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May 7, 2001

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
The Portals, TW-A325
445 12th Street, SW
Washington, DC 20554

Re: ***Errata to GPS Comments*** **- ET Docket No. 98-153**
Ultra-Wideband (UWB)

Dear Ms. Salas:

Time Domain Corporation's (TDC's) April 25, 2001, Comments and April 26, 2001 Errata to Comments filed in response to the Commission's Request for Comments on Five Reports Addressing Potential Interference from Ultra-Wideband Transmission Systems contained errors caused by computer formatting problems.

1. Some of the cross-referenced entries in Table 6, which provides a summary of the results presented in Tables 8 through 15, were incorrect, and

2. the two cross-references in the "Comment" column of Table 7 stating "See Section 0" have been corrected.

A complete copy of the filing with corrections is attached. Please note that the following additions to the document were made. In the document section discussing the NTIA terrestrial scenarios, text was added to explain why TDC used different values for the L_{veg} parameter. Also, to aid in double-sided printing of the document, two blank pages have been added – one following the cover page and one following the Executive Summary.

Should any questions arise concerning this errata filing, please do not hesitate to contact me.

Sincerely,

<u>*submitted electronically*</u>
Paul Withington
Vice President

Att.

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Before the
Federal Communications Commission
Washington, DC 20554

In the Matter of Revision of Part 15 of the FCC's Rules Regarding Ultra-wideband Transmission Systems	ET Docket 98-153

Comments of Time Domain Corporation

In Response to the Request for Comments on
Five Reports Addressing Potential Interference from
Ultra-Wideband Transmission Systems
in Public Notice DA 01-753, March 26, 2001

Revised May 7, 2001

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April 25, 2001

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Executive Summary

The studies examining the possible interaction of global positioning satellite (GPS) transmissions and ultra-wideband (UWB) signals show that UWB devices employing pulse position modulation resulting in white noise-like signals can be authorized at the general limits set forth in Part 15 of the Commission's Rules without jeopardizing GPS services. The Johns Hopkins University Applied Physics Lab (JHUAPL) analysis of the data acquired during testing conducted by the University of Texas Advanced Research Lab (UTARL), the Stanford University/Department of Transportation study, and the NTIA GPS report all supply data that are, in large part, similar.

The fact that testing examining the effect of white noise-like emissions on GPS receivers conducted by engineers and scientists yielded similar data is hardly remarkable. The key points on which the Commission should focus extend far beyond the basic data. The challenge is to understand the assumptions that went into the analytical modeling in which the data were used. Accordingly, these reports differ, notably, in the conclusions they draw from analysis of the data.

In the following Comments, Time Domain Corporation (TDC) shows that the different conclusions reached in these studies rest in large measure upon certain assumptions as to what should be deemed to constitute *harmful interference.* Both NTIA and Stanford assumed unrealistic operational scenarios and employed mathematical modeling to reach erroneous conclusions dependent on the flawed underlying assumptions. In contrast, JHUAPL was able to draw upon the results of testing at UTARL that included both outdoor radiated testing in conjunction with controlled indoor testing as well as extensive simulations that validated the experimental. As a result, JHUAPL was able to provide the Commission with several operational GPS Measures of Performance (MOPs) that will aid the agency in assessing the likely interaction of GPS and UWB in real world environments.

All of the reports showed that with white noise-like UWB signals, the interactions with GPS signals are predictable given the extensive body of knowledge that reflects the effects of white noise on GPS signals. The UWB implementation that TDC has developed is like white noise. When realistic propagation models and deployment scenarios are considered, the reports support the conclusion that UWB signals that appear much like white noise can be authorized at the Part 15 general limits without posing a risk of harmful interference to GPS.

These comments also address the report from Qualcomm that discusses the possible interaction of UWB signals with CDMA Personal Communications Service (PCS) operations. As with the NTIA and Stanford analyses, the Qualcomm report also suffers from the use of unrealistic assumptions as to the level of PCS transmissions that can provide reliable service, and the nature and level of UWB energy that can be assumed to interact with a PCS phone. When realistic deployment and operational scenarios are used, it is clear that white noise-like UWB operations can be implemented at the general Part 15 limits without causing harmful interference to PCS operations.

TDC urges the Commission to complete the analysis of the extensive record in this proceeding responding to the agency's comprehensive Notice of Proposed Rule Making in order that rules can be implemented to bring the benefits of UWB technology to the American public on an unlicensed Part 15 basis.

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Before the
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In the Matter of Revision of Part 15 of the FCC's Rules Regarding Ultra-wideband Transmission Systems	ET Docket 98-153

Comments of Time Domain Corporation

I. Introduction

Time Domain Corporation (TDC) respectfully submits these comments in response to the FCC Request for Comments on five reports assessing the potential for Ultra-Wideband (UWB) systems to cause harmful interference to Personal Communications Services (PCS) telephones and Global Positioning System (GPS) receivers.[1] The University of Texas Advanced Research Laboratory (UTARL) submitted a report entitled "Final Report: Data Collection Campaign for Measuring UWB/GPS Compatibility Effects" (hereinafter the "UTARL Report"); Johns Hopkins University Applied Physics Laboratory (JHUAPL) submitted a report addressing the interference potential to GPS Receivers entitled: "Final Report: UWB-GPS Compatibility Analysis Project" (hereinafter the "JHUAPL Report") which analyzed the data collected as described in the UTARL Report; NTIA submitted a report entitled "Assessment of Compatibility Between Ultrawideband Systems and Global Positioning System (GPS) Receivers" (the "NTIA Report"); Stanford University and the Department of Transportation submitted test results in two phases entitled "Potential Interference to GPS from UWB transmitters" (the "Stanford Report"); and Qualcomm submitted a report addressing interference potential to the operation of PCS telephones (the "Qualcomm Report"). In these comments, TDC provides a detailed technical analysis of each report.

Each of the GPS and PCS analysis reports offers the basis for authorization of UWB devices on a Part 15 basis. In these comments, TDC will show that the data from all three GPS Reports exhibit the same trends, and that the differences in conclusions reached in the three reports stem from mathematical assumptions made by both NTIA and Stanford regarding the definition of harmful interference and other parameters. Once these different mathematical assumptions are adjusted to reflect the real world operating conditions of both GPS and UWB and adjusted to be consistent with FCC decisions in related proceedings, it will be clear that a properly designed UWB signal operating at Part 15 power levels will not cause harmful interference to GPS systems.

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[1] *See* Comments Requested on Reports Addressing Potential Interference from Ultra-Wideband Transmission Systems, DA 01-753, ET Docket No. 98-153 (Mar. 26, 2001).

II. Unlicensed Devices Regulated Under Part 15 May Not Cause Harmful Interference.

Part 15 of the Commission's rules states that unlicensed device operation "is subject to the conditions that no harmful interference is caused."[2] The term "harmful interference" has been part of the FCC and NTIA's spectrum management lexicon for decades. For a device to be considered to cause harmful interference, the FCC asserts that the device must cause "interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service." NTIA's own definition tracks closely this FCC definition, and the NTIA/ITS website glossary adds that harmful interference "must cause serious detrimental effects, such as circuit outages and message losses, as opposed to interference that is merely a nuisance or annoyance that can be overcome by appropriate measures."

The Commission has repeatedly applied its clear definition of harmful interference in a number of service specific instances.[3] In each instance, the agency has offered sound guidance as to the contours of what is and what is not harmful interference, and has made clear that harmful interference must result in serious degradation of service.[4]

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2 47 C.F.R. § 15.5(b).

3 *See* TDC Comments at 5-7, 9-13 (Feb. 23, 2001) and at 1-3 (Mar. 12, 2001).

4 *See id.*

The results presented in the NTIA and Stanford Reports were based solely on receiver protection criteria and bear no direct relation to harmful interference. On the other hand, the analysis conducted by JHUAPL (based on the UTARL data) focused upon the concept of harmful interference as a function of the "detrimental effects" to the GPS receiver versus UWB transmitter distance from the GPS receiver. In analyzing the UTARL data, JHUAPL aimed to provide the Commission with information to develop a definition of harmful interference for UWB-GPS interaction based on the actual operational impact of UWB and other Part 15 devices upon a GPS receiver.

Throughout this proceeding TDC has lauded the Commission's recognition of the critical role that Part 15 general levels serve in defining spectrum policy. These levels, which work hand-in-hand with the guiding principle of "harmful interference," have increased the value of spectrum use by enabling the peaceful coexistence of overlapping signals and emissions from licensed and unlicensed devices.

III. An Overview of the GPS Testing Efforts As They Relate to Harmful Interference

A. NTIA

It should be noted that NTIA stated that their "primary objective of this study is to define maximum allowable UWB equivalent isotropically radiated power (EIRP) levels that can be tolerated by GPS receivers, when used within various operational applications, without causing degradation to GPS operations." This is interesting to note because the analysis was to determine degradation which equates to "can the GPS receiver see some effect, however minimal" rather than an analysis to determine what level can be tolerated before the degradation would equate to "harmful interference" as defined in their own regulations.

In its development of recommended power levels for UWB devices operating in various GPS operational scenarios, NTIA chose a testing procedure that is very similar to a criterion that was recently rejected by the Commission in the *700 MHz Report and Order*.[5] In that proceeding, the FCC rejected an assertion from Motorola that harmful interference will result from a 1 dB increase in the noise floor. Very few systems operate at the thermal noise floor limit and for the scenarios used by the NTIA, thermal noise is not the proper limit. Rather, GPS receiver performance is limited by the usual problems from which all radio systems suffer, such as signal blockages and multipath. The NTIA analysis does not create estimates of the baseline performance of GPS receivers in its scenarios and then estimate the marginal impact of UWB on those baselines. By ignoring the fact that GPS will not work at all in many places and will work poorly in many more places, the NTIA report does not state the fact that GPS cannot be reliably applied to every possible geo-location requirement, and overestimates the impact of UWB signals.

Take, for example, one unrealistic scenario used in their analysis. For their reacquisition tests, the model NTIA used was that of a vehicle moving down a road that would have the GPS signal blocked by a building or other obstacle for a distance of some

50 meters or approximately 162 feet. The concept was to relate the reacquisition time in this situation to the reacquisition time required if a UWB transmitter were present. To simulate satellite signal loss NTIA interrupted the signal representing the GPS satellite signal and generated an equivalent code offset of 50 meters in that satellite signal. Then, in the presence of a UWB transmitter, the reacquisition time of the GPS receiver was measured. What NTIA failed to account for in the modeling of this scenario was the movement of the vehicle mounted GPS receiver. Any moving vehicle would quite rapidly be beyond the range of a UWB transmitter operating at the proposed Part 15 limits in a matter of only a few short seconds even if the transmitter were directly adjacent to the roadway. Further, the typical reacquisition time for a moving GPS receiver (located atop a vehicle) is significantly longer than the reacquisition time that receiver has for fixed location operation. Analysis based on such poorly conceived modeling scenarios should be disregarded if it is purported to equate to harmful interference as defined by either the FCC or NTIA.

B. Stanford/DOT

The Stanford Report states that the GPS Receiver RFI Susceptibility Limit, which has presumably been equated to harmful interference, is -170.1 dBm/Hz – only 3.9 dB higher than the thermal noise floor of -174 dBm/Hz. At this level, all FCC Part 15 compliant Class A and B digital devices (*e.g.,* computers), radio receivers as well as a

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[5] *See* Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules, *Second* Memorandum *Opinion And Order,* WT Docket No. 99-168 at ¶ 6 (rel. Jan. 12, 2001) ("700 MHz Order").

host of incidental radiators (*e.g.,* motor-driven appliances) will have to be turned off within restricted areas of operation, such as in and around airports to avoid causing harmful interference. If the -170.1 dBm/Hz GPS Receiver Susceptibility Limit had a relation to real-world impact, one would expect to find that GPS Systems would already have difficulty operating – regardless of UWB equipment. Moreover, there are a number of other RF systems that are legally permitted to radiate even higher powered signals within the GPS bands, including out-of-band and spurious emissions from TV stations, land mobile communications systems, and ISM equipment.[6]

C. JHUAPL

Unlike Stanford and NTIA, JHUAPL did not attempt to guess at what the FCC might choose for its definition of harmful interference for the UWB-GPS interaction. Instead, they chose to use their considerable expertise in GPS risk assessment[7] to create 12 GPS Measures of Performance (MOPs), which included the number of satellites tracked by the GPS receiver, the number of satellites used in the navigation solution, the position dilution of precision, the receiver position error, the carrier-to-noise ratio, the pseudorange measurement noise, the pseudorange double difference bias, the pseudorange double difference noise, the reacquisition time for one tracked satellite, the

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6 *See generally* the emissions masks in Parts 15, 22, 90 and 18 of the Commission's Rules.

7 *See, e.g.,* GPS Risk Assessment Study Final Report, The Johns Hopkins University Applied Physics Laboratory, operating under contract to the Air Transport Association (Jan. 1999) *available at* <http://www.jhuapl.edu/transportation/aviation/gps/gps.pdf>.

reacquisition time for four tracked satellites, the reacquisition time for all-in-view tracked satellites, and the reacquisition probability of four navigated satellites. JHUAPL then plotted the effect of UWB on these MOPS versus the effective separation distance between the UWB device and the GPS receiver in order to fully characterize the interaction. This information should assist the FCC in determining what constitutes harmful interference for the UWB-GPS interaction.

It is helpful to refer to one of the graphs from the JHUAPL Report to illustrate the presentation of the GPS MOP vs. separation distance. Both the NTIA report and the JHUAPL Report recognized that the time it takes a GPS receiver to reacquire a satellite was the most sensitive to increases in noise. Figure 1, taken from the JHUAPL Report,[8] shows the impact of a single Part 15 Class B compliant UWB emitter on the satellite reacquisition time of a GPS receiver. As can be seen in the figure, emissions from a single UWB emitter, operating in compliance with the FCC's existing Part 15 Class B limits, causes a GPS receiver's satellite reacquisition time to deviate from nominal by less than 10 seconds when the separation distance is 10 meters for both the minimum possible GPS signal power level as well as the "Live Sky" constellation. The "Live Sky" constellation consisted of GPS signal levels representative of actual levels measured at Holloman AFB on July 26, 2000. The "Min Sky" constellation used GPS signal levels

[8] JHUAPL Report, Figure 6-16 at 6-28.

equal to the minimum guaranteed received power levels as listed in GPS Standard Positioning Service Signal Specification.[9]

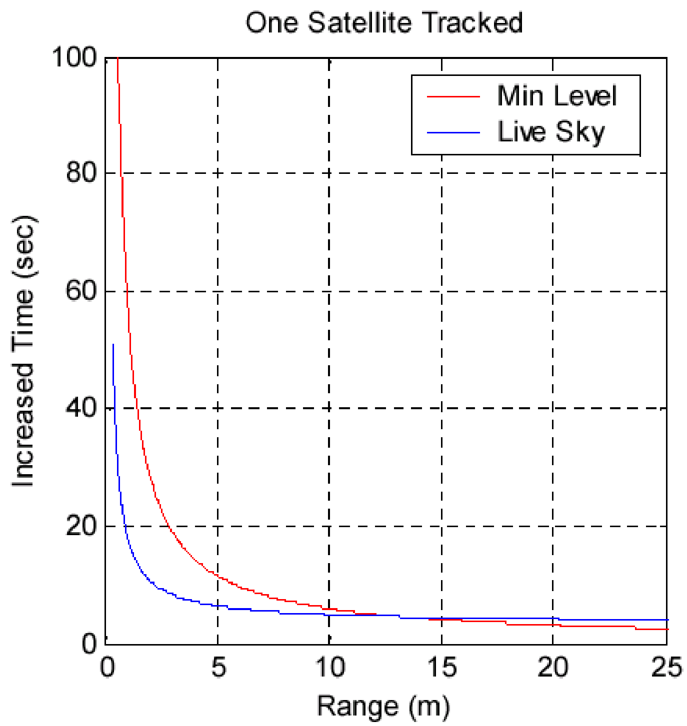

Figure 1. Impact of a single Part 15 Class B compliant UWB emitter on the satellite reacquisition time of a GPS receiver

Thus, at a distance of 10 meters the impact of a single Part 15 Class B UWB emitter has a minimally discernible effect (as compared to values in a quiescent state) on a GPS receiver tracking a single satellite at both the high and low measures of GPS signal levels.

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[9] 2d Ed., June 1995.

