pattern is key in performing an EMC analysis.

2. The measurements made on the ASR-8 radar may not be representative of the potential for interference to the new generation Doppler type radars (ASR-9 and ASR-11). The Doppler radars, which process out ground clutters, may have higher antenna gain levels on the horizon. It was noted that the ASR-8 had an antenna vertical tilt angle of +1.5^o and the ASR-9 had an antenna vertical tilt angle of only +0.5^o.

3. The ATCBI-5 measurements were conducted on the enroute radar ARSR-4. The ATCBI-5 antenna on the ARSR-4 may have different elevation gain characteristics than the ATCBI-5 antennas on the ASRs. Also, the antenna heights of the ASRs may be lower than the ARSRs. Therefore, the measurements on the ATCBI-5 assessing the potential for interference from UWB devices may not be worst case.

4. The ATCBI-5 radar has a 10 dB higher noise level and lower antenna gain than the ARSR-4 and ASR-8 radars. Therefore, the UWB signal levels only exceeded the protection criteria of -10 dB by one dB.

5. Measurements conducted on the ARSR-4 and ATCBI-5 showed that CW-like interference can cause a reduction in the receiver gain. Therefore, in addition to an increase in the receiver noise floor, the desired target levels may be affected. This degradation mechanism was not investigated.

7. Measurements on the potential for interference from incidental radiator devices (electric drill, electric razor and hair drier) to the ARSR-4, ASR-8 and ATCBI-5 showed that only the electric razor could be observed above the ARSR-4 system noise level at the IF output. However, the receiver noise level at the IF output was observed and there was no increase in the noise level at the IF output due to the electric razor. Therefore, the measurements indicate that the RMS emission level of the electric razor is significantly less that the RMS emission levels of the UWB characteristics used in the measurements.

APPENDIX D

PEAK POWER IN A 50 MHz BANDWIDTH

D.1 INTRODUCTION

The following is a discussion of the peak power of a UWB signal in a receiver 50 MHz IF bandwidth to average (RMS) power in a 1 MHz reference bandwidth. The FCC proposed in the UWB NPRM that the peak power limit be based on a 50 MHz bandwidth.[107] The receiver transfer properties for both non-dithered and dithered UWB signals in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth as a function of the UWB signal PRF are provided. It is assumed that the UWB device emission bandwidth is greater than 50 MHz and uniform across the receiver bandwidth. Also, the calculations do not include any additional peak power factor for gated UWB signals.

The following equations given below were developed based on measurements and simulations contained in the ITS Report.[108]

D.2 PEAK POWER BWCF TRANSFER PROPERTIES FOR NON-DITHERED UWB SIGNALS

For non-dithered UWB signals, the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz can be calculated using Equations 3-9 through 3-12 in Section 3 of this report. The peak power BWCF equations for non-dithered UWB signals are provided below.

For $B_{IF} \leq 0.45$ PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 0, \quad \text{for } B_{IF} \leq 0.45 \text{ PRF and } B_{Ref} < \text{PRF} \qquad \text{(D-1)}$$

$$BWCF_P = 10\log(\text{PRF}/B_{Ref}), \quad \text{for } B_{IF} \leq 0.45 \text{ PRF and } B_{Ref} \geq \text{PRF} \qquad \text{(D-2)}$$

For $B_{IF} > 0.45$ PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 20\log_{10}(B_{IF}/0.45\times\text{PRF}), \quad \text{for } 0.45 \text{ PRF} \leq B_{IF} < 1/T \text{ and } B_{Ref} < \text{PRF} \qquad \text{(D-3)}$$

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2\times B_{Ref}\times\text{PRF})], \quad \text{for } 0.45 \text{ PRF} \leq B_{IF} < 1/T \text{ and } B_{Ref} \geq \text{PRF} \qquad \text{(D-4)}$$

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[107] *See* UWB NPRM, *supra* note 2, at ¶ 42.

[108] *See* ITS Report, *supra* note 14, at Section 8, Appendix B and D.

D.3. PEAK POWER BWCF TRANSFER PROPERTIES FOR DITHERED UWB SIGNALS

The analytical approach used in the UWB analysis report considers that when the UWB time waveform response at the receiver IF output is noise-like an average signal power level is used in assessing receiver performance degradation. Therefore, for dithered UWB signals, the BWCF equations in Section 3 for peak power are not directly applicable for determining the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth. Recognizing that for Gaussian noise, the peak to average (RMS) power ratio is 10 dB.

