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.

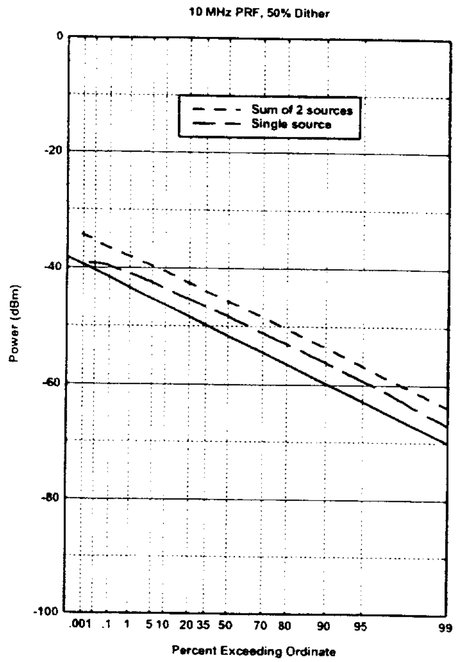

Figure 5.2-1. Aggregate Case 1

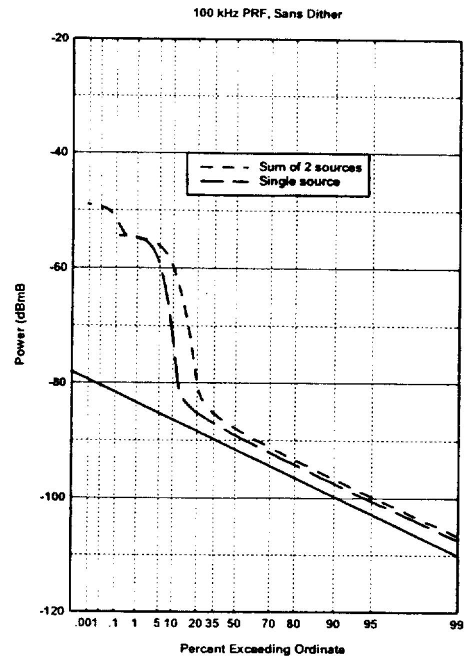

Figure 5.2-2. Aggregate Case 2

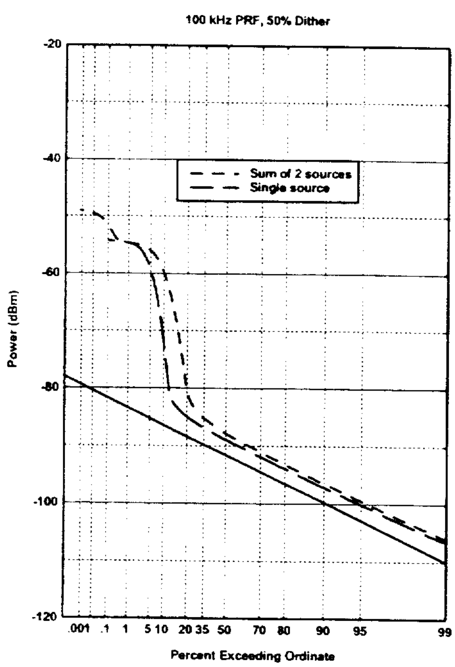

Figure 5.2-3. Aggregate Case 3

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 $K^{-1/2}$ 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.

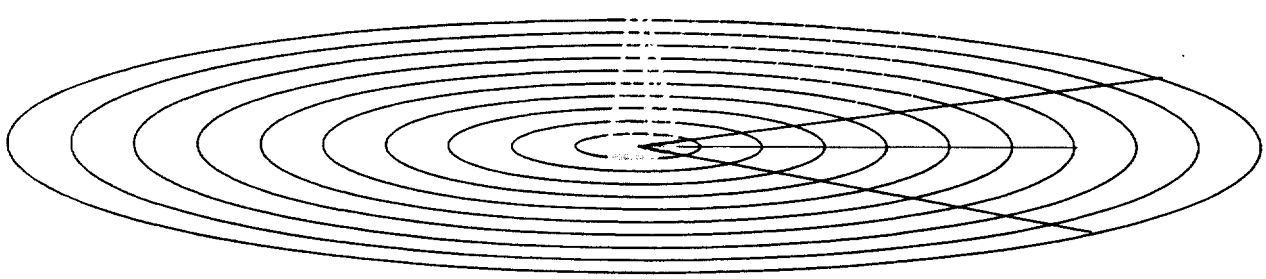

Figure 5.3.1

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

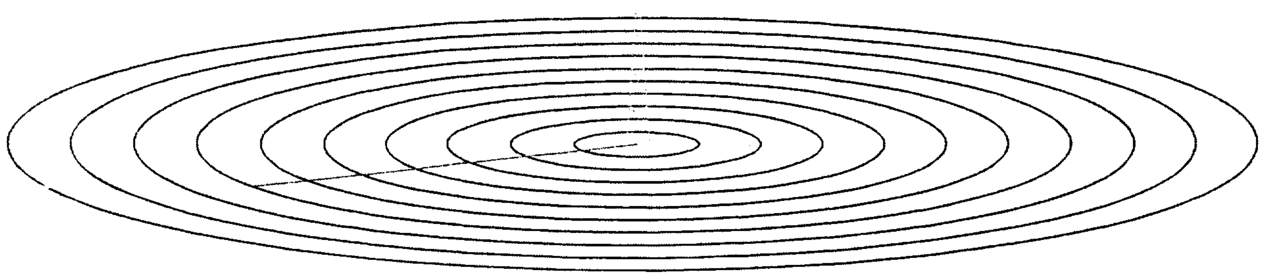

Figure 5.3.2

[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.