IV. The UTARL/JHUAPL, NTIA, and Stanford Data Indicate the Same Trends.

In order to define workable UWB regulations, the FCC must decide what constitutes harmful interference in the case of the UWB-GPS interaction. The JHUAPL report provides the FCC with directly applicable information regarding the operational impact of UWB on GPS receivers. On the other hand, in order to apply the information provided in the NTIA and Stanford reports, the Commission must incorporate real-world environmental and operational considerations. The NTIA and Stanford reports do not attempt to fully characterize the effect of UWB on GPS under real-world operational scenarios. These reports rely entirely on GPS receiver protection criteria that, when exceeded, do not necessarily correspond to the sort of operational impact on the GPS system that the FCC and NTIA would consider to be harmful interference.

TDC analyzed in detail the various test configurations and procedures used in each study. In so doing, TDC has determined that, despite the variety of test setups, UWB simulators, GPS receivers and simulators, test configurations, procedures, and monitored parameters in each of the studies, the results are actually very similar for UWB signals that use random pulse position modulation (PPM). Each report recognizes that UWB random PPM signals appear in the passband of a GPS as white noise – which is a very well understood impact, and is also the UWB signal type that TDC plans to implement.

In these comments, TDC illustrates the similarity among the data contained in the three reports by comparing the GPS performance parameter variation relative to white noise and white-noise-like UWB signals. TDC will also show that all three studies also agree upon which UWB PRFs appear in the passband of a GPS receiver as pulse like or white-noise-like signals, and that the NTIA and JHUAPL reports also agree that for white-noise-like UWB signals, the effect of multiple UWB devices is the same as the effect of multiple white-noise-like devices already regulated under Part 15 of the FCC's rules.

The differences in the conclusions presented in the NTIA report, as compared to the JHUAPL report, will be shown to be based on mathematical assumptions that in some cases are erroneous, in other cases are overly conservative, and in still other cases are not consistent with the FCC and NTIA definition of "harmful interference."

A. Classification of UWB Emissions

There are three major classifications of UWB emissions: CW-like, pulse-like, and white-noise-like. UWB pulses that occur at regularly spaced intervals create emissions spectra that are classified as "CW-like." Since the pulses are periodic they create spectral lines in the frequency domain – much like continuous wave signals – hence the term "CW-like."

TDC uses UWB pulse-position modulation (PPM), an implementation of UWB that results in a smearing of the spectral energy over the UWB frequency band. Because TDC is most familiar with UWB PPM emissions, TDC's comments on the various GPS analysis reports will focus on this particular UWB implementation. A GPS receiver perceives UWB PPM emissions in one of two ways: as a pulse-like emission or as a white noise-like emission. UWB PPM PRFs that are significantly lower than the receiver bandwidth appear pulse-like, and as the PRF approaches the receiver bandwidth the receiver perceives the UWB emissions as white noise-like. For example, a typical GPS receiver has a receiver bandwidth of 2 MHz for C/A code and 20 MHz for P code, so UWB emissions with PRFs of less than one-third to one-half the receiver bandwidth can be expected to impact GPS receivers in a pulse-like manner, while those with PRFs that are greater than the receiver bandwidth can be expected to impact GPS receivers in a white noise-like manner. (In between, is a transition region). All three GPS testing efforts agree in this respect.

B. Discussion of the More Sophisticated PPM used by TDC as Compared to That Used by Both Stanford and NTIA

Time Domain uses very sophisticated noise-coding techniques to ensure that its signals are white-noise-like. The UWB signal generator used by Stanford in no way created a noise-like signal. Rather, it created signals with very pronounced spectral features. First, their "noise code" consisted of a pattern that repeated itself every nine pulses. This would ensure that spectral features appear every $PRF_{MHz}/9$ MHz, which with a 19.942 MHz PRF makes a spectral comb line right in the middle of the GPS L1 band. Second, the Stanford timing system only divided time into 1 nanosecond intervals, which is insufficient to break up spectral features at 1.57542 GHz and guarantees that there will be spectral features no matter the length of the noise-code.[10] TDC's timing system

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[10] In order to decorrelate (*i.e.*, make white noise-like) the spectrum of a UWB pulse train, the time coding circuitry must divide time into increments that are at least 1/10th of

divides time into 3 ps intervals, giving it the capability to decorrelate the spectral features of its emissions throughout the range of frequencies over which it plans to operate.

C. The PRF Dependence of UWB Emission Classification is Nearly Identical in All Three Reports.

The JHUAPL report[11] indicates the same PRF dependence of the UWB emission classification, as do excerpts from the Stanford report shown in Figure 9 through Figure 11, and as does an excerpt from the NTIA report shown herein as Table 1. All three studies agree that, in general, a GPS receiver is more robust in resisting pulse-like UWB emissions that are the same average power as white noise-like UWB emissions. The studies also agree that an UWB emission at the same average power as the others and is classified as CW-like causes much greater effects to the GPS receivers, when spectral lines are in the L1 or L2 frequency band, than either pulse- or white noise-like UWB emissions. Finally, the JHUAPL report showed that white noise-like UWB sources had no greater impact on a GPS receiver than either a source of pure white noise or a non-transmitting walkie-talkie operating at or below Part 15 power levels in the GPS L1 band.

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the length of a single cycle at a given frequency. At a frequency of 1.575 GHz, a single cycle is 635 ps long. Thus, the timing system must divide time into 64 ps increments if the signal is to be noise-like within the GPS L1 band. TDC's systems trigger pulse generation at integer multiples of 3 ps.

[11] *See* Figure 2 through Figure 8, which are drawn from the JHUAPL Report and the errata document filed with the FCC on April 24, 2001.

1. The Analysis Conducted by JHUAPL

Figure 2 through Figure 7 are excerpts from the JHUAPL report of GPS signal correlation and cross correlation graphs. These graphs show the UWB signal classification dependence on PRF and modulation type, as well as the interference impact for different UWB signal classifications. Figure 2 through Figure 7 can best be interpreted by noticing that the closer the red, yellow, and green color band is to the top of the chart, indicating little or no UWB attenuation required, the less the UWB is impacting the GPS receiver. The closer the color band is to the bottom of the chart, indicating more UWB attenuation required, the more the UWB is impacting the GPS receiver. Figure 2 shows the white noise correlation and is included as a baseline comparison to the various UWB signal types.

By comparing Figure 3 through Figure 6 (UWB PPM signals of 1, 5, 10 and 20 MHz PRFs, respectively) to the white noise baseline in Figure 2, one can see that they all have similar correlation properties, which indicates that the GPS receiver is impacted in a similar manner by those emissions. However, by comparing Figure 3 to Figure 2, one can see that the GPS receiver reacts less to the UWB PPM of 1 MHz than it does to white noise, as one would expect for pulse-like UWB emissions, as noted above.

By comparing Figure 7 to Figure 2, one can tell that the GPS receiver reacts less to white noise than it does to a periodic (*i.e.*, unmodulated) UWB emission at a PRF of 19.94 MHz, which also follows the trend of the CW-like UWB emissions, stated above. It is instructive to point out that JHUAPL did not have any raw data from unmodulated 19.94 MHz UWB systems such as the one used by Stanford. JHUAPL was able to use the experimental data it had for UWB PPM systems to develop a theoretical model for the UWB-GPS interaction, and then extended that theoretical model to other UWB implementations such as the one used by Stanford. As can be seen from Figure 7, the theoretical model JHUAPL developed accurately predicted the more severe impact a 19.94 MHz PRF unmodulated UWB system would have on GPS.

Finally, Figure 8 summarizes the JHUAPL comparison of the UWB PRF versus UWB signal classification type. Figure 8 indicates the interference impact on GPS receivers for pulse-like, CW-like, and white noise-like UWB emissions, and shows that TDC's UWB PPM is white noise-like or pulse-like (depending on its PRF) which impacts GPS the least of all UWB emissions.

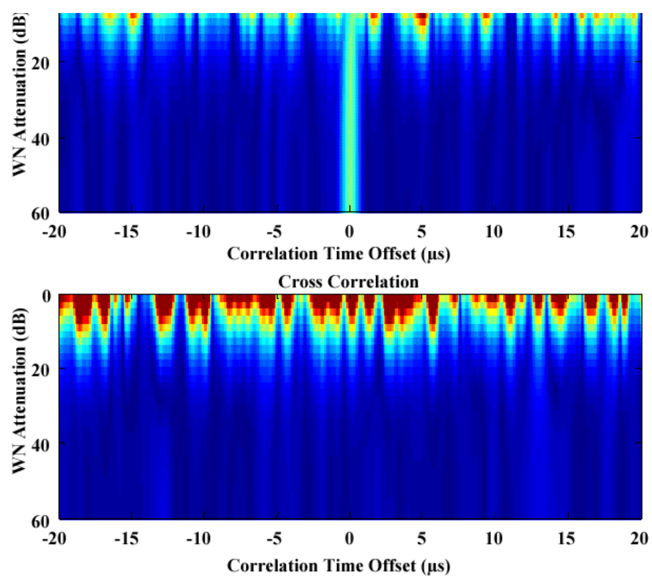

Figure 2. JHUAPL GPS Correlation with Injected White Noise.
(JHUAPL Report Figure 5-15)

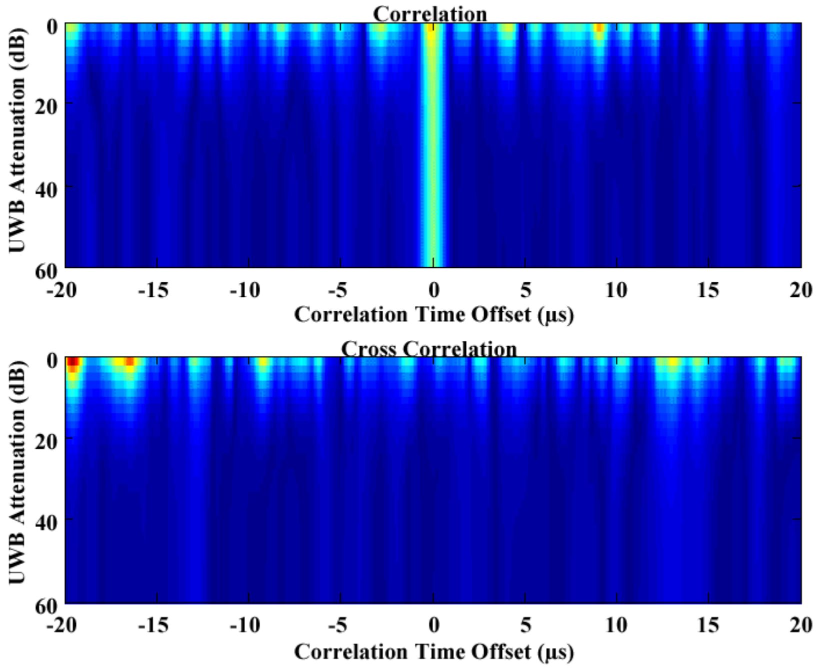

Figure 5-16 GPS Correlation with Injected UWB Signal (PRF=1MHz)

Figure 3. JHUAPL GPS Correlation with Injected UWB PPM Signal (1 MHz PRF)

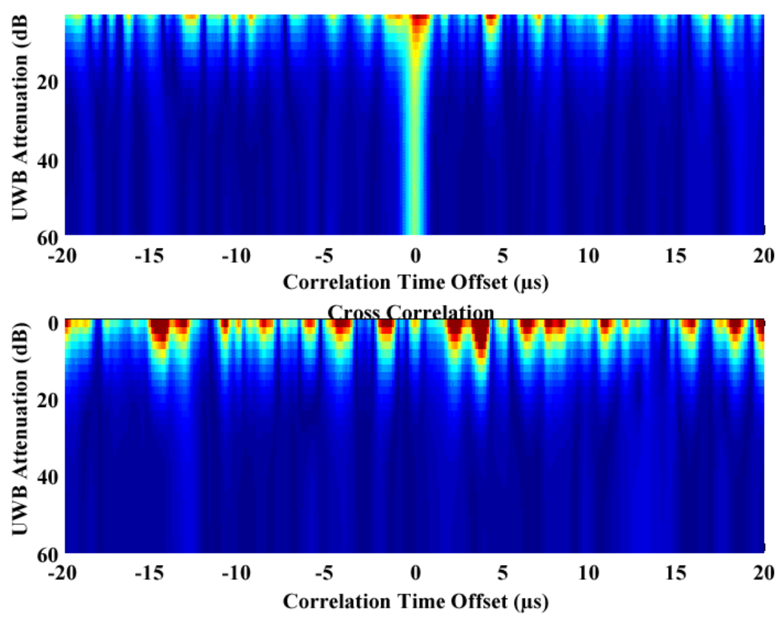

Figure 4. JHUAPL GPS Correlation with Injected UWB PPM Signal (5 MHz PRF)

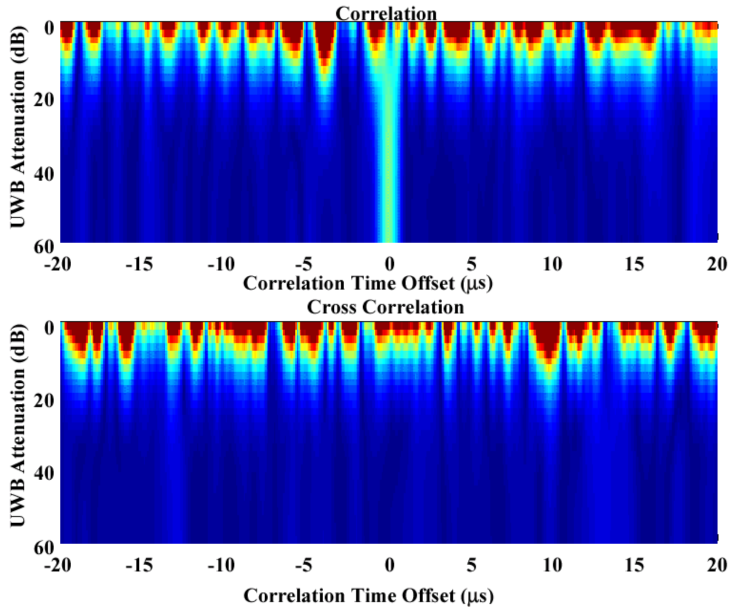

Figure 5. JHUAPL GPS Correlation with Injected UWB PPM Signal (10 MHz PRF)

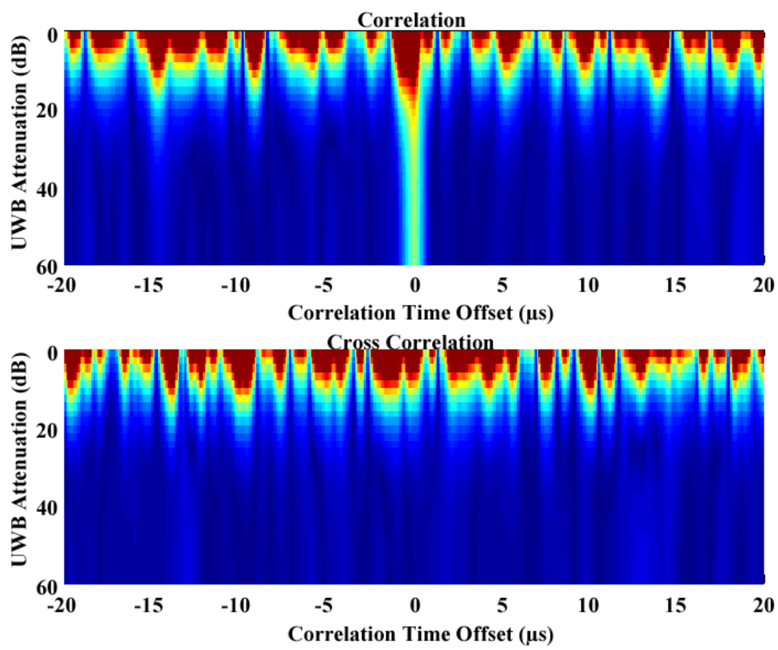

Figure 5-19 GPS Correlation with Injected UWB Signal (PRF=20MHz)

Figure 6. JHUAPL GPS Correlation with Injected UWB PPM Signal (20 MHz PRF)