For $B_{IF} \leq$ 2.0 PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 10 + 10\log_{10}(B_{IF}/B_{Ref}), \quad \text{for } B_{IF} \leq 2.0 \text{ PRF} < 1/T \text{ and } B_{Ref} = \text{Any value} \qquad \text{(D-5)}$$

For B_{IF} > 2.0 PRF, the peak power $BWCF_P$ can be expressed as:

$$BWCF_P = 10\log_{10}[B_{IF}^2/(0.2\times B_{Ref}\times PRF)], \quad \text{for } B_{IF} > 2.0 \text{ PRF} < 1/T \text{ and } B_{Ref} = \text{any value} \qquad \text{(D-6)}$$

NOTE: For the above equations, the receiver IF bandwidth (B_{IF}), UWB signal PRF, and measurement reference bandwidth (B_{Ref}) values are in MHz.

D.4 SUMMARY DISCUSSION OF PEAK POWER IN A 50 MHz BANDWIDTH

Figure D-1 shows the peak power in a 50 MHz bandwidth (B_{IF} = 50) to the average (RMS) power in a 1 MHz bandwidth (B_{Ref} = 1) for both non-dithered and dithered UWB signals and a range of PRFs based on the above equations. The FCC has proposed a 50 MHz reference bandwidth for establishing the peak power limit, and a 20 dB limit on the peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth.[109] From Figure D-1, for non-dithered UWB signals, a 20 dB peak power limit would restrict the UWB signal PRF to greater than 11.1 MHz. For dithered UWB signals, the lowest achievable peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth is 27 dB, and occurs for UWB signal PRFs equal to or greater than 25 MHz. Therefore, for dithered UWB signals, a 20 dB limit of peak power in a 50 MHz bandwidth to average (RMS) power in a 1 MHz bandwidth is not achievable. For a 30 dB peak limit, the PRF of non-dithered UWB devices would be limited to greater than 3.5 MHz, and the PRF of dithered UWB devices would be limited to greater than 12.5 MHz.

[109] The measurement procedure the FCC uses for average power for Part 15 compliance is an average logarithmic value. The analysis contained in this appendix uses an average (RMS) power level.

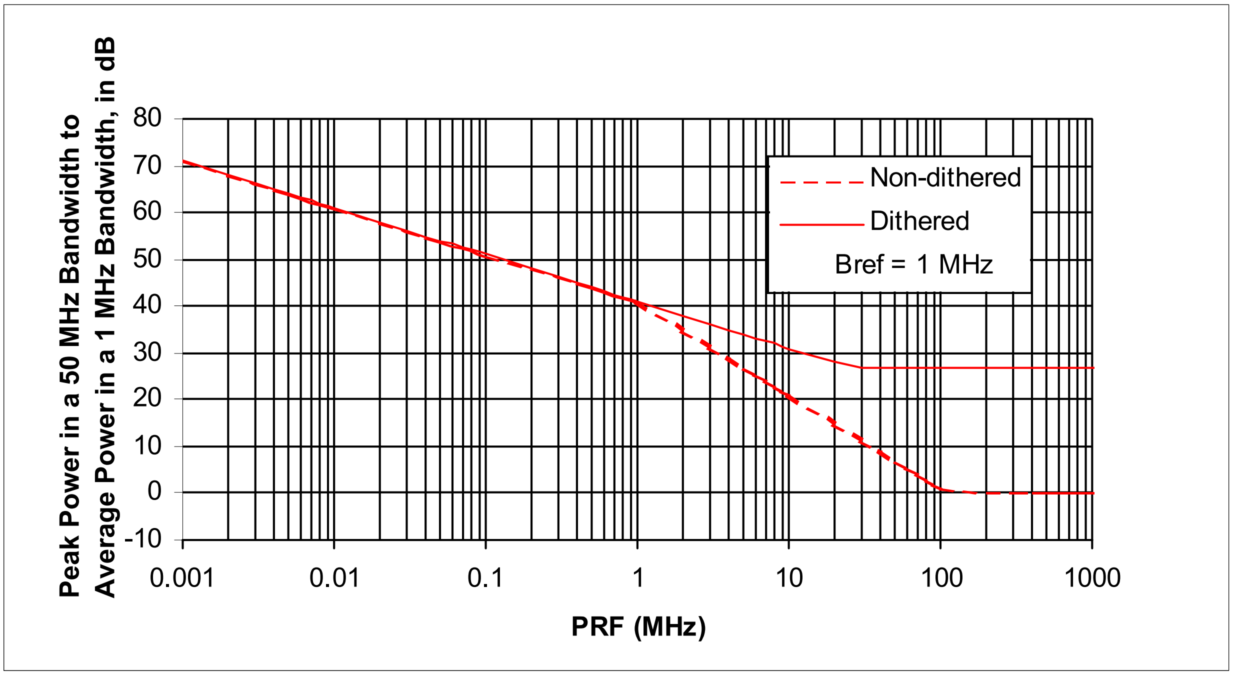

Figure D-1. Peak Power in a 50 MHz Bandwidth to Average (RMS) Power in a 1 MHz Bandwidth as a Function of UWB Signal PRF.

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