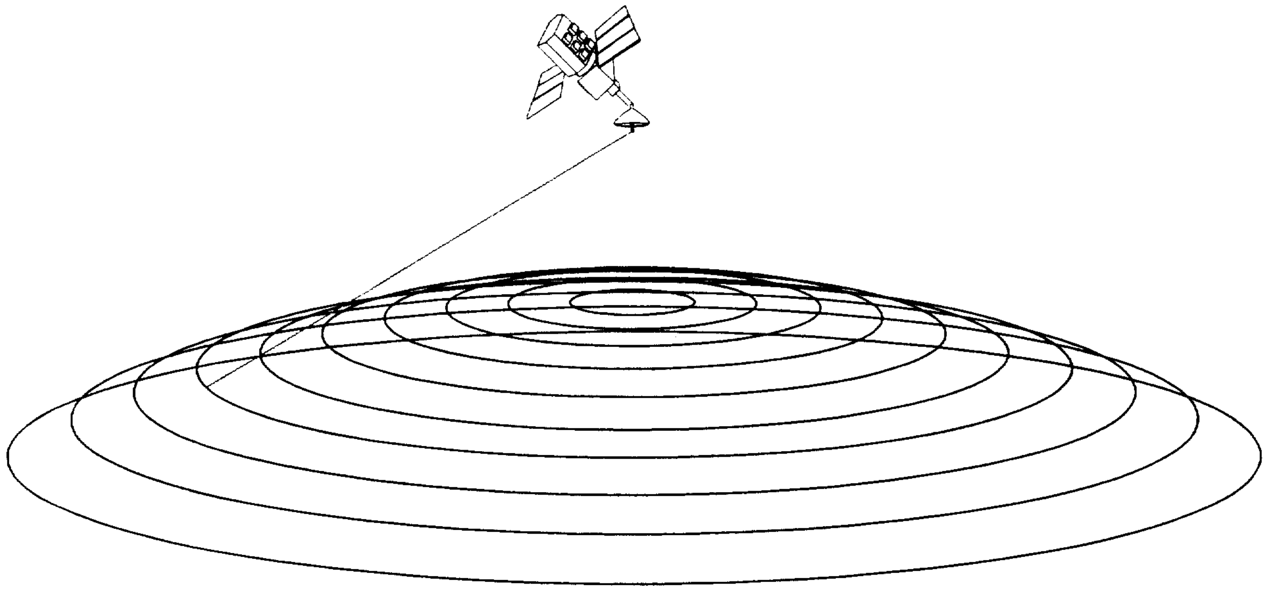

Figure 5.3.3.

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

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

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.

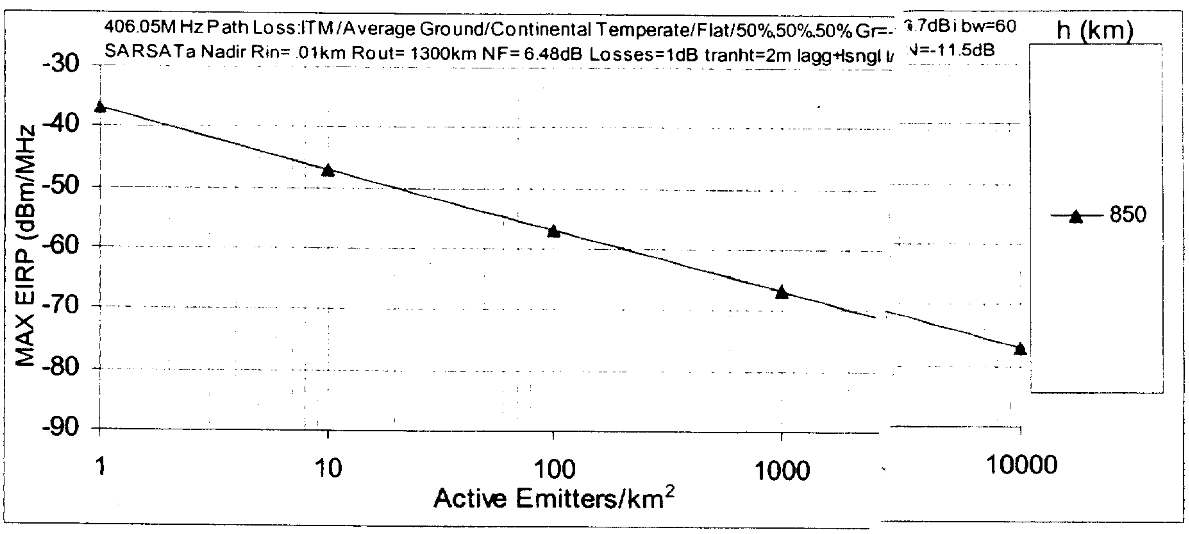

Figure 5.5.1 SARSAT Uplink

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.