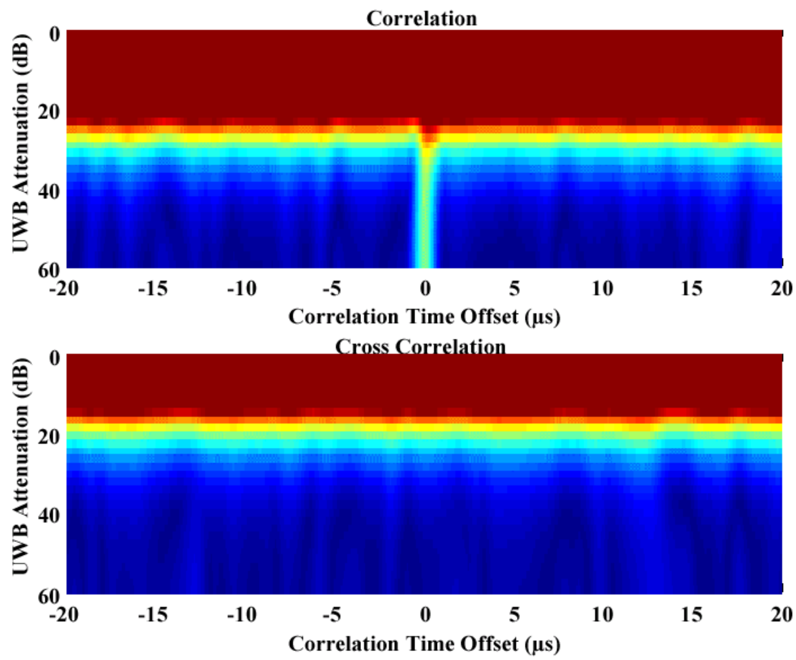

Figure 5-20 GPS Correlation with Injected UWB Signal (PRF=19.94MHz; Undithered)

Figure 7. JHUAPL GPS Correlation with Injected UWB Periodic Signal (19.94 MHz PRF)

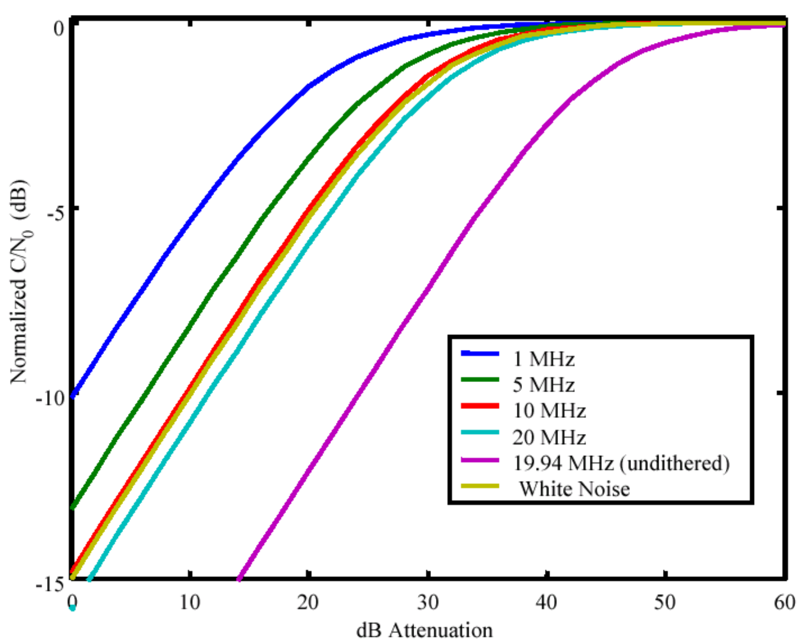

Figure 5-21 Normalized C/N_0

Figure 8. JHUAPL Normalized GPS C/N_o versus PRF and Signal Type

2. The Testing Performed by Stanford

The Stanford test effort classified all UWB signal types relative to white noise, since GPS performance variation in the presence of white noise is well understood throughout the industry. Figure 9 is a plot of GPS performance as measured by Stanford relative to injected white noise. All subsequent Stanford plots use Figure 9 as the baseline metric to determine a better or worse type of evaluation, relative to white noise, of different UWB modulation techniques. Figure 10, for example, is a UWB PPM signal operating at a 15.94 MHz PRF, and can be seen to impact the GPS receiver in a manner that is very similar to the white noise baseline. Figure 11 is a plot of a UWB PPM signal operating at a 2 MHz PRF, which impacts the GPS receiver less than white noise does, thereby indicating a pulse-like signal. Figure 12 is a UWB signal operating at a periodic (*i.e.*, unmodulated) 19.94 MHz PRF, which impacts the GPS receiver much more than white noise does, indicating a CW-like signal type.

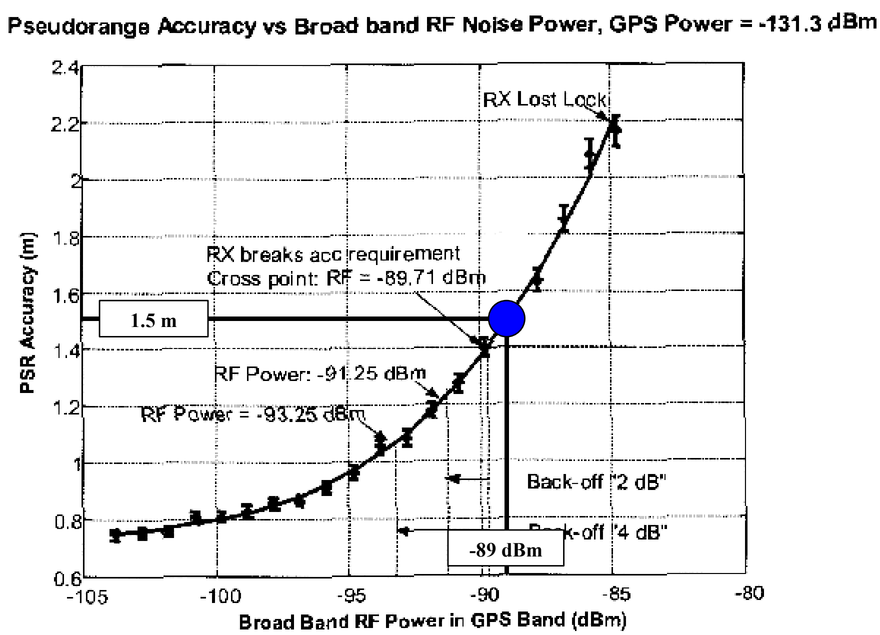

Figure 9. Stanford GPS White Noise Injection Normalization

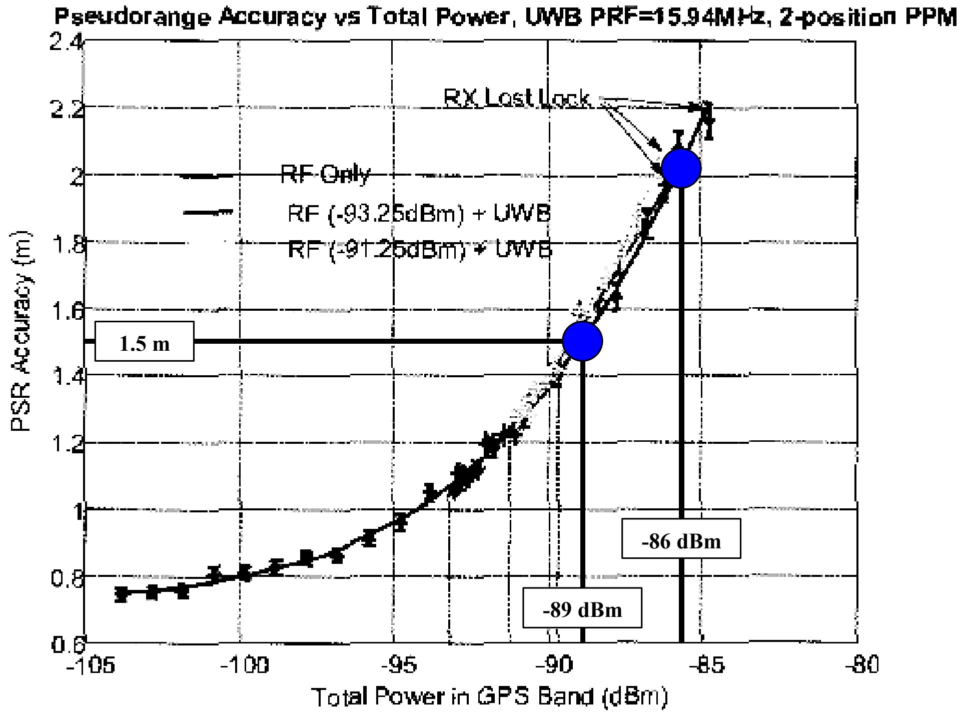

Figure 10. Stanford GPS Injected UWB PPM (15.94 MHz PRF)

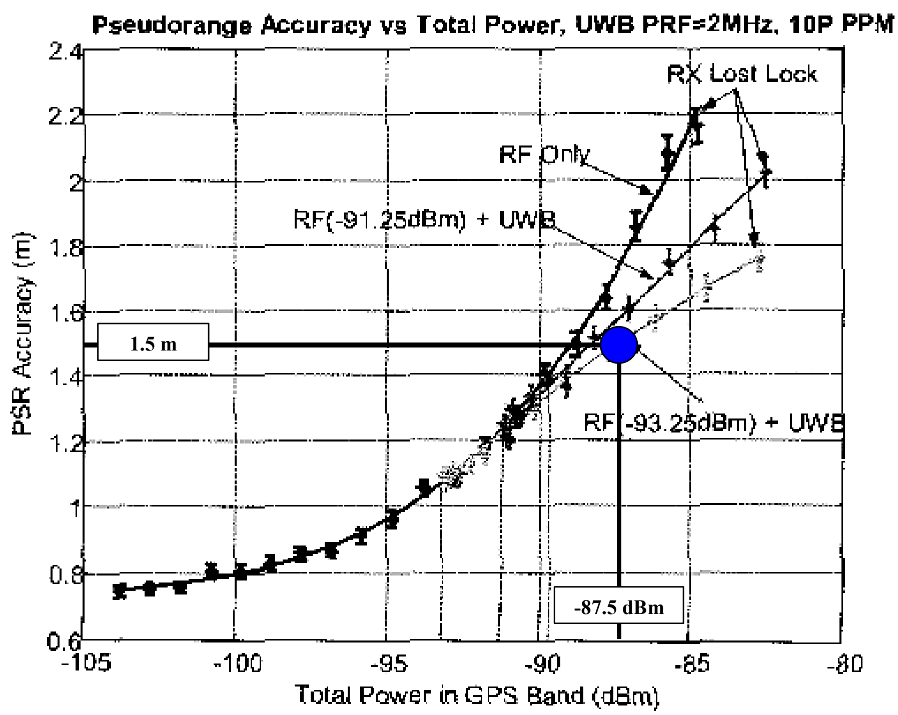

Figure 11. Stanford GPS Injected UWB PPM (2 MHz PRF).

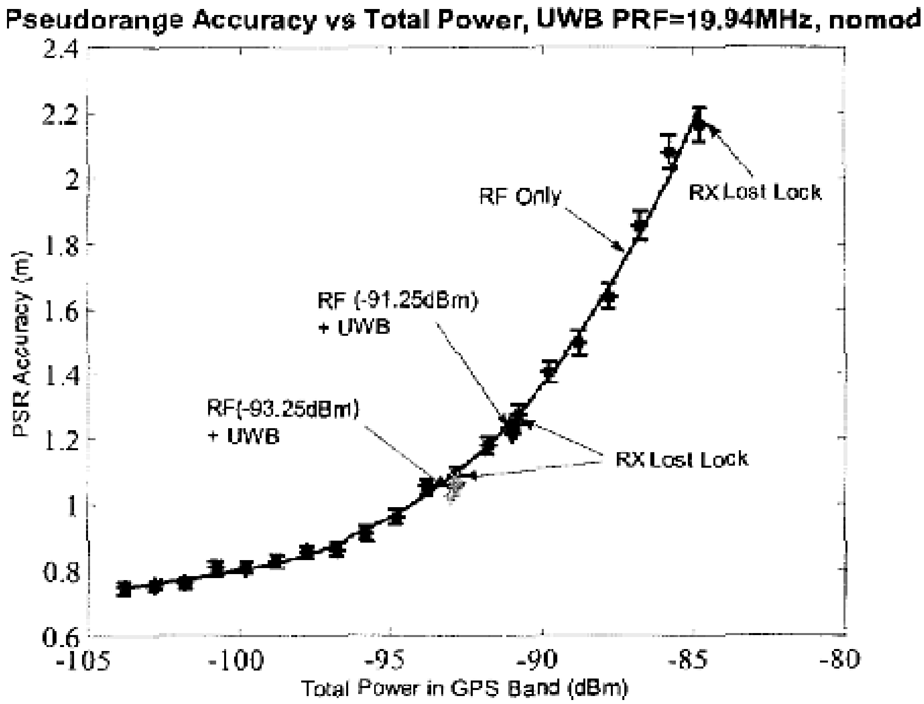

Figure 12. Stanford GPS Injected UWB CW Like (19.94 MHz PRF)

3. NTIA Testing

Table 1 lists the NTIA UWB classifications versus PRF and modulation type. The results of Table 1 agree with Figure 8 taken from the JHUAPL test report and Figure 9 through Figure 12 taken from the Stanford test report. All three reports conclude that 1 to 2 MHz UWB PPM signals appear as pulse-like signals to a GPS receiver while UWB PPM signals with higher PRFs (5 MHz and above) appear as white noise-like signals to a GPS receiver.

Table 1. NTIA Categorization of UWB Signal Permutations[12]

1 MHz PRF, No Mod, 20% Gate	Pulse-Like
1 MHz PRF, OOK, 100% Gate	Pulse-Like
1 MHz PRF, OOK, 20% Gate	Pulse-Like
1 MHz PRF, 50% abs, 100% Gate	*Pulse-Like*
1 MHz PRF, 50% abs, 20% Gate	Pulse-Like
1 MHz PRF, 2% rel, 100% Gate	*Pulse-Like*
1 MHz PRF, 2% rel, 20% Gate	Pulse-Like
5 MHz PRF, 50% abs, 20% Gate	Pulse-Like
5 MHz PRF, 2% rel, 20% Gate	Pulse-Like
20 MHz PRF, 50% abs, 20% Gate	Pulse-Like
20 MHz PRF, 2% rel, 20% Gate	Pulse-Like
1 MHz PRF, No Mod, 100% Gate	CW-Like
5 MHz PRF, No Mod, 100% Gate	CW-Like
5 MHz PRF, No Mod, 20% Gate	CW-Like
5 MHz PRF, OOK, 100% Gate	CW-Like
5 MHz PRF, OOK, 20% Gate	CW-Like
20 MHz PRF, No Mod, 100% Gate	CW-Like
20 MHz PRF, No Mod, 20% Gate	CW-Like
20 MHz PRF, OOK, 100% Gate	CW-Like
20 MHz PRF, OOK, 20% Gate	CW-Like
5 MHz PRF, 50% abs,100% Gate	*Noise-Like*
5 MHz PRF,2% rel, 100% Gate	*Noise-Like*
20 MHz PRF, 50% abs, 100% Gate	*Noise-Like*
20 MHz PRF, 2% rel, 100% Gate	*Noise-Like*
Highlighted italicized text indicates Random Pulse-Position Modulation	

D. Comparing the UTARL/JHUAPL, NTIA and Stanford Data

In order to compare the JHUAPL, NTIA, and Stanford GPS test results it is necessary to calculate the total interference power received by the GPS receiver. Both NTIA and Stanford testing utilized both UWB and white noise summed at the GPS

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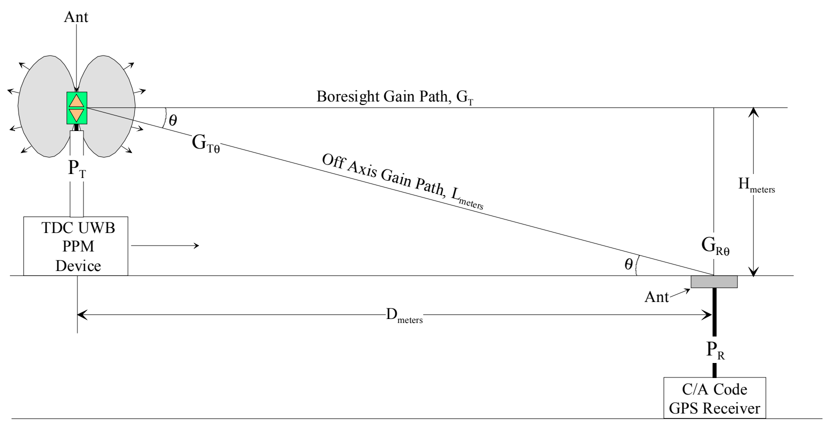
12 Source: Table 2-5 NTIA Report.

receiver input as the total interference power, and because both report GPS performance variations with respect to injected UWB power or total injected power (*i.e.*, UWB plus white noise), the total interference power is easy to calculate.