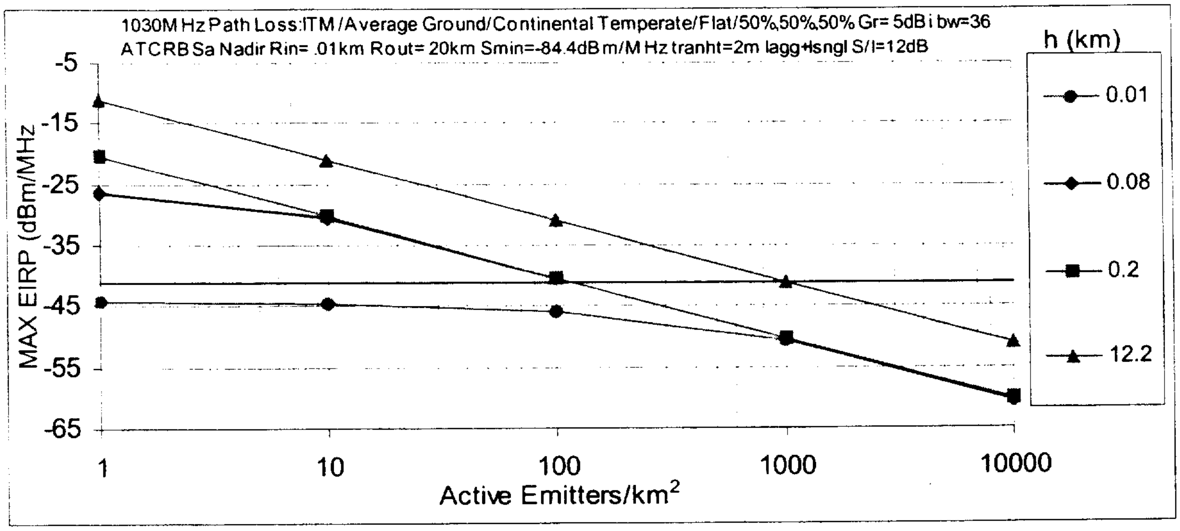

Figure 5.5.2 ATCRBS (Airborne Transponder)

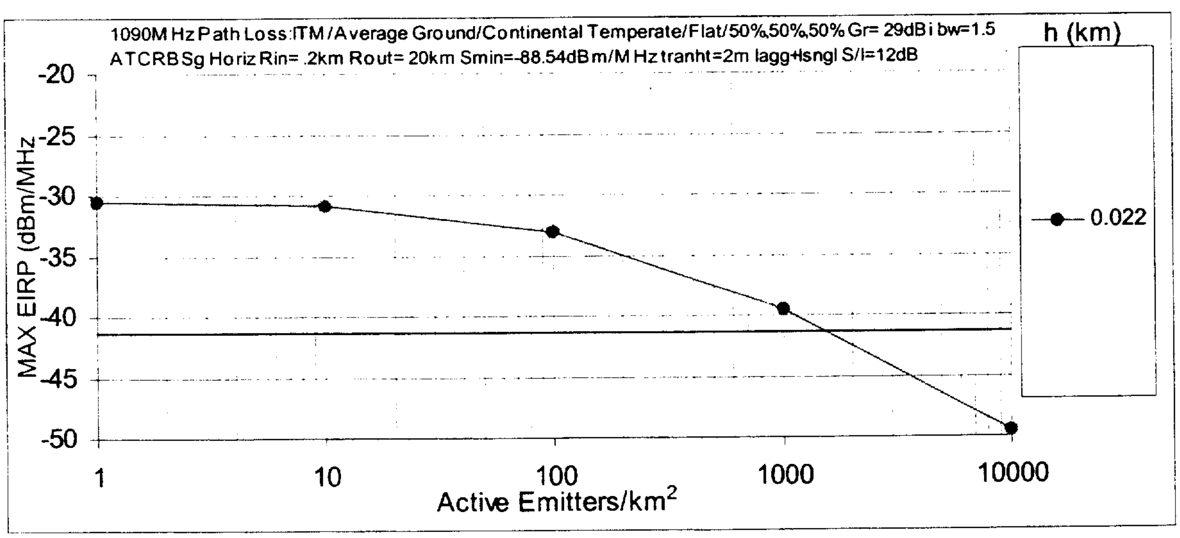

Figure 5.5.3 ATCRBS (Ground Interrogator)

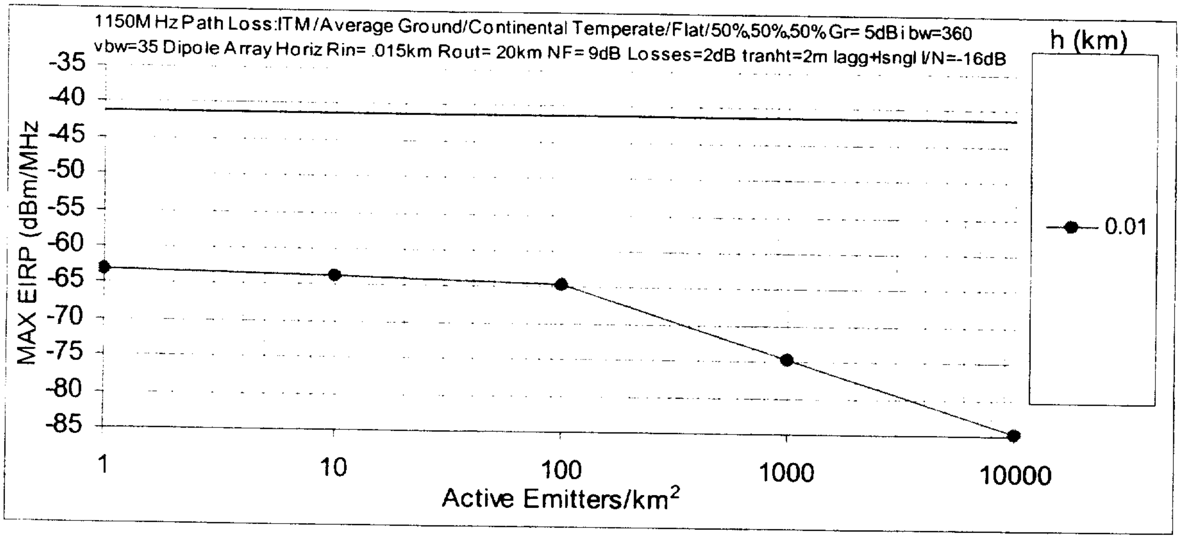

Figure 5.5.4 DME (Ground Transponder)