The JHUAPL condensed measures of performance (MOPs) report GPS performance variations with respect to distance. The total injected power received by the GPS receiver can be calculated for the JHUAPL MOPs using the radiated test geometry shown in Figure 13. For example, the GPS received power, P_R, at a distance, D_{meters} = 5 m, is –89.5 dBm/20 MHz as shown in the table of Figure 13. Figure 13 includes a table that lists the calculated total injected UWB noise used in the UTARL test setup, which is directly related to the JHUAPL MOP GPS variation versus distance.

In order to perform an "apples" to "apples" comparison across all three reports, only white noise-like UWB emissions are considered due to the ease of calculating the resultant total power of multiple uncorrelated noise sources. This is important because both the NTIA and the Stanford testing externally combined white noise with the UWB signal prior to injection into the GPS receiver. Since the UWB emissions that are being compared are white-noise-like, the total injected JHUAPL UWB power and the total injected power used by NTIA and Stanford can be directly compared.

It should be noted in the Figure and accompanying table below that both the distance from the UWB source to the GPS receiver varied ,and that the height of the UWB source above the plane of the GPS receiver also varied. As a result, the incident angle of radiation from the UWB source to the GPS receiver varied causing a variation in the UWB power level received by the GPS receiver. As the distance increased, the level of UWB power received by the GPS receiver decreased, as a function of both increasing distance and decreasing angle of incidence relative to the main lobe of the GPS receiver. This is very important to note, because it is a factor not accounted for in many of the modeling scenarios presented in the various reports that will be addressed later in these comments.



d (m)	*h*h_{UWB}(m)	h_{GPS} (m)	θ (degrees)	$G_{T\theta}$ (dBi)	$G_{R\theta}$ (dBic)	P_R (dBm/20 MHz)
0.5	0.597	0.438	17.6	-3.25	3.0	-67.8
1.0	0.718	0.438	15.6	-3.25	3.0	-73.8
1.5	0.718	0.438	10.6	-2.25	3.0	-76.1
2.0	0.718	0.438	8.0	-2.25	0	-81.5
2.5	1.00	0.438	12.7	-3.25	3.0	-81.6
3.0	1.00	0.438	10.7	-2.25	3.0	-82.1
3.5	1.00	0.438	9.2	-2.25	0	-86.4
4.0	1.00	0.438	8.0	-2.25	0	-87.6
5.0	1.29	0.438	9.7	-2.25	0	- 89.5
8.0	1.29	0.438	6.1	-2.25	0	-93.5

$P_{R\ L1}$(dBm/20MHz) = $P_{T\ L1}$(dBm/MHz) + $G_{T\theta}$(dBi) + $G_{R\theta}$(dBic) + M(dB) + 27.55(dB) - $20\text{Log}_{10}(f_{MHz})$ - $20\text{Log}_{10}(L_{meters})$ + $10\text{Log}_{10}(20)$

$L_{meters} = H_{meters}/\sin(\theta)$ $\theta = \tan^{-1}(H_{meters}/D_{meters})$ L_1 = 1575.42 MHz = f_{MHz} $P_{T\ L1}$ = -46.8 dBm/MHz @ 10 MHz PRF

M = -3.0 dB = Linear to circular polarization loss G_T(1575.42 MHz) = -1.25 dBi

Figure 13. UTARL Radiated Test Geometry

E. The Satellite Re-Acquisition Times Found by JHUAPL, NTIA and Stanford Are Nearly Identical for White Noise-like UWB Signals.

Both the UTARL/JHUAPL and NTIA test reports monitored the sensitivity of satellite re-acquisition time versus injected noise (UWB and white). NTIA simulated two different random PPM schemes that were both classified as noise-like for PRFs of 5 and 20 MHz, as shown in Table 1and Table 2. Since the calculated UTARL/JHUAPL injected UWB power is a single number, the white noise-like UWB power levels measured during the NTIA testing shall be averaged for purposes of comparison.

NTIA reported, in the Reacquisition column of Table 2, the injected UWB power that caused a sharp increase in satellite reacquisition time. The mean of the power levels (highlighted with the yellow mark shown in the Reacquisition column of Table 2) will be compared to the UTARL/JHUAPL UWB injected power level of –89.5 dBm/20 MHz (the UWB power level that caused a sharp increase in satellite reacquisition time) as shown in Figure 14. NTIA summed the UWB noise power with a white noise source of -93 dBm/20 MHz for a total injected noise power level of –90.4 dBm/20 MHz.[13]. The power levels that caused a sharp increase in satellite reacquisition time found by NTIA and JHUAPL are less than 1 dB different from each other.

The one data point that the Stanford test report has on satellite reacquisition time is shown in Figure 9 with an injected total power level of –89.71 dBm/20 MHz, which is

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[13] This value represents the sum of the average value of the Interference Susceptibility Levels from the Reacquisition column for white-noise-like UWB emissions in Table 2 and the injected white noise power.

less than 0.2 dB different from the power level found by JHUAPL. Therefore, the NTIA, JHUAPL, and Stanford test reports indicate close agreement on the total noise-like power level required to cause a sharp increase in satellite reacquisition times of C/A code GPS receivers.

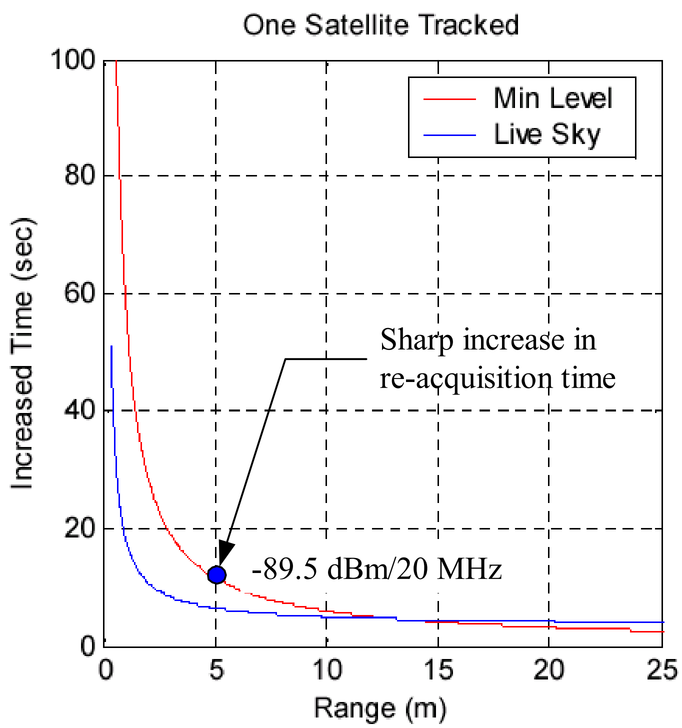

Figure 14. JHUAPL Increase in Re-Acquisition Time vs. Distance

Table 2. NTIA Test Results for C/A Code GPS Receivers[14]

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

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

Yellow italicized text indicates white noise-like UWB emissions.

14 NTIA Report, Table 2-1 at 2-3.

F. The Single Satellite Break Lock Levels Found by JHUAPL, NTIA and Stanford Are Very Similar.

The JHUAPL, Stanford and NTIA reports monitored the threshold of break lock of a single satellite versus injected noise (UWB and white). NTIA simulated two different random PPM schemes that were both classified as noise-like for PRFs of 5 and 20 MHz, as seen in Table 1 and Table 2.

NTIA reported, in the Break-lock column of Table 2, the injected UWB power that caused the GPS receiver to break lock on a single satellite. The mean of the power levels (highlighted with the yellow mark shown in the Break-lock column of Table 2) will be compared to the JHUAPL UWB injected power level of –81.5 dBm/20 MHz at 2 meters[15] (from the Table in Figure 13) as shown in Figure 15. NTIA summed the UWB noise power with a white noise source of power of -93 dBm/20 MHz for a total injected noise power of -85.9 dBm/20 MHz. The JHUAPL power of -81.5 dBm/20 MHz correlates with the loss of a single satellite, which is less than 4.5 dB different than the NTIA mean injected noise power of -85.9 dBm/20 MHz, and from the Stanford level of –86 dBm/20 MHz shown in Figure 10 and -85 dBm/20 MHz[16] shown in Figure 9. All three reports agree to within 4.5 dB when assessing the UWB break lock threshold of a single GPS satellite.

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[15] The 2 meter point represents when the graph shows the first incremental satellite to be lost.

[16] This value represents the sum of the average value of the Interference Susceptibility Levels from the Breaklock column for white-noise-like UWB emissions in Table 2 and the injected white noise power.

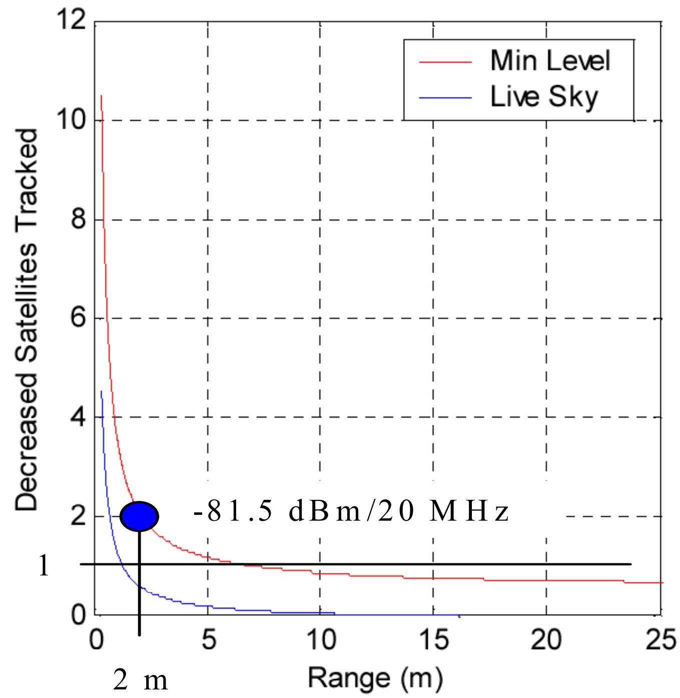

Figure 15. JHUAPL Satellite Break Lock versus Distance

G. The Pseudorange Error Levels Found by JHUAPL and Stanford Are Very Similar.

Both JHUAPL and Stanford examined the impact of UWB on GPS position error. The increase in GPS position error as reported by Stanford, from a UWB PPM signal classified as noise-like, is shown in Figure 10 to be 1.5 m at an injection level of -89 dBm/20 MHz (which is the same as level that was found for white noise, as shown in Figure 9). The increase in GPS position error as reported by the JHUAPL test report, from a UWB PPM classified as noise-like, is shown in Figure 16 to be 1.5 m at an injection level of –90.2 dBm/20 MHz. The two test reports are less than 1.2 dB different on their assessment of increased position error from noise-like UWB signals.

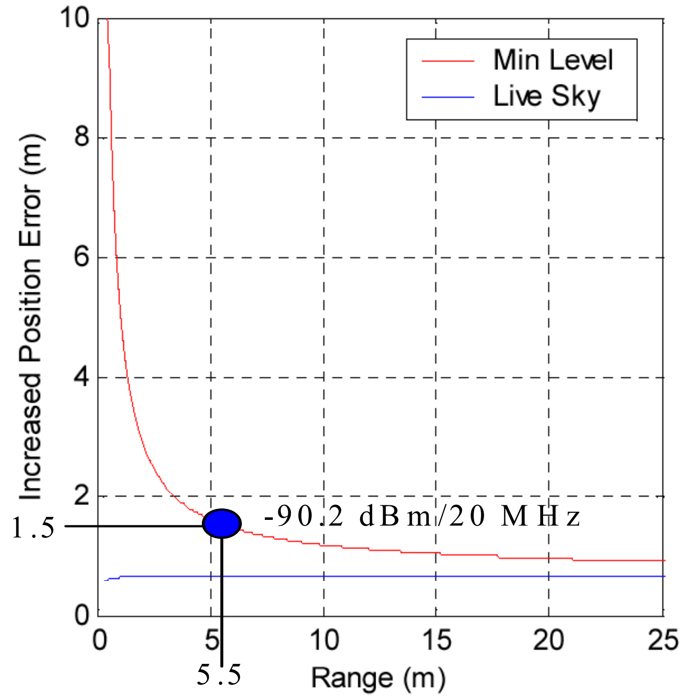

Figure 16. JHU Increase in Position Error versus Distance

H. The C/N$_o$ and Correlation Noise Levels Found by of JHUAPL, NTIA and Stanford Are Very Similar.

Both the NTIA and Stanford testing complemented the injected UWB noise by externally adding white noise to the GPS receiver input. NTIA's rationale is based on ITU Recommendation ITU-R M.1477, which calls for using a minimum C/N$_0$ of 34 dB for safety of life analysis. To create the 34 dB C/N$_0$, NTIA used a GPS signal level of -130 dBm and summed a constant external white noise source of -93 dBm/20 MHz with both the GPS signal and UWB signal at the GPS receiver input. The external noise added by NTIA is intended to represent the worst-case C/A code co-channel self-interference of all the satellites in view. Stanford also summed an external white noise with the injected UWB but did not hold the noise level constant, so the C/N$_0$ ratio varied throughout the

Stanford testing. TDC agrees with the ITU recommendation of using 34 dB, but only for safety-of-life GPS applications. TDC has implemented a C/N_o of 37 dB – documented by RTCA[17] as shown in Table 3 – for all non-safety-of-life applications as explained in Section VI.A.1 of this document. Because the 34 dB C/N_o is only valid for safety of life applications, and a C/N_o of 37 dB should be used in all other GPS operational scenarios, a reduction of the injected white noise by both NTIA and Stanford should have been included in order to assess the impact of UWB on non-safety of life GPS applications.

Since there is not a separate results database for testing performed at a 37 dB C/N_o ratio, a simple calculation can be performed that will adjust all NTIA and Stanford measured UWB power levels to the correct values for non-safety-of-life GPS applications. Table 3 shows the required values for the adjustment calculation with a net increase of 2.6 dB for all measured and computed UWB power levels reported by NTIA and Stanford for non-safety of life applications.

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17 Assessment of Radio Frequency Interference Relevant to the GNSS, RTCA Document No. RTCA/DO-235 (Jan. 27, 1997).

Table 3. Link Budget Analysis and Correlation Noise Calculations

	RTCA DO-235			
	Aviation Budget (based on WAAS)	**MSS Budget (based on GPS)**	**NTIA Budget (based on ITU & RTCA)**	**TDC Budget (Based on GPS)**
Reference Carrier Power, (dBm)	**-131.0**	**-130.0**	**-130.0**	**-130.0**
Rcvr Antenna Gain to s/c, (dBic)	**-4.5**	**-4.5**	**-4.5**	**-4.5**
Correlator Losses, (dB)	**-2.5**	**-1.6**	**-2.0**	**-1.6**
Received Carrier Power, (dBm)	**-138.0**	**-136.1**	**-136.5**	**-136.1**
Thermal Noise Density, (dBm/Hz)	**-171.6**	**-173.1**	**-172.0**	**-172.0**
GPS Receiving System Noise Figure @ 298°K, (dB)	**2.3**	**0.8**	**1.9**	**1.9**
C/N_o, (dB-Hz)	**33.6**	**37.0**	**34.0**	**37.0**
Coorelation Noise, (dBm/Hz)	**-171.6**	**-173.1**	**-170.5**	**-173.1**
Coorelation Noise, (dBm/20 MHz)	**-98.6**	**-100.1**	**-97.5**	**-100.1**
Delta between TDC and NTIA Correlation Noise Level (dB)				-2.6

NOTE: NTIA used the following equation: (N_o = Reference Carrier Power - Correlator Loss - C/N_o) to calculate the power level of the external white noise source that represents the total satellite channel correlation noise. NTIA used a white noise power of -166 dBm/Hz instead of -168.6 dBm/Hz for a difference of 2.6 dB. Since the NTIA correlation noise was 2.6 dB too high then increasing the measured UWB noise power by an additional 2.6 dB will account for this difference in the scenario matrix.

A comparison of various GPS performance parameters and UWB signal classification types documented in the JHUAPL, NTIA, and Stanford Reports shows some close agreement. All three reports completely agree on the UWB modulation types and resulting spectral features that each create. All document the same GPS performance impacts relative to the UWB signal classification of CW, pulse, or noise-like. Moreover, all show the same demarcation between PRFs and modulation type relative to the class of signal. For example, low PRFs that are PPM appear as pulse-like signals to GPS receivers.

As to the effect of UWB on GPS performance, all three reports agree to within a very small margin. For example, the small differences of 1 dB, 1.2 dB, and 4.5 dB in satellite reacquisition time, single satellite break-lock and pseudorange error, respectively, among the JHUAPL, NTIA and Stanford test reports can easily be attributed to measurement uncertainty, differences in test setup, the use of different GPS receivers, and GPS parameter repeatability.

The results in the NTIA and Stanford Reports themselves differ by 2 to 3 dB. For example, the Stanford white noise break lock threshold was found to be –84.5 dBm, as shown in Figure 9, while the NTIA white noise break lock threshold was measured as -87 dBm/20 MHz as shown in Table 2. The difference in the break lock threshold between the two reports is 2.5 dB.[18]

The largest difference of 4.5 dB for the single satellite breaklock between the JHUAPL report relative to the other two test reports only accounts for a change of UWB to GPS impact distance of 1.7 to 1, (i.e. 3 to 5 meters or 3 to 1.7 meters, depending on which sign the difference takes). The fact that the single satellite breaklock level was the most widely varying GPS performance measure in the 3 tests is not entirely surprising,

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[18] However, since Stanford used a –131.3 dBm GPS signal level while NTIA used a –130 dBm GPS signal level, one would expect the break lock threshold of the Stanford testing to occur at a lower level than the NTIA break lock, at a level of –88.3 dBm/20 MHz instead of –84.5 dBm/20 MHz, leading to an apples-to-apples difference of 3.8 dB.

since the most widely varying test setup parameter between the different tests was the GPS satellite constellation used, as will be discussed in a later section.

Since each testing effort took decidedly different approaches in order to assess the impact of UWB on GPS operation, and each report arrived at essentially the same degree of impact, the Commission should have a high degree of confidence in using the "real-world" conclusions of the JHUAPL test report.

I. Conclusions Drawn by JHUAPL and NTIA on the Effect of Multiple UWB Devices

TDC employs random PPM with 3 picosecond pulse position time resolution that enables TDC to produce a gaussian (noise-like) distributed frequency spectrum. Results from both the JHUAPL and NTIA test reports confirm that UWB signals that employ random PPM with PRFs greater than approximately 3 MHz appear as noise-like emissions to GPS receivers. NTIA states, "The results of Case I show that, if the individual interference signals cause an effect that is noise-like, the aggregate signal will be noise-like with the power of the effective aggregate interfering signal determined by summing the average power of the individual UWB signals."[19] Case I is explained in Table 2-3 on page 2-5 of the NTIA report listing 6 UWB devices each operating at a 10 MHz PRF with 2% relative dithering. The NTIA aggregate test results are based on testing multiple noise-like UWB sources in a conducted test setup without verifying the propagation model with actual radiated test results.

Aggregate radiated testing was performed at UTARL in order to determine the "real world" additive effect of multiple noise-like UWB emitters on GPS receivers. As many as 16 UWB PPM noise-like emitters were used simultaneously during the UTARL aggregate radiated testing of different GPS receivers. The UTARL aggregate radiated testing implemented a more than worst case scenario of 16 UWB emitters arranged in a circle in an open level field around the GPS receiver with each UWB antenna above 6 degrees of elevation with respect to the GPS receiving antenna. All UWB devices were FCC Class B compliant and all were radiating approximately -47 dBm/MHz. The JHUAPL test report states on page G-1 that, "If UWB signals add like Gaussian noise, then carrier to noise ratio (C/N_o) should decrease as a linear function of 2^N injected signals or devices (when all N devices are at a constant range from the GPS receiver). The results of the aggregate testing, as stated by JHUAPL on page G-2, are, "… the degradation in normalized C/N_o, and therefore also C/N_o is a linear function of 2^N devices. Therefore, the theory that UWB signals add like Gaussian noise is demonstrated by the test result."

The conclusions of the NTIA and JHUAPL test reports validate what TDC has been saying from the start: that TDC's time modulated UWB emissions are white-noise-like and combine as white noise and that the closest emitter dominates the link budget assessment.

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19 *See* NTIA Report at 2-15.

J. JHUAPL Analyzed Data Taken in the Real World, While Stanford and NTIA Did Not.

The JHUAPL Report is the only report to show the actual performance impact of UWB emissions on real GPS receivers in a way that has any relevance to the real world utilization of these devices. Moreover, the JHUAPL Report based its conclusions not just on conducted measurements taken indoors in an anechoic chamber, but also validated and compared those results to real outdoor radiated tests to ensure that they made no erroneous assumptions in their theoretical analysis that failed to account for some real world effect.

By contrast, NTIA and Stanford chose not to do any real world outdoor testing. Moreover, the NTIA's only radiated test was conducted within an anechoic chamber and used only a GPS antenna, not a complete GPS system. Thus, in order to come up with conclusions that applied to real world operational scenarios, NTIA chose to account mathematically for the real world through the use of a series of assumptions that were never experimentally validated to ensure their applicability. Each of these assumptions describes a worst-case condition that may or may not be realistic, thereby making the probability of the operational scenarios actually representing "real world" conditions infinitesimally small.

V. The Conclusions Made by JHUAPL and Those Made by NTIA Differ, Although the Data for White Noise-Like UWB Signals are Very Similar.

The JHUAPL Report[20] concluded the following:

1) UWB time coding or modulation implementation determines the nature of the resulting UWB signal. This nature in turn determines the impact on a particular GPS receiver implementation and its performance. The choices of time coding parameters can produce significant differences in the amount and type of performance effect experienced by GPS receivers.

2) The theoretical analysis and statistical data evaluation show that properly time coded UWB signals can be produced that have characteristics similar to white noise within the GPS frequency spectrum. White noise energy is uniformly distributed in frequency and will not excite any complex interactions in GPS receivers. The properties of white noise allow it to be characterized by average power when taken in the context of overall GPS receiver performance, and this performance is a well-studied interaction. The UWB devices tested by ARL:UT produce signals that are white noise-like. In the aggregate, these signals are also white noise-like.

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20 *See* JHUAPRL Report at ES-1.

3) As shown in the JHUAPL Report, coding schemes exist that can produce non-white noise-like UWB signals that can have a greater impact on GPS performance than those effects shown herein.

4) For UWB devices with average powers that are compliant with the current FCC Part 15 regulations, the performance of GPS receivers exhibits severe degradation when the separation between the GPS receiver and UWB devices is less than about 3 meters. This distance is based solely on the GPS receivers and UWB devices tested by ARL:UT. As the separation decreases below 3 meters, all users of these GPS receivers will be severely impacted, and in the extreme, lose lock on all satellites. This phenomenon is exhibited across all relevant measures of performance analyzed. The single Part 15 device that was analyzed induced similar behavior in the GPS receivers.

5) For separations greater than 3 meters, GPS receiver performance converges to nominal levels. The minimum separation at which degradations are acceptable depends on individual user scenarios including performance thresholds, GPS receiver type, and UWB signal type and application.

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

The NTIA report did not present conclusions that characterized the UWB-GPS interaction from a real world, operational performance perspective. Instead, NTIA took the results of the raw data, coupled it to a series of mathematical assumptions that are based on an unrealistic worst case environment, and presented a table of ill-defined operational scenarios for two different types of GPS receivers and several different implementations of UWB, alongside recommended power level reductions relative to Part 15 Class B power levels that it concluded would be adequately protective of these scenarios.

A. Real-World Operational Impact vs. Mathematical Assumptions

To illustrate the different conclusions drawn when assessing the actual operational impact on a GPS receiver versus those drawn when applying unrealistic mathematical assumptions, it is helpful to compare the JHUAPL results to the mathematical conclusions obtained by NTIA in its operational scenario for maritime applications of GPS.

NTIA states that when GPS is used aboard vessels UWB emitters could get no closer than 37.5 meters from the GPS receiver antenna, which is mounted atop a mast.[21] The NTIA operational scenario also assumed that there were four UWB emitters

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[21] NTIA Document Entitled "Proposal for a General Operational Scenario for Assessing Potential Interference to Terrestrial Global Positioning System Receivers From Ultrawideband Systems", presented by NTIA at the Operational Scenarios Meeting (Dec. 7, 2000).

equidistant from the GPS receiver, *i.e.,* that there would be 6 dB more power than from a single UWB emitter. NTIA found that for its worst-case maritime scenario the UWB emissions would have to be reduced by 15.03 dB (about 96.9%) from the Part 15 Class B levels.

It is instructive to utilize Figure 6-16 from the JHUAPL Report to understand the implications of NTIA's 15.03 dB reduction. Figure 17 shows the impact of UWB emissions on reacquisition time – the most affected GPS operational parameter identified by the NTIA. The range scale of the JHUAPL base figure has been adjusted to show the NTIA report's effective separation ranges. The base figure from the JHUAPL report has also been adjusted to show not one UWB emitter but 4 emitters, *i.e.*, 6 dB of UWB power has been added.

The real-world experimental data analyzed by JHUAPL shows that when the UWB emitters are more than 10 meters away, the reacquisition time is essentially nominal, *i.e.,* the same as it would be without the UWB signal. This is true even for the Min Sky case examined by JHUAPL, where all satellites are assumed to be operating at their specified end of life power. (It is unlikely that all satellites will simultaneously be at their end-of-life power levels in the real-world, so the Min Sky case actually presents an overly conservative worst-case scenario. Moreover, as the next generation of GPS satellites will have as their specified end-of-life power level today's existing maximum power levels, this is not likely to ever occur.)

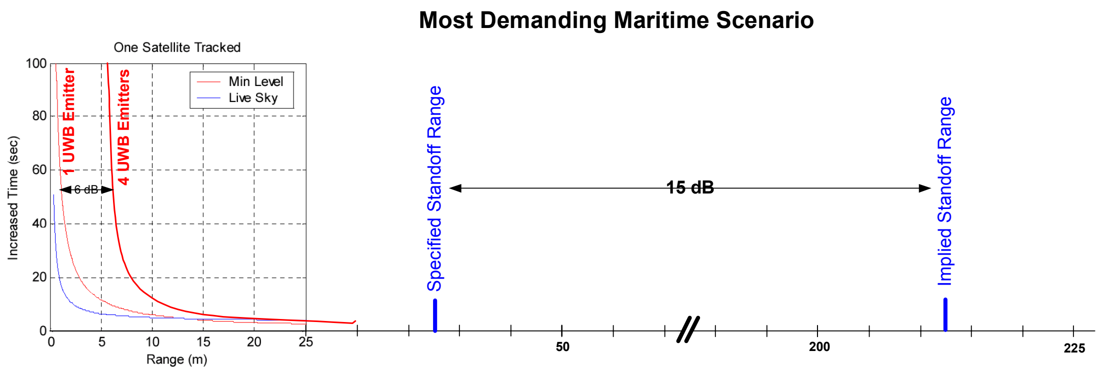

Figure 17. The impact of UWB emissions on GPS reacquisition time

Figure 17 shows that the NTIA Report implies that four UWB emitters, each emitting at the Part 15 Class B power level and each equidistant from a GPS receiver, would have to be nearly 213 meters away from that receiver so as not to exceed the receiver protection criteria chosen by NTIA. The analysis conducted by JHUAPL, which was based on real-world experimental measurements and assessments of the operational impact on the GPS receiver due to UWB, shows that the 4 UWB emitters could be within 10 to 15 meters without causing any measurable operational impact on GPS reacquisition times. Thus, NTIA's mathematical assumptions and receiver protection criteria do not apparently relate to what is observable in the real world.

Because the JHUAPL analysis shows that 4 UWB emitters would have to be within 10 to 15 meters to have a measurable operational impact on the GPS receiver, and that even at Part 15 Class B power levels, UWB would meet NTIA's most stringent maritime requirements. In later sections of this filing, TDC will undertake a more comprehensive analysis of NTIA's operational scenarios, and will demonstrate that had NTIA chosen real-world factors for their mathematical models, their data and resulting conclusions would parallel those made by JHUAPL.

B. The Analytical Process Used By NTIA And By Stanford Contained Basic Inadequacies – Many Of Which Were Identified By TDC And Others in Comments On The Respective Test Plans.

1. GPS Satellite Constellation

One important indicator of GPS receiver performance is accuracy of position determination. A typical GPS terminal receives eight (or more) satellite signals, and to determine location and altitude, must process at least four of the signals. NTIA's GPS report correctly noted that there are typically 6 to 11 satellites visible simultaneously from any point on the surface of the earth.[22] The Stanford test plan did not use the minimum constellation of 4 satellites required to obtain GPS positioning information. Rather, Stanford used a GPS simulator modeling a single satellite that was operating at a power level of only 4 dB above thermal noise limits. This does not correspond to any real world situation. No GPS receiver can operate to provide positioning information when receiving only a single satellite signal. Despite Time Domain's comments to Stanford pointing out this failure to even attempt to simulate real world conditions, Stanford chose to conduct all of its tests using this unrealistic single satellite test configuration and stated that its purpose was to compare UWB emissions to white noise.

While NTIA's original test plan was modeled after the Stanford plan, they chose in the end to use a GPS constellation that consisted of a more realistic (yet still not "real-world") constellation that consisted of four satellites. One of the satellites was set at a lower power level and was located at or near the zenith, and three satellites were set at

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22 *See* NTIA Report at iv.

higher power and were located at the horizon. While NTIA's constellation did consist a sufficient number of satellites to provide a position reading, it was not based on any real world condition that would ever be likely to exist, because – as NTIA recognizes – most GPS receivers can receive signals from 6 to 11 satellites at any one time; a GPS receiver would be more likely to obtain signal from multiple satellites located near the zenith rather than at the horizon; and the signal from the zenith satellite would likely be at a higher power than those at the horizon.

By contrast, the JHUAPL analysis effort made use of a complete constellation of satellites, creating both Live Sky and Min Sky constellations to be utilized in the conducted measurements. As noted earlier in these comments (and in the UTARL and JHUAPL Reports), the Live Sky constellation consisted of GPS signal levels representative of actual levels measured at Holloman AFB, and the Min Sky constellation used GPS signal levels equal to the minimum guaranteed GPS received power levels. The JHUAPL analysis can therefore be expected to better model real world conditions than either the Stanford or NTIA tests, which did not utilize a real-world satellite constellation.

2. Lack of Radiated Testing by Stanford and NTIA

NTIA apparently performed no radiated testing. Radiated testing is necessary to check the laboratory configurations and measurements, and, in particular, to assess the actual impact of ambient signals, antennas, and multipath interference. Instead, NTIA apparently created some mathematical values to use in its operational scenarios to account for some of these factors.

NTIA and Stanford should have included outdoor radiated testing to address antenna effects, the impact of multipath interference and that of ambient noise. The radiated section should have included tests to validate the predictions of the conducted test data, *i.e.,* the testing needed a "control" for comparative purposes. The GPS receivers should have been taken outside to, at a minimum, validate their performance in the laboratory with the real world, with and without UWB signals present. Had they done so, NTIA would not have had to create numerical values to account for some of these real world conditions, since they could have used experimental real world values instead.

The environment is a major factor in determining GPS performance. There are many sources of interference, such as incidental and unintentional radiators, as well as licensed transmitters with spurious emissions in the GPS bands. In addition, in many environments the dominant source of interference is multipath propagation of the GPS signal (*i.e.,* additional self-interference from reflections of the signals).

In contrast to both NTIA and Stanford, the JHUAPL Report included outdoor radiated tests to determine the effects of a single UWB device, multiple UWB devices, and other Part 15 devices a variety of GPS receivers. JHUAPL was able to use the results of the radiated testing, in conjunction with the more controlled conducted test results, to validate its theoretical model and ensure that it had properly accounted for the "real world." After all, the "real world" is where these devices will be used.

3. Use of a White Noise Source

Both NTIA and Stanford simultaneously injected UWB and white noise into the GPS receivers tested. Time Domain has already commented extensively on the simultaneous use of a white noise source in these measurements. While we believe that it is useful to attempt to determine whether the effect of white noise-like UWB signals is the same as that of other Part 15 devices that behave as white noise sources we continue to believe that a more general testing approach would have used a UWB signal source without the simultaneous injection of white noise. Such an approach would have provided UWB interference measurements that could have then been used in conjunction with the already well documented impact of white noise to model many possible operational scenarios, and not just one scenario that assumes a worst-case aviation scenario.

4. NTIA Chose to Inject an Incorrect Amount of White Noise.

NTIA injected white noise to obtain a C/N_o ratio of 34 dB for all their testing and then used these results for the analysis of all operational scenarios. The appropriate value that should have been used in non-aviation applications is 37 dB. To understand why, it is critical to understand what this ratio means and where the 34 dB value comes from.