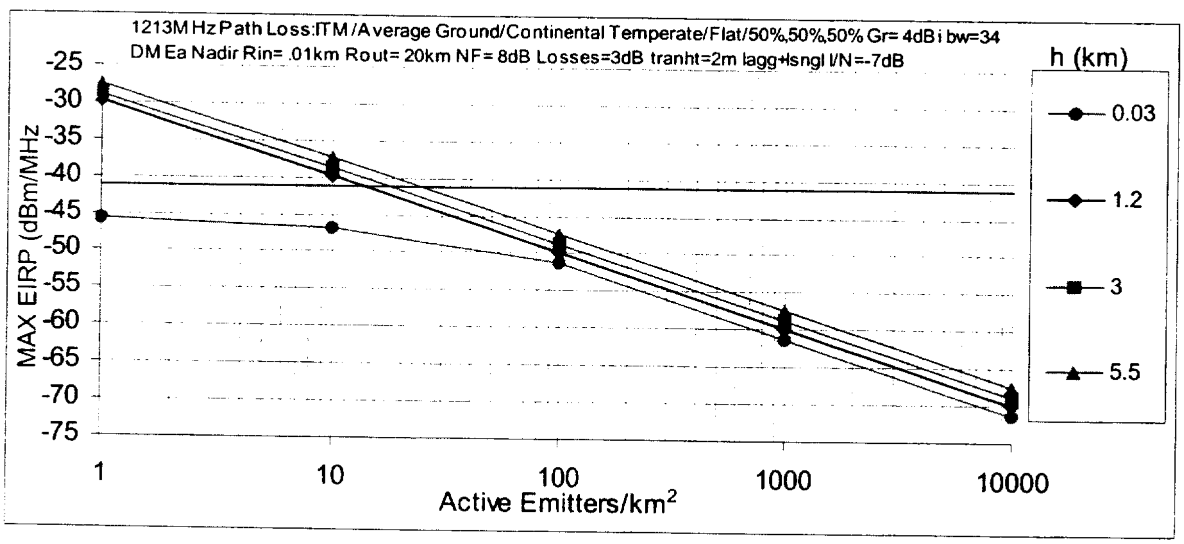

Figure 5.5.5 DME (Airborne Interrogator)

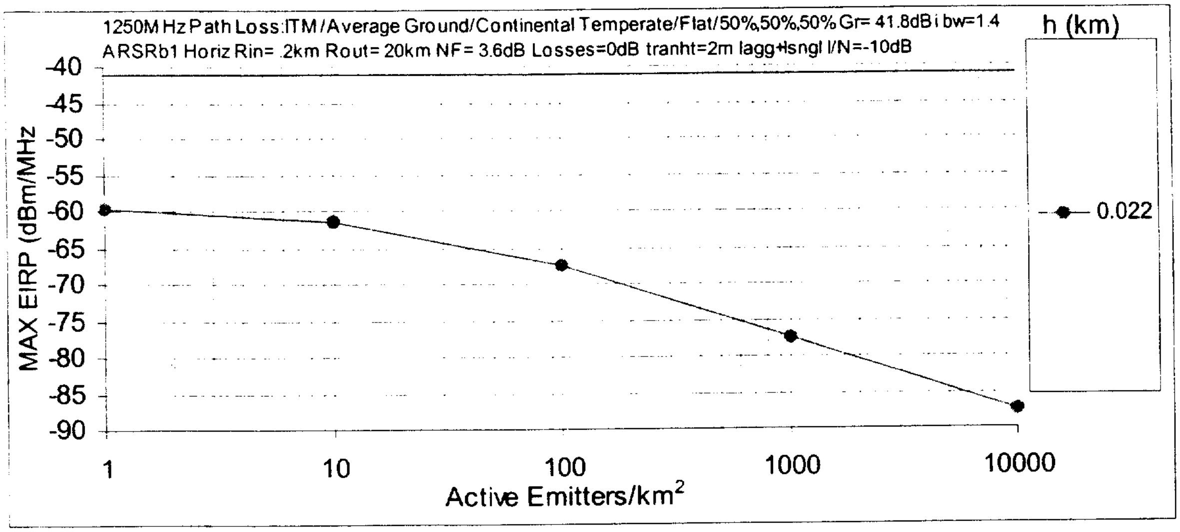

Figure 5.5.6 ARSR-4

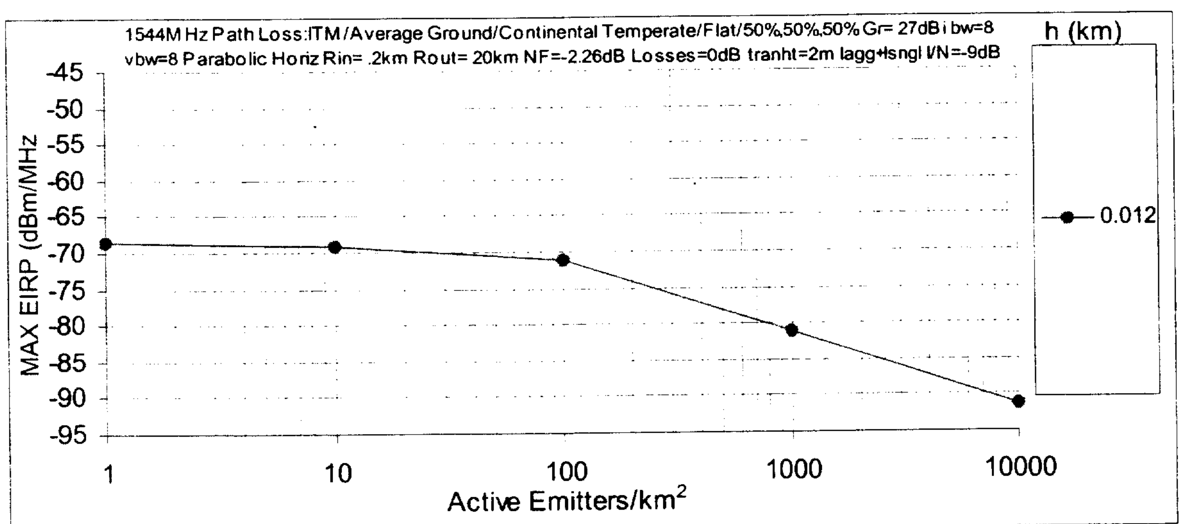

Figure 5.5.7 SARSAT LUT Downlink

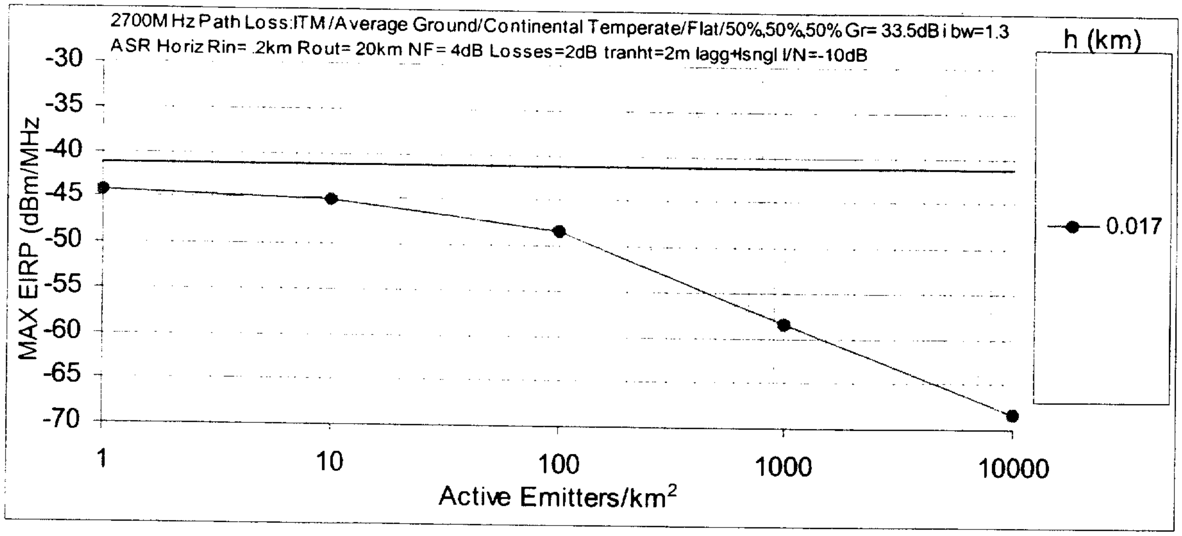

Figure 5.5.8 ASR-9

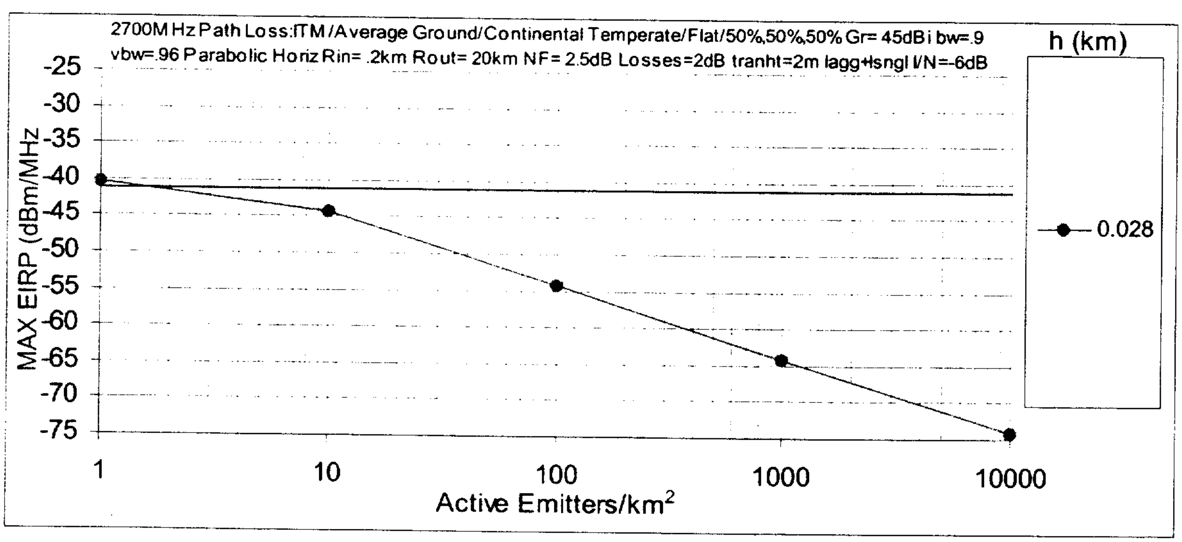

Figure 5.5.9 NEXRAD