The GPS satellites all transmit on exactly the same frequency band and use code division multiple access (CDMA) technology to allow the reception of each of the transmissions. The CDMA decoding process allows a GPS receiver to tune into each transmission; nevertheless, each satellite's transmission interferes with the reception of the other transmissions. NTIA injected white–noise to simulate this self-interference such that it resulted in a 34 dB value for C/N_o.

In a real GPS receiver, this level of self-interference is a not fixed value, however. Figure 18 shows how the level of interference varies with time and causes C/N_o to fall to nearly 34 dB for individual satellites only for brief periods of time. Because of the stringency of the aviation safety-of-life requirements, the aviation community recommends using a 34 dB C/N_o for its analyses as it is slightly worse than the worst-case value. However, as can be seen in Figure 2, when some C/N_o values are low, most of the other satellite signals have C/N_o ratios around 37 dB.[23] In this figure, the receiver is tracking approximately ten satellites. Of these ten, when the worst satellite has a C/N_o slightly higher than 34 dB (at around 30,000 seconds); two are at about 35 dB; six are around 37 dB; and one is over 40 dB. NTIA's simulation of a 34 dB C/N_o ratio for all satellite signals in all of its analyzed configurations is therefore unrealistic.

[23] The MSS advocates have used this 37 dB C/No value. *See* RTCA DO-235, Table E.7-1.

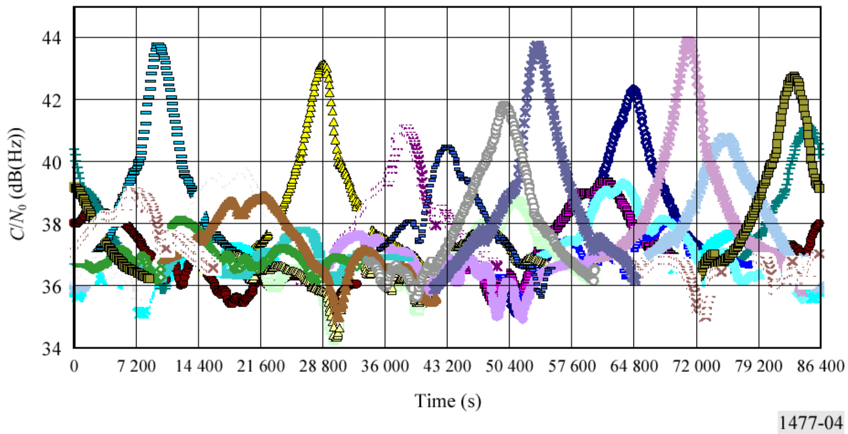

Figure 18. C/N$_o$ Levels for a GPS Receiver Tracking Multiple Satellites[24]

Aircraft can reasonably expect to have the best possible propagation paths to the GPS satellites, so in their case, this self-interference noise is a performance limit. However, this would not be the case for GPS receivers in other operational environments. Terrestrial applications of GPS receivers, especially those that are used in urban and suburban environments, face harsh propagation environments. The dominant factors in GPS performance in urban and suburban environments will be signal blockages and multipath fading, not self-interference. Because of this TDC believes a rational and realistic C/N$_o$ value for all applications other than aviation applications is 37 dB.[25]

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[24] Recommendation, ITU-R M.1477, Technical And Performance Characteristics Of Current And Planned Radionavigation-Satellite Service (Space-To-Earth) And Aeronautical Radionavigation Service Receivers To Be Considered In Interference Studies In The Band 1 559-1 610 MHz (Nov. 2000), Figure 4.

[25] *See* n.23, *supra* (explaining that the MSS advocates have used a C/No of 37 dB).

5. NTIA Failed to Account for the Use of a Circularly Polarized Antenna

NTIA failed to note that GPS antenna gain is specified as dBic (decibels relative to an isotropic circularly polarized antenna).[26] NTIA did not account for the circular to isotropic polarization change; this resulted in a 3 dB overstatement of the power that would be received by a GPS antenna. Table 4 shows the NTIA's Operational Scenario Recommendations as corrected to include both the 37 dB C/N_o values (for all but the aviation scenarios) and the correction for the circular to linear antenna polarization.

Table 4. NTIA's Assumptions Adjusted for Realistic (37 dB) C/No Values for Non-Aviation Scenarios and Adjusted for a 3 dB Polarization to Linear

Scenario, UWB Density, GPS Rec.	NTIA's EIRP Reduction (dB)	Adjusted Reduction (dB)
Maritime Outdoor, Multiple, C/A	15.03	9.43
Maritime Indoor, Multiple, C/A	6.31	0.71
Railway Outdoor, Multiple, C/A	22.51	16.91
Railway Indoor, Multiple, C/A	19.68	14.08
Terrestrial Outdoor, Multiple, C/A	26.83	21.23
Terrestrial Outdoor, Single, C/A	31.79	26.19
Terrestrial Indoor, Multiple, C/A	22.14	16.54
Surveying Outdoor, Multiple, Code Less	24.27	21.27
Surveying Outdoor, Single, Code Less	-41.30	-41.30
Aviation NPA Outdoor, Multiple, C/A	17.49	14.49
Aviation ER Outdoor, Multiple, C/A	-41.30	-41.30
Aviation ER Indoor, Multiple, C/A	-41.30	-41.30

VI. Corrections to Operational Scenarios As Described by NTIA

With the exception of the aviation scenarios, the NTIA provides only the thinnest descriptions of the scenarios it has used to develop its requirements that UWB emissions

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[26] *See, e.g.*, Table E at E-40 in Assessment of Radio Frequency Interference Relevant to the GNSS, RTCA Document No. RTCA/DO-235 (Jan. 27, 1997).

must be reduced from Part 15 Class B levels. Consequently, for many of the scenarios that the NTIA has listed, it is difficult to visualize how exactly how UWB transmitters would come into the area of the GPS receiver. Nevertheless, based on what can be inferred from the NTIA report, TDC believes the NTIA's scenarios have numerous faulty assumptions.

As can be seen from Table 5, the only true safety-of-life application that the NTIA's analyses could possibly project a need for a reduction in UWB power is their Aviation Non-Precision Approach scenario. As discussed in this section, TDC believes, when realistic mathematical assumptions are used, there is no valid argument for a requirement for a reduction below Part 15 Class B levels even for this scenario.

A. Erroneous Assumptions

1. Propagation of L-Band Signals Transmitted from Satellites

Many analyses of the impact of UWB on narrowband systems, including the NTIA's GPS report, have assumed simplistic propagation models. Below TDC draws from propagation literature to show that, within buildings, where UWB is likely to be found, GPS will not have a safety-of-life level of reliability. The GPS link budget, assuming minimum GPS signal power, contains only about 6 dB of margin and signal attenuation in excess of this margin can prevent reception of the GPS signal. TDC has found that 15% of the time in suburban areas, 27% of the time in urban mid-rise areas, and 36% of the time in urban steel canyons GPS satellites are unavailable because the excess loss is significantly greater than 6 dB.[27] These are the regions with the highest densities of people. Since the GPS link budget, when assuming the minimum GPS signal power, has only about 6 dB of margin, signal attenuations greater than this margin prevent the reception of the GPS signal.

The NTIA report implies that all GPS satellites will be available 100% of the time in all geographic areas, and then implies that UWB signals would always reduce the performance of the GPS system. However, these implications are flawed because NTIA does not utilize realistic propagation assumptions. It must be understood that free space propagation paths are very rare. This is certainly true for GPS transmissions.

The key factors that characterize GPS signal propagation path are multipath and blockages. Blockages from buildings and trees are a significant factor for the use of GPS in urban and suburban areas. In its analyses, the NTIA assumes a 9 dB loss for UWB transmissions from within a building. But that 9 dB also applies to GPS transmissions to GPS receivers within buildings; which suggests that, on average, GPS receivers won't work within buildings. Figure 19 taken from Goldhirsh and Vogel[28] shows the attenuation for an exterior room they measured. It also shows a value similar to the 9 dB value used by the NTIA. However, this graph also shows that 10% of the time the fading

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[27] *See* Table 5.

[28] J. Goldhirsh & W. J. Vogel, Handbook of Propagation Effects for Vehicular and Personal Mobile Satellite Systems, The Johns Hopkins University, Applied Physics Laboratory (JHUAPL report number A2A-98-U-0-021) and the University of Texas at Austin, Electrical Engineering Research Laboratory (UT:EERL report number EERL-98-12A) (Dec. 1998) at 8-6.

at the L1 GPS band would be worse than 16 dB. It also shows that at the L1 band frequency, a GPS signal would experience a fade of 11 dB or more 50% of the time.

This data shows the impact of just a single wall. The measurements were made in a room with a window in a building constructed of concrete block masonry. When there are whole buildings in the propagation path or when measured in an interior room, the attenuation would clearly be much greater. Moreover, there are other features in the environment to consider as well.

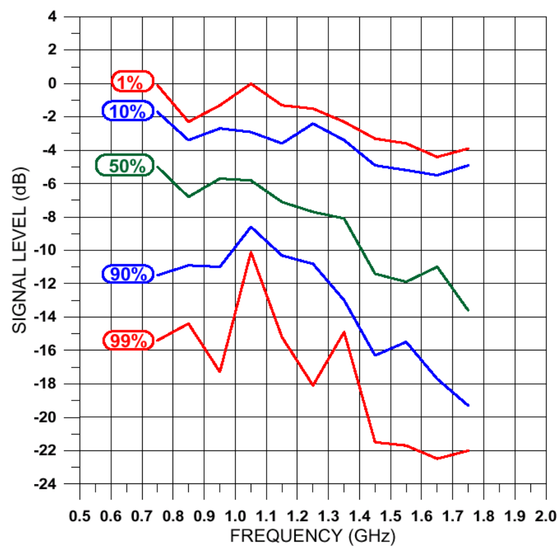

Figure 19. Cumulative probabilities of relative signal levels as a function of frequency.[29]

While no two trees are exactly alike, Goldhirsh and Vogel present measurements that suggest an average attenuation at 1.6 GHz for foliage would be around 11 dB.[30] The impact of a stand of trees along a roadway is shown in Figure 20. The model presented in

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29 *See* Goldhirsh & Vogel at 8-6.

30 Goldhirsh & Vogel at 2-5.

this Figure says that for transmissions from satellites with low elevation angles, a receiver operating along a tree-lined street will experience significant fading. For example, for a satellite halfway between the horizon and the zenith, there is a 10% probability that the fade will be 9 dB or more. This is clearly applicable to GPS transmissions.

It is easy to visualize that as GPS satellites get closer to the horizon, GPS signals are much more likely to encounter blockages – buildings and trees for example. Satellites that are higher in the sky have a lesser probability of being blocked, but are less likely to find a direct path into buildings.

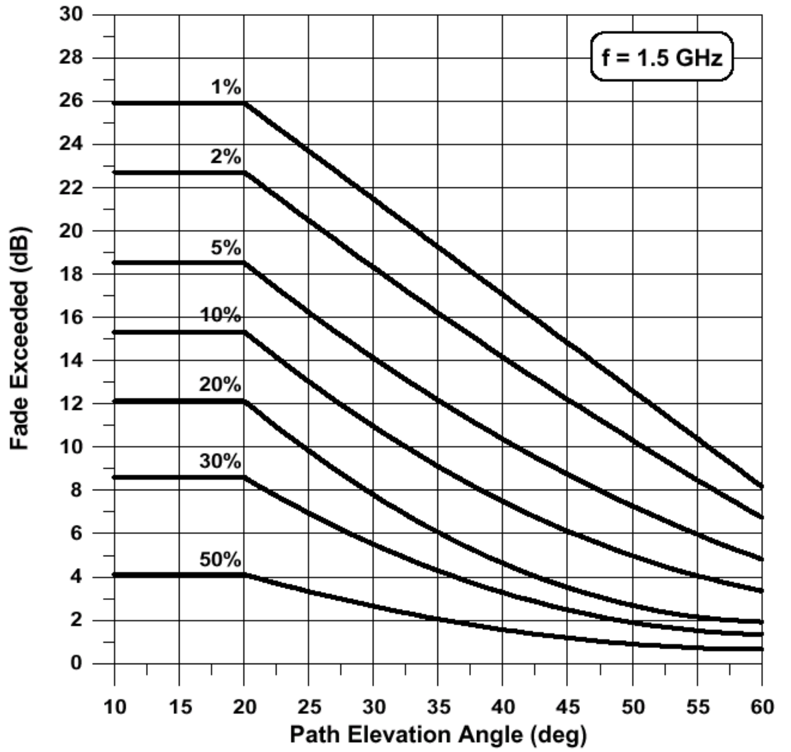

Figure 20. An estimate of L-Band (1.5 GHz) fade values exceeded versus elevation angle for a family of fixed percentages for a roadway lined with trees.[31]

A. Davidson reports that GPS signals propagate to the earth's surface in either a "two path summation" mode or a "signal shadowed" mode in suburban residential, urban and steel canyon areas[32]. The measured results are summarized in Table 5.

In the mid-latitudes, the median (50%) elevation angle to the satellite is less than 35 deg. From Table 5 we see that GPS satellites are in the signal shadowed mode at least

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[31] *See id.* at 3-11.

[32] A. Davidson, "Land Mobile Radio Propagation to Satellites," Proc. of 1991 Antenna Applications Symposium, U. of Illinois, 25-27 Sept. 1991. Davidson's results support the earlier measurements of G. C. Hess, "Land Mobile Satellite Excess Path Loss Measurements", IEEE Trans. on Vehicular Technology, Vol. VT-29, No. 2, May 1980, pp. 290-297.

30% of the time that the satellite is below 35 deg in a suburban environment (excess loss is 6.5 dB), 55% of the time in urban mid-rise areas (excess signal shadowed loss is 12 to 13 dB), and 72% of the time in urban steel canyons (excess loss is 16 dB). Thus for a significant fraction of the time (50% of 30% = 15% in suburban, 50% of 55% = 27% in urban mid-rise, and 50% of 72% = 36% in urban steel canyons) GPS satellites are unavailable (excess loss is greater than 6 dB) in many metropolitan regions.

Table 5. Propagation Model for GPS Signal by Environment.

	TWO PATH SUMMATION MODE			***SIGNAL SHADOWED MODE***		
Elevation, deg	***Mean, dB***	***Standard deviation, dB***	***% time spent in mode***	***Mean, dB***	***Standard deviation, dB***	***Max., dB***
Suburban Residential						
10-20	1.0	2.0	50	6.5	5.0	18.0
20-35	0.5	2.5	70	6.5	4.5	19.0
35-65	1.0	2.0	90	6.5	4.5	22.0
Urban Mid-Rise						
10-20	1.0	2.5	30	13.0	4.0	20.5
20-35	-1.0	2.25	45	12.0	5.0	23.5
35-65	-0.5	2.0	75	11.0	6.0	25.0
Steel Canyons						
20-35	-2.0	2.0	28	16.0	5.5	23.0
35-65	-1.0	2.0	45	13.5	6.5	25.5

In conclusion, it can be seen that for many if not all of NTIA's operational scenarios, the assumption that the GPS signal will always be available to a safety-of-life level of certainty is seriously flawed.

2. Propagation Path for UWB signal

The NTIA also assumes that the propagation path between the UWB emitter and the GPS receiver is dominantly line-of-sight. The only attenuation the NTIA included was a 9 dB reduction for average attenuation through the exterior wall of a building for scenarios where it assumed that the UWB emitter was within a building. This will lead to overstating the impact of UWB emissions.

The same factors discussed in Section VI.A.1 apply to UWB signals. Even over short ranges there will be clutter, ground reflections, and vegetation. The factors will attenuate signals and create multipath. Fading will occur, for example:

- 5 dB fades or more occur 27% of the time;
- 10 dB fades or more occur 9% of the time; and
- 15 dB or more occur 3% of the time.

Movement in the environment, *e.g.,* people, branches, and cars, creates multipath effects; these effects should have been incorporated into NTIA's model.

3. UWB Antenna Alignment

In the case of the NTIA's non-precision approach scenario, the NTIA assumed that all UWB emitters would be directed upward and the maximum amount of energy would be directed upward. However, for the non-aviation scenarios, it seems probable that the main beam of the UWB antenna is not pointed into the GPS antenna. For most of UWB applications, omni-directional dipole antennas will be used. Thus, the NTIA analysis overstates the interference potential by not incorporating this factor. TDC has used a –2 dB factor to account for this. (This is independent of polarization losses.)

4. UWB "Allocation"

Time Domain does not believe that assigning a total power allocation to UWB (as opposed to other Part 15 devices) is necessary or reasonable. The operational scenario analysis that "allows for" a certain amount of UWB power in some situations and a different amount in other situations is like allowing the emissions from Palm Pilots to be at Part 15 power levels when the devices are being used outdoors, but requires the power level to be reduced indoors to account for the possible existence of emissions from personal computers.

5. Manufacturing Variation of GPS Receivers

TDC objects to the NTIA's 3 dB adjustment for "manufacturing variations." NTIA stated in its report:

> The ITS measurement effort did not consider multiple samples of each model of GPS receiver. Therefore, it is not possible to determine if there is a statistical variation in the performance of GPS receivers. As an estimate,

> a 3 dB factor has been included to take into account likely variations among GPS receivers of the same model as well as variations in GPS receivers from different manufacturers.[33]

TDC cannot imagine that the aviation industry would accept a 3 dB variance from their stringent specifications (which corresponds to a 50% variance); nor does TDC believe that any safety-of-life application or survey receivers would also be allowed to operate at anything but the highest levels of performance. But the NTIA included a 3 dB adjustment for manufacturing variation from their specifications in their aviation and surveying scenarios. A variance greater than 3 dB will likely occur but its inappropriate to assume the 3 dB should be added to account for the variation. After all, a "manufacturing variance" is a 50/50 probability that the receiver used will deviate from the norm – in either a positive or negative direction.

TDC notes that the cellular telephone industry has established tight specifications for their handsets and manufacturers are able to maintain those specifications. In our experience quality manufacturing bounds its product performance far tighter than the NTIA assumed. Therefore, TDC believes the 3 dB manufacturers variation is already accounted for in the other parameters and has ignored it in its analysis. Moreover, the receivers allegedly all meet the MOPs performance criteria. Thus, an individual receiver's performance will be better than or equal to what is required to meet the MOPS. Since NTIA's mathematical analysis is based on a receiver meeting the MOPS, it can be assumed that, mathematically speaking, their model receiver would be at a performance

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[33] NTIA Report Section 3.1.6 at 3-5.

level of just meeting the specification. In this case, actual receivers would typically be better that the mathematically modeled receiver used in the NTIA analysis in which case the 3 dB adjustment should actually be in favor of allowing higher UWB power levels.

6. Using a 10 m Separation Distance for the Terrestrial Applications

In its operational scenario for terrestrial applications, NTIA chose to use a separation distance of 2 m, a value suggested by the US GPS Industry Council. NTIA apparently decided to use this distance even though an operational scenario for terrestrial applications NTIA developed for the December 7, 2000, Operational Scenarios meeting recommended the use of a 10 m separation distance. In fact, in the document NTIA presented at this meeting[34], NTIA stated that "It is believed that this is a reasonable distance separation because a GPS user will have a large measure of control over its immediate environment at a distance of 10 meters." Time Domain agrees, and believes that a 2 meter separation distance cannot be supported. One only has to ask "how many Part 15 devices could be authorized if this criteria were applied to them" to realize just how unsupportable this distance is.

In 1979, the FCC issued an Order intended to protect television receivers from interference caused by computers. In this Order, the Commission found that interfering

[34] Document Entitled "Proposal for a General Operational Scenario for Assessing Potential Interference to Terrestrial Global Positioning System Receivers From Ultrawideband Systems, presented by NTIA at the Operational Scenarios Meeting (Dec. 7, 2000).

devices less than 10 meters apart are typically under the control of a single user who can control their operation to limit interference. The Commission explained:

> The separation distance is a basic parameter in computing tolerable levels of signal that may be radiated by a computer. We are most interested in protecting an individual who is receiving interference from his neighbor's computer. To a lesser extent, we are concerned about devices in the same household. In a household, the homeowner or apartment dweller can choose which device he wants to operate. For example, if a second TV set in the same house is receiving interference from a computing device in an adjacent room, there are a number of steps he can take to remedy or minimize the problem, or as a last option, he can always choose which is most important to operate--the TV set or the computing device. One of the first and easiest corrective steps he can take is to move the two pieces of equipment further apart. … The Commission recognizes, of course, that there will be instances when the separation distance is less than 10 meters. In many such cases, we anticipate there will be mitigating circumstances which will counteract the shorter separation distance, such as greater attenuation due to additional walls between the computer and the TV receiver. We also anticipate that, in many cases, the orientation of the TV receiver with respect to the computer will help reduce pickup of the undesired computer signal.[35]

About 10 years after the FCC adopted the limits for computing devices in 1979, it expanded the limits in frequency (i.e. above 1000 MHz) and made them generally applicable in its Part 15 rewrite of 1989. This Order and subsequent rulings have affirmed the 10 meter separation distance.

> In general, we find that interference cases involving a single user operating both the interfering device and the victim receiver are more easily corrected than those instances where these devices are operated by different parties. Such interference problems involving a single use can usually be corrected by simply reorienting the lamp or receiver. … The public is better served by technical standards designed primarily to minimize interference

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[35] Amendment of Part 15 to redefine and clarify the rules governing restricted radiation devices and low power communication devices, 47 RR 2d 256, 79 FCC 2d 67 (1980).

> problems in those situations where the interfering device and the victim receiver are not under common control.[36]

We believe that NTIA's choice to use a 2 meter separation distance is not supported in any rulemaking. The FCC has chosen not to regulate for situations in which the user is either self-interfering or can otherwise control the situation by changing the orientation or location of the device he/she is trying to use. Accordingly, in the analysis that follows, TDC has incorporated a 10 meter separation distance into NTIA's operational scenarios.

B. The NTIA's Results Adjusted for Realistic Assumptions

When more realistic assumptions are incorporated into the NTIA analyses the results are dramatically different. Table 6 presents NTIA's data with realistic assumptions incorporated.

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[36] FCC Regulations Concerning RF Lighting Devices, *Report & Order*, 63 RR 2d 1714, 2 FCC Rcd 6775 (1987). *See also* Amendment of Part 15 to redefine and clarify the rules governing restricted radiation devices and low power communication devices. 47 RR 2d 256, 79 FCC 2d 67 (1980) ("The radiation limit for a Class B computing device … is designed to provide a reasonable degree of protection for a TV receiver in a residential area receiving at least a Grade A TV signal and located 10 meters (33 feet) or more from Class B computers with one or more walls between the computer and TV receiver. … In arguing [that a separation distance of 10 meters is inadequate to protect TV reception], both Atari and AMST fail to acknowledge the large number of variables in developing such a limit. The likelihood of worst case factors occurring at the same time is very small. In addition to the dimensions of time, space and frequency, … the First Report discusses additional factors such as: greater attenuation due to walls and orientation of both the TV antenna and home computers could substantially reduce emanations of computers located closer than 10 meters.").

Table 6. Realistic Assumptions Dramatically Change the Results of the NTIA's Analyses[37]

Scenario, UWB Density, GPS Rec.	NTIA Initial Assumptions (dB)	Adjusted Assumptions (dB)
Maritime Outdoor, Multiple, C/A	15.0	-6.8
Maritime Indoor, Multiple, C/A	6.3	-15.5
Railway Outdoor, Multiple, C/A	22.5	-9.5
Railway Indoor, Multiple, C/A	19.7	-11.3
Terrestrial Outdoor, Multiple, C/A	26.8	-5.0
Terrestrial Outdoor, Single, C/A	31.8	-10.0
Terrestrial Indoor, Multiple, C/A	22.1	-8.7
Surveying Outdoor, Multiple, Code Less	24.3	-5.0
Surveying Outdoor, Single, Code Less	27.3	-4.6
Aviation NPA Outdoor, Multiple, C/A	17.5	-3.8
Aviation ER Outdoor, Multiple, C/A	-5.8	-12.0
Aviation ER Indoor, Multiple, C/A	-4.8	-14.1

Positive values would indicate a need to reduce the emitted UWB power from the Part 15 Class B level. Negative values indicate that there is no need to reduce the limit, because the model suggests that there is a margin.

Scenario By Scenario Review. The analysis below assumes white noise-like UWB emitters.

a) Overview of Variables

Some variables are from the NTIA Report (at 3-1). TDC has added additional variable to account for factors the NTIA left out.

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[37] Positive values indicate a need to reduce the emitted UWB power from the Part 15 Class B level; negative values indicate that there is no need to reduce the limit, because the model suggests that there is some margin.

Table 7. GPS Link Budget Variables

Variable	Definition	Comment
I_T	The interference threshold of the UWB signal at the input of the GPS receiver (dBm/MHz).	$I_{UWB} - 4.5dBic$
I_{UWB}	The measured UWB power at the input to the GPS receiver (dBm/20 MHz).	Table 201 from NTIA Report. T his is the minimum of the white-noise-like power levels identified by the NTIA.
M	Linear to circular antenna polarization loss (dB).	This value is always –3 dB. See Section V.B.5.
G_r	The gain of the GPS antenna in the direction of the UWB device (dBic).	From NTIA Report.
L_P	The radio wave free space propagation loss (dB).	$20Log_{10}(F_{MHz}) + 20Log_{10}(D_{\min}) - 27.5dB$
L_{veg}	Propagation loss due to vegetation (dB).	Scenario specific
$G_{T\theta}$	Off-axis alignment loss of UWB transmit antenna with respect to the GPS receiving antenna (dB).	Scenario specific. See Section VI.A.3.
L_{mult}	The factor to account for multiple UWB devices (dB).	From NTIA Report.
N_{UWB}	Number of noise like UWB devices	$10Log_{10}(L_{mult})$
L_{allot}	The factor for interference allotment (dB).	Zero; see Section VI.A.4.
L_{man}	The factor to account for manufacturer variations in GPS receivers (dB).	Always 0; see Section VI.A.5.
L_{AF}	The activity factor of the UWB device (dB).	Scenario specific.

L_{BA}	The building attenuation loss (dB).	From NTIA Report.
L_{safety}	The aviation safety margin (dB).	From ITU-R 1477; for aviation scenarios only. See Section V.B.4.
L_{fade}	Loss due to multipath fading from static and dynamic obstructions such as cars, people, etc. (dB).	See Section VI.A.2.
D_{min}	Minimum separation (meters).	From NTIA, unless NTIA used a distance less than 10 meters. See Section VI.A.6.
$EIRP_{max}$	The maximum allowable EIRP of the UWB device (dBm/MHz).	Calculated from the above.

b) Maritime Scenarios

The NTIA's maritime scenarios assume vessels moving through constricted waterways. Movement will move the vessel away from an interferer and will result in multipath, which will result in significant periods when the UWB signal has faded. All of this ensures that GPS will remain effective even in the presence of UWB emitters. Using conservative assumptions, TDC believes that the NTIA scenario would have shown at least 6 dB to 15 dB of margin for noise-like UWB emitters operating at Part 15 Class B power levels.

The NTIA assumed the maritime applications would use a C/A code receivers with antennas mounted atop a mast. Thus, UWB emitters would be in the lowest gain aspect of the GPS receive antenna. After adjusting the values of the variable in accordance with Table 7, TDC also adjusted the values of:

- The off-axis alignment factor, $G_{T\theta}$, to account for the fact that not all the UWB emitters will have their antennas patterns bore-sighted on the GPS receiver antenna. A 2 dB reduction of UWB signal power for this scenario.

- The scattering loss, L_{fade}, which results from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls. A very small 2 dB reduction of UWB signal power has been incorporated for this scenario.

- The loss due to vegetation, L_{veg}, because it would seem likely that UWB users would be on the shore where there would be vegetation. A very small 2 dB reduction of UWB signal power has been incorporated for this scenario.

- Activity factor, L_{AF}, to account for the fact that UWB emitters will not be transmitting continuously, e.g., if one UWB device is transmitting then another must be receiving. A 3 dB reduction in UWB power has been assumed.

Table 8. Maritime Scenarios Adjusted for Realistic Assumptions

	Outdoor		Indoor	
Variable Name	TDC Values	NTIA Values	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.0	-95.0	-95.0	-95.0
34 C/No to 37 C/No Adj.	2.6	0.0	2.6	0.0
I_T (dBm/20 MHz)	-99.5	-99.5	-99.5	-99.5
* M (dB)	-3.0	0.0	-3.0	0.0
G_r (dBic)	0.0	0.0	0.0	0.0
* G_T (dBi)	-1.3	0.0	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0	-2.0	0.0
L_p (dB)	68.2	68.2	67.9	67.9
* L_{fade} (dB)	-2.0	0.0	-4.0	0.0
* L_{veg} (dB)	-2.0	0.0	0.0	0.0
N_{UWB}	4.0	4.0	4.0	4.0
$L_{mult\ (dB)}$	6.0	6.0	6.0	6.0
L_{allot} (dB)	0.0	3.0	0.0	3.0
L_{man} (dB)	0.0	3.0	0.0	3.0
L_{AF} (dB)	3.0	0.0	3.0	0.0
L_{BA} (dB)	0.0	0.0	9.0	9.0
L_{safety} (dB)	0.0	0.0	0.0	0.0
D_{min}	38.9	38.9	37.7	37.7
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0	13.0	13.0
$EIRP_{max}$	-34.5	-56.3	-25.8	-47.6
FCC EIRP (dBm/MHz)	-41.3	-41.3	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-6.8	15.0	-15.5	6.3

c) Railway Scenarios

NTIA's railway scenarios also assume moving. As with the maritime scenarios, movement will separate the vehicle from the interferer and will result in multipath, which will lead to significant periods when the UWB signal has faded. This ensures that GPS will remain effective even in the presence of UWB emitters. Using conservative assumptions, TDC believes that the NTIA scenario would have shown at least 9 dB to 11 dB of margin for noise-like UWB emitters operating at Part 15 Class B power levels.

Presumably, the GPS receiver is mounted atop railroad cars and engines. Within a rail yard, the railroad operator would have control; thus, UWB emitters would only be within a few meters when the equipment is being moved between yards. After adjusting the values of the variable in accordance with Table 7, TDC also adjusted the values of:

- The off-axis alignment factor, $G_{T\theta}$, to account for the fact that not all the UWB emitters will have their antennas patterns bore-sighted on the GPS receiver antenna. A 2 dB reduction of UWB signal power for this scenario.

- The scattering loss, L_{fade}, which results from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls. A 10 dB reduction of UWB signal power has been incorporated for this scenario since there will be very strong multipath signals for the assumed antenna alignments (from reflections off the metal railroad equipment). Fades 5 dB or deeper occur 27% of the time and 10 dB or greater fades occur 9% of the time in cluttered environments.

- The loss due to vegetation, L_{veg}, because it would seem likely that railroad tracks located near public areas would have vegetation. A very small 2 dB reduction of UWB signal power has been incorporated for this scenario.

- Activity factor, L_{AF}, to account for the fact that UWB emitters will not be transmitting continuously, e.g., if one UWB device is transmitting then another must be receiving. A 3 dB reduction in UWB power has been assumed.

Table 9. Railway Scenarios Adjusted for Realistic Assumptions

	Outdoor		Indoor	
Variable Name	TDC Values	NTIA Values	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.0	-95.0	-95.0	-95.0
34 C/No to 37 C/No Adj.	2.6	0.0	2.6	0.0
I_T (dBm/20 MHz)	-99.5	-99.5	-99.5	-99.5
* M (dB)	-3.0	0.0	-3.0	0.0
G_r (dBic)	-4.5	-4.5	0.0	0.0
* G_T (dBi)	-1.3	0.0	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0	-2.0	0.0
L_p (dB)	56.4	56.2	56.4	53.3
* L_{fade} (dB)	-10.0	0.0	-10.0	0.0
* L_{veg} (dB)	-4.0	0.0	0.0	0.0
N_{UWB}	4.0	4.0	3.0	3.0
L_{mult} (dB)	6.0	6.0	4.8	4.8
L_{allot} (dB)	0.0	3.0	0.0	3.0
L_{man} (dB)	0.0	3.0	0.0	3.0
L_{AF} (dB)	3.0	0.0	3.0	0.0
L_{BA} (dB)	0.0	0.0	9.0	9.0
L_{safety} (dB)	0.0	0.0	0.0	0.0
D_{min}	10.0	9.8	10.0	7.0
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0	13.0	13.0
$EIRP_{max}$	-31.8	-63.8	-30.0	-61.0
FCC EIRP (dBm/MHz)	-41.3	-41.3	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-9.5	22.5	-11.3	19.7

d) Terrestrial Scenarios

NTIA assumed for its terrestrial scenarios (which are predominantly consumer applications), that the devices should have a 2 meter protection criterion. TDC disagrees, but notes that the JHUAPL Report found that even with a nearly ideal propagation the data showed that in a radiated test regime, reacquisition time started to deviate from nominal at about 3 meters. In the real-world the impact of UWB would have been far less perceptible. Even with conservative assumptions, TDC believes the NTIA would have projected 5 dB to 10 dB of margin.