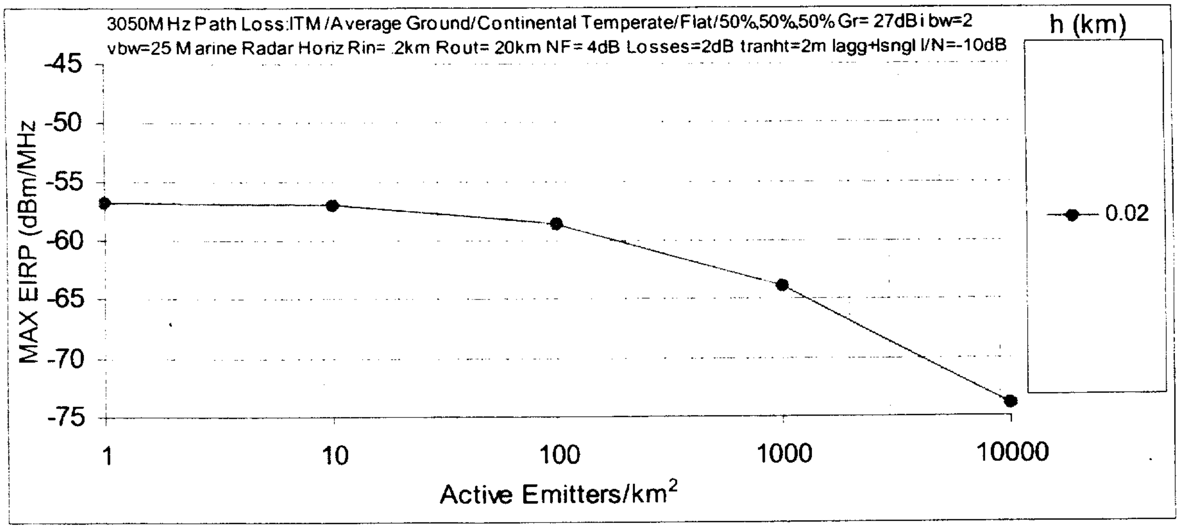

Figure 5.5.10 Marine Radar

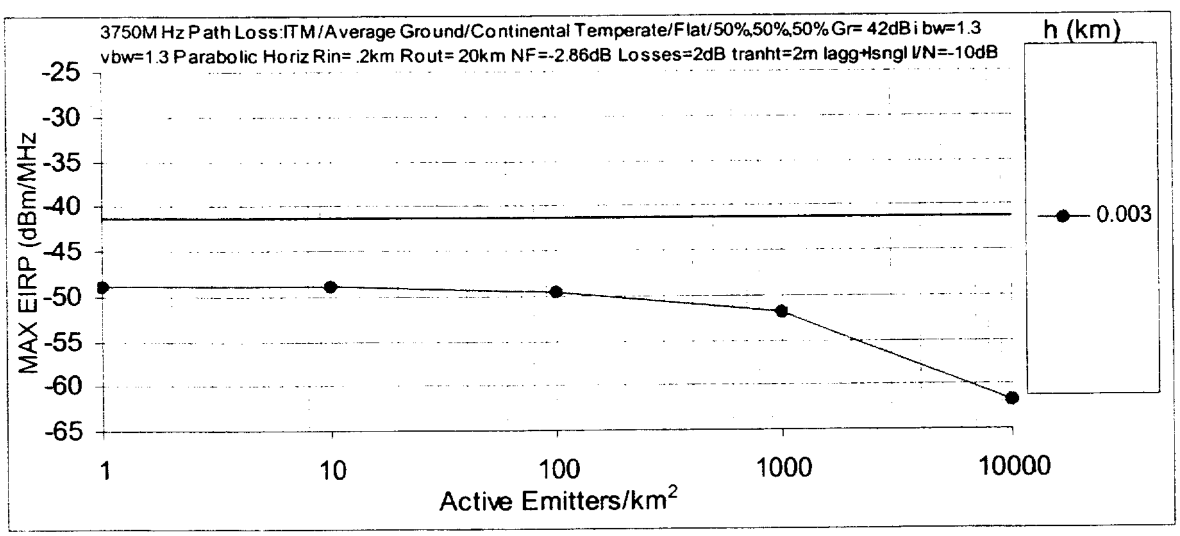

Figure 5.5.11 Fixed Satellite Earth Station (5° elevation tilt).

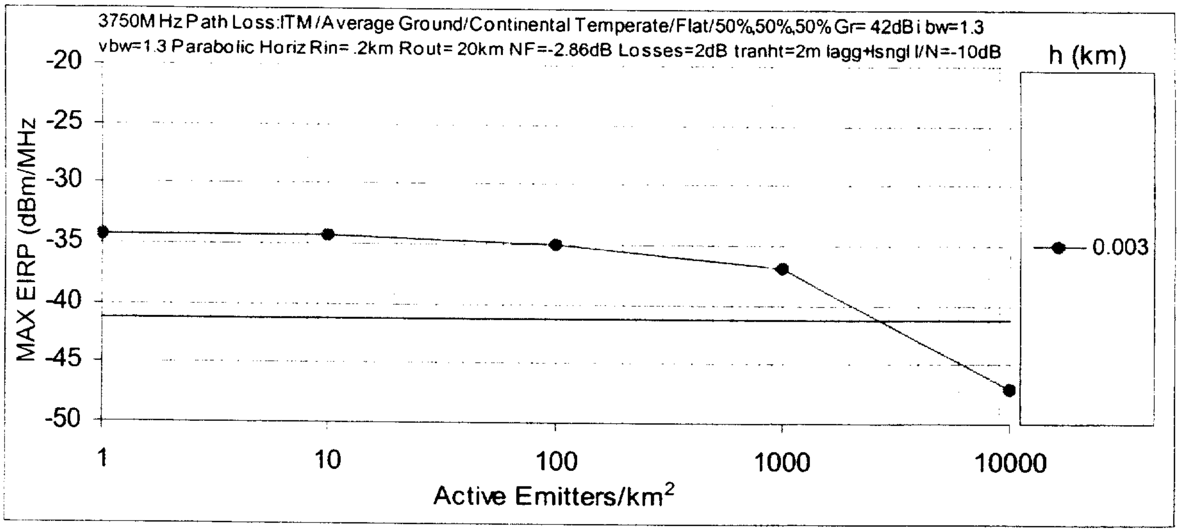

Figure 5.5.12 Fixed Satellite Earth Station (20° elevation tilt).

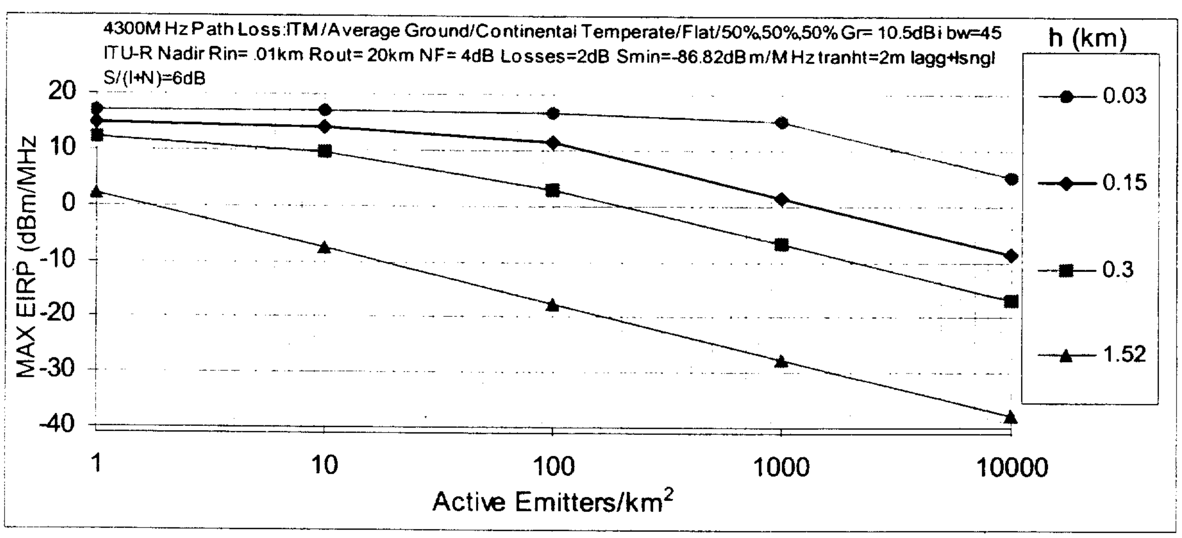

Figure 5.5.13 Radar Altimeter (Pulsed).

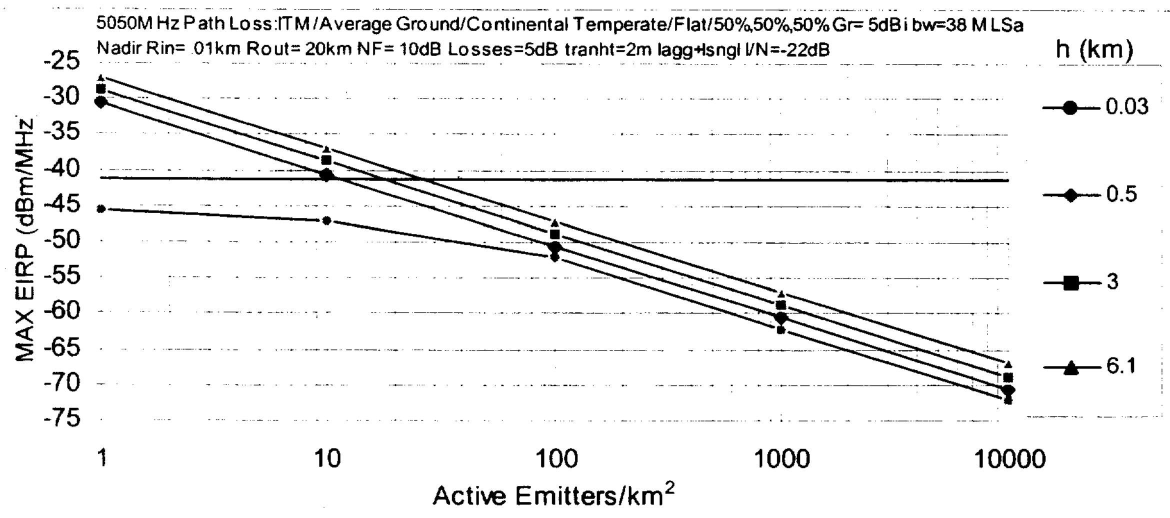

Figure 5.5.14 Microwave Landing System (Airborne)

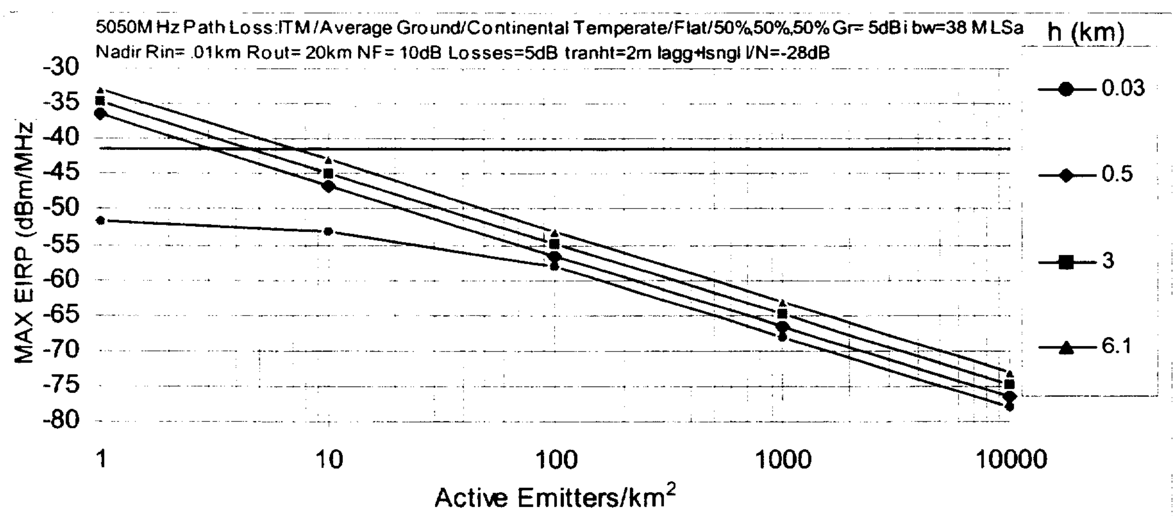

Figure 5.5.15 Microwave Landing System (Airborne).

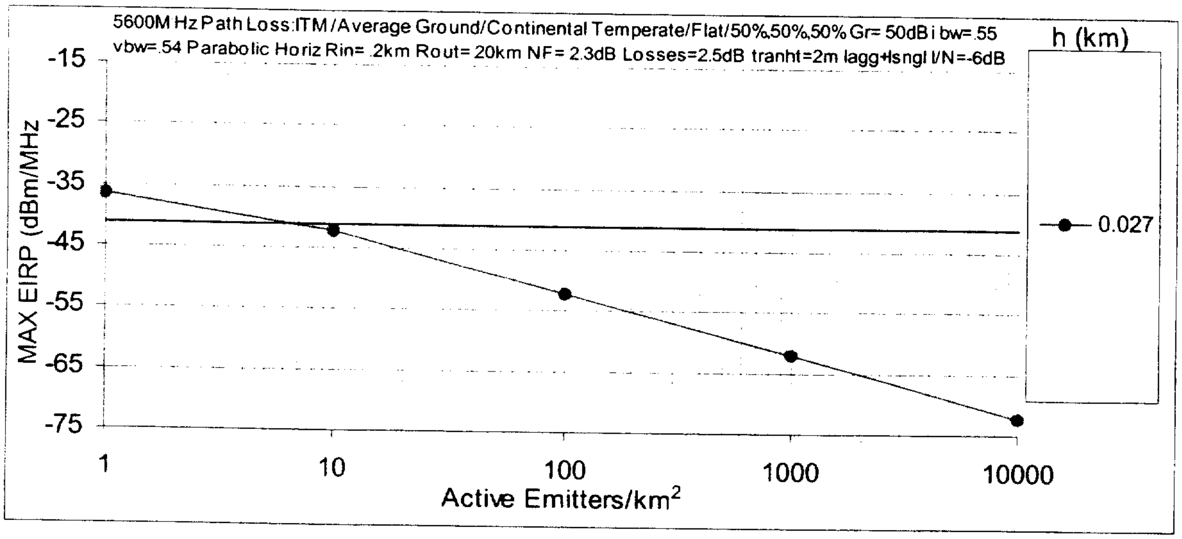

Figure 5.5.16. TDWR

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/km²)	UWB Emitter Density Where Permitted EIRP Equals -41.3* dBm/MHz RMS (units/km²)
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).

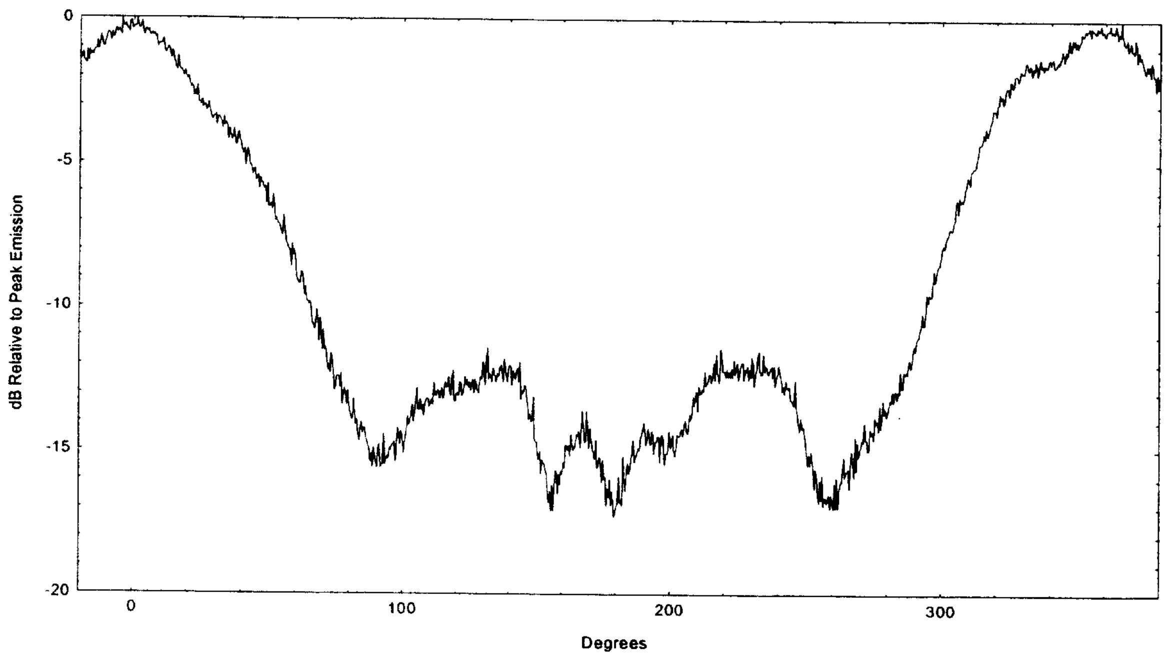

Figure 5-6-1. Example of Directional UWB Antenna Pattern

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.