NTIA assumed in their terrestrial scenarios that the applications would use a C/A code receivers. The NTIA assumed that GPS receivers would be used by consumers for a variety of applications, including receivers integrated into cellphones as part of an E911 solution. After adjusting the values of the variable in accordance with Table 7, TDC also adjusted the values of:

- The off-axis alignment factor, $G_{T\theta}$, to account for the fact that not all the UWB emitters will have their antennas patterns bore-sighted on the GPS receiver antenna. A 2 dB reduction of UWB signal power for this scenario.

- The scattering loss, L_{fade}, which results from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls. A 10 dB reduction of UWB signal power has been incorporated for this scenario since there will be very strong multipath signals for the assumed antenna. 10 dB fades occur 68% of the time in cluttered environments.

- A 3 dB reduction of UWB signal power has been incorporated for the single terrestrial scenario for loss due to vegetation, L_{veg}. A 3 dB reduction is well less than a single tree's average attenuation. Since people often occupy spaces with shrubbery and trees this seems reasonable. A 4 B factor was included for the multiple scenario, since with multiple units it seemed more probable that there would be additional shadowing.

- Activity factor, L_{AF}, to account for the fact that UWB emitters will not be transmitting continuously, e.g., if one UWB device is transmitting then another must be receiving. A 3 dB reduction in UWB power has been assumed.

Table 10. Terrestrial Scenarios with Multiple UWB Emitters Adjusted for Realistic Assumptions.

Multiple Interferer Terrestrial Operational Scenario for a C/A Code GPS Receiver				
	Outdoor		Indoor	
Variable Name	TDC Values	NTIA Values	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.0	-95.0	-95.0	-95.0
34 C/No to 37 C/No Adj.	2.6	0.0	2.6	0.0
I_T (dBm/20 MHz)	-99.5	-99.5	-99.5	-99.5
* M (dB)	-3.0	0.0	-3.0	0.0
G_r (dBic)	0.0	0.0	0.0	3.0
* G_T (dBi)	-1.3	0.0	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0	-2.0	0.0
L_p (dB)	56.4	56.4	55.1	55.1
* L_{fade} (dB)	-10.0	0.0	-10.0	0.0
* L_{veg} (dB)	-4.0	0.0	0.0	0.0
N_{UWB}	4.0	4.0	4.0	4.0
$L_{mult\ (dB)}$	6.0	6.0	6.0	6.0
L_{allot} (dB)	0.0	3.0	0.0	3.0
L_{man} (dB)	0.0	3.0	0.0	3.0
L_{AF} (dB)	3.0	0.0	3.0	0.0
L_{BA} (dB)	0.0	0.0	9.0	9.0
L_{safety} (dB)	0.0	0.0	0.0	0.0
D_{min}	10.0	10.0	8.6	8.6
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0	13.0	13.0
$EIRP_{max}$	-36.3	-68.1	-32.6	-63.4
FCC EIRP (dBm/MHz)	-41.3	-41.3	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-5.0	26.8	-8.7	22.1

Table 11. Terrestrial Scenarios with Single UWB Emitter Adjusted for Realistic Assumptions.

	Outdoor	
Variable Name	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.0	-95.0
34 C/No to 37 C/No Adj.	2.6	0.0
I_T (dBm/20 MHz)	-99.5	-99.5
* M (dB)	-3.0	0.0
G_r (dBic)	0.0	0.0
* G_T (dBi)	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0
L_p (dB)	56.4	42.4
* L_{fade} (dB)	-10.0	0.0
* L_{veg} (dB)	-3.0	0.0
N_{UWB}	1.0	1.0
$L_{mult\ (dB)}$	0.0	0.0
L_{allot} (dB)	0.0	0.0
L_{man} (dB)	0.0	3.0
L_{AF} (dB)	3.0	0.0
L_{BA} (dB)	0.0	0.0
L_{safety} (dB)	0.0	0.0
D_{min}	10.0	2.0
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0
$EIRP_{max}$	-31.3	-73.1
FCC EIRP (dBm/MHz)	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-10.0	31.8

e) Surveying Scenarios

NTIA's surveying scenarios do not assume motion; this is because in order for survey receivers to achieve the highest possible level of performance they cannot be moved quickly. Moreover, they must be placed such that there are no obstructions that would block the sky – and satellites – and create complex multipath. However, it is likely that if a UWB emitter is close enough to be near a survey receiver, it will be moving and so again the UWB signal will experience multipath fading. Also it seems unlikely that the UWB device would be transmitting all the time, so there will be periods when the UWB signal is not present. All of this ensures that GPS will remain effective even in the presence of UWB emitters. Using conservative assumptions, TDC believes that the NTIA scenario would have shown at least 5 dB of margin for noise-like UWB emitters operating at Part 15 Class B power levels.

NTIA assumed in their surveying scenarios that the applications would use a C/A code receivers that integrated a L2 codeless receiver capability to improve accuracy with antennas mounted atop tripods 3 meters above the ground. To achieve best performance such systems must be located away from structures to ensure an unobstructed view of the sky. The NTIA assumed that UWB emitters would be located somewhere where they would be 10 meters above the ground. After adjusting the values of the variable in accordance with Table 7, TDC also adjusted the values of:

- The off-axis alignment factor, $G_{T\theta}$, to account for the fact that not all the UWB emitters will have their antennas patterns bore-sighted on the GPS receiver antenna. A 2 dB reduction of UWB signal power for this scenario.

- The scattering loss, L_{fade}, which results from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls. A 10 dB reduction of UWB signal power has been incorporated for this scenario since there will be very strong multipath signals for the assumed antenna alignments. 10 dB fades occur 68% of the time in cluttered environments.

- A 4 dB reduction of UWB signal power has been incorporated for this scenario for loss due to vegetation, L_{veg}. A 4 dB reduction is well less than a single tree's average attenuation. Since people often occupy spaces with shrubbery and trees this seems reasonable.

- Activity factor, L_{AF}, to account for the fact that UWB emitters will not be transmitting continuously, e.g., if one UWB device is transmitting then another must be receiving. A 3 dB reduction in UWB power has been assumed.

In the multiple emitter case, the NTIA assumed that two emitters were so much further away than the nearest emitter that the power contributed by the other two emitters was negligible relative to the nearest emitter (thus, TDC set the number of emitters to 1).

Table 12. Surveying Scenarios with Multiple UWB Emitters Adjusted for Realistic Assumptions.

	Outdoor	
Variable Name	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-108.0	-108.0
34 C/No to 37 C/No Adj.	2.6	0.0
I_T (dBm/20 MHz)	-112.5	-112.5
* M (dB)	-3.0	0.0
G_r (dBic)	0.0	0.0
* G_T (dBi)	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0
L_p (dB)	65.9	65.9
* L_{fade} (dB)	-10.0	0.0
* L_{veg} (dB)	-4.0	0.0
N_{UWB}	1.0	1.0
$L_{mult\ (dB)}$	0.0	0.0
L_{allot} (dB)	0.0	3.0
L_{man} (dB)	0.0	3.0
L_{AF} (dB)	3.0	0.0
L_{BA} (dB)	0.0	0.0
L_{safety} (dB)	0.0	0.0
D_{min}	30.0	30.0
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0
$EIRP_{max}$	-36.3	-65.6
FCC EIRP (dBm/MHz)	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-5.0	24.3

Table 13. Surveying Scenarios with A Single UWB Emitter Adjusted for Realistic Assumptions.

	Outdoor	
Variable Name	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-108.00	-108.00
34 C/No to 37 C/No Adj.	2.60	0.00
I_T (dBm/20 MHz)	-112.50	-112.50
* M (dB)	-3.00	0.00
G_r (dBic)	3.00	3.00
* G_T (dBi)	-1.25	0.00
* $G_{T\theta}$ (dB)	-2.00	0.00
L_p (dB)	65.94	65.94
* L_{fade} (dB)	-10.00	0.00
* L_{veg} (dB)	-4.00	0.00
N_{UWB}	1.00	1.00
$L_{mult\ (dB)}$	0.00	0.00
L_{allot} (dB)	0.00	3.00
L_{man} (dB)	0.00	3.00
L_{AF} (dB)	3.00	0.00
L_{BA} (dB)	0.00	0.00
L_{safety} (dB)	0.00	0.00
D_{min}	30.00	30.00
dBm/20 MHz to dBm/MHz (dB)	13.01	13.01
$EIRP_{max}$	-36.72	-68.57
FCC EIRP (dBm/MHz)	-41.30	-41.30
FCC EIRP - $EIRP_{max}$	-4.58	27.27

f) Aviation Scenarios

The NTIA's analysis really only found one safety-of-life scenario where its assumptions and analysis projected a requirement for a power limit reduction. This scenario was the aviation non-precision approach scenario. However, with a more realistic set of assumptions, even this projection is excessively conservative.

Aircraft will be moving. Such movement will separate the aircraft from UWB emitters and create multipath fading of UWB emission. TDC believes that there will be at least 3 dB to 12 dB margin even using very conservative assumptions.

After adjusting the values of the variable in accordance with Table 7, TDC also adjusted the values of:

- The off-axis alignment factor, $G_{T\theta}$, to account for the fact that not all the UWB emitters will have their antennas patterns bore-sighted on the GPS receiver antenna. A tiny 1 dB reduction of UWB signal power for this scenario.

- The scattering loss, L_{fade}, which results from the fact that most of the world is cluttered with objects that will reflect the UWB signals and create frequency selective nulls. A tiny 3 dB reduction of UWB signal power has been incorporated for this scenario since there will be multipath signals for the assumed antenna alignments and the aircraft will be moving. 10 dB fades occur 68% of the time in cluttered environments.

- TDC assumed no loss due to vegetation, L_{veg}, since the areas at the ends of the runways will probably be cleared of brush.

- TDC assumed no activity factor, L_{AF}, even though a 3 dB reduction in UWB power seems reasonable.

Table 14. Non-Precision Approach Scenario

	Outdoor	
Variable Name	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.00	-95.00
34 C/No to 37 C/No Adj.	0.00	0.00
I_T (dBm/20 MHz)	-99.50	-99.50
* M (dB)	-3.00	0.00
G_r (dBic)	-10.00	-10.00
* G_T (dBi)	-1.25	0.00
* $G_{T\theta}$ (dB)	-1.00	0.00
L_p (dB)	68.74	68.74
* L_{fade} (dB)	-3.00	0.00
* L_{veg} (dB)	0.00	0.00
N_{UWB}	4.00	4.00
$L_{mult\ (dB)}$	6.02	6.02
L_{allot} (dB)	0.00	10.00
L_{man} (dB)	0.00	3.00
L_{AF} (dB)	0.00	0.00
L_{BA} (dB)	0.00	0.00
L_{safety} (dB)	6.00	6.00
D_{min}	41.40	41.40
dBm/20 MHz to dBm/MHz (dB)	13.01	13.01
$EIRP_{max}$	-37.54	-58.79
FCC EIRP (dBm/MHz)	-41.30	-41.30
FCC EIRP - $EIRP_{max}$	-3.76	17.49

Table 15. En Route Navigation Scenario

	Outdoor		Indoor	
Variable Name	TDC Values	NTIA Values	TDC Values	NTIA Values
I_{UWB} (dBm/20 MHz)	-95.0	-95.0	-95.0	-95.0
34 C/No to 37 C/No Adj.	0.0	0.0	0.0	0.0
I_T (dBm/20 MHz)	-99.5	-99.5	-99.5	-99.5
* M (dB)	-3.0	0.0	-3.0	0.0
G_r (dBic)	-10.0	-10.0	0.0	-10.0
* G_T (dBi)	-1.3	0.0	-1.3	0.0
* $G_{T\theta}$ (dB)	-2.0	0.0	-2.0	0.0
L_p (dB)	86.0	86.0	86.0	86.0
* L_{fade} (dB)	-3.0	0.0	-10.0	0.0
* L_{veg} (dB)	0.0	0.0	0.0	0.0
N_{UWB}	4.0	4.0	10.0	10.0
$L_{mult\ (dB)}$	6.0	6.0	10.0	10.0
L_{allot} (dB)	10.0	10.0	10.0	10.0
L_{man} (dB)	0.0	3.0	0.0	3.0
L_{AF} (dB)	0.0	0.0	0.0	0.0
L_{BA} (dB)	0.0	0.0	9.0	9.0
L_{safety} (dB)	6.0	0.0	6.0	6.0
D_{min}	303.0	303.0	303.0	303.0
dBm/20 MHz to dBm/MHz (dB)	13.0	13.0	13.0	13.0
$EIRP_{max}$	-29.3	-35.5	-27.2	-36.5
FCC EIRP (dBm/MHz)	-41.3	-41.3	-41.3	-41.3
FCC EIRP - $EIRP_{max}$	-12.0	-5.8	-14.1	-4.8

The NTIA's continues to project a build-up of noise from aggregates of UWB emitters. As discussed in Section VI.A.1 a satellite's signal has significant problems getting to users on the ground, then basic physics requires the reverse is true, *i.e.,* that emissions from the ground will encounter the same propagation channel characteristics.

The propagation channels from the ground to aircraft and to satellites are essentially the same (ignoring a longer path length and ionospheric effects). This fact prevents there being an aggregate problem.

VII. GPS Conclusions

Future GPS satellites will have more power.[38] Today's Live Sky real-world performance is representative to tomorrow's minimum performance. These future satellites will have other enhancements that will further improve the GPS system's robustness; these improvements include the addition of a C/A coded channel to L2 and the new L5 channel with characteristics similar to today's L2 channel. These additional channels are necessary to overcome the inherent fragility of today's GPS system; weaknesses that were recognized well before the GPS community began to claim concern with UWB equipment. Additionally, since L2 and L5 are both lower in the spectrum than L1, the natural roll-off of UWB signals will further isolate them from UWB emissions.

While the NTIA Report states that UWB emissions threaten the GPS system, GPS is well known to be a fragile system. It is only in highly ideal circumstances that it has sufficient robustness to be used for safety-of-life applications that demand the highest possible reliability. The NTIA Report also contains analyses that state that UWB emissions should be reduced by up to 32 dB; the NTIA Report does not, however, show the actual operational impact of UWB emissions on a GPS receiver without layering on its unrealistic mathematical assumptions. Using assumptions that reflect realistic scenarios shows that GPS and UWB can coexist peacefully.

VIII. PCS and UWB

The Qualcomm submission on March 5, 2001 (the "Qualcomm Report") does not add any new or substantive information to the UWB docket. The PCS model developed by Dr. Padgett of Telcordia (the 'Telcordia Model") presents an exhaustive model of the theoretical response of a CDMA PCS system to time modulated UWB signals.[39] Documentation that Time Domain ("TDC's PCS submission") submitted to the docket also shows that this theoretical model does not accurately describe the results of real-world, open field testing.[40] TDC's PCS submission shows that even at separation distances of less than 1 meter, it was not possible to reliably detect the presence of a UWB emitter.[41]

The testing described in the Qualcomm Report suffers from weaknesses common to misunderstandings about UWB and the Part 15 general limits. TDC summarizes this shortcomings in the subsections that follow.

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38 "NAVSTAR GPS Modernization"-GPS Block IIR/IIF/OCS Modernization Status, Capt. Doug Roth, GPS JPO (May-9, 2000) (Public release-distribution unlimited).

39 *See* Sprint/TDC Joint Filing September 12, 2000.

40 *See* TDC Comments (Oct. 27, 2000) Appendix A.

41 *See* TDC Comments (Oct. 27, 2000) Appendix A, Figure 1 and associated discussion.

A. A 1 dB Increase in the Receiver Noise Floor Is Not Harmful Interference.

Qualcomm confused a 1 dB increase in a receiver's noise floor with harmful interference[42]. As TDC has already stated in its response to the NTIA Report on Potential Interference to Selected Federal Systems from Ultra-Wideband Transmission Systems[43], a 1 dB increase in a receiver's noise floor cannot be equated with either the FCC or NTIA definition of harmful interference[44], both of which state that for something to be considered harmful interference, it must cause serious degradation, obstruct or repeatedly interrupt intended communications. Moreover, the criterion for harmful interference used here by Qualcomm is the same criterion that was recently received and rejected by the Commission in the *700 MHz Report and Order*. In that proceeding, the FCC rejected an assertion from Motorola that harmful interference will result from a 1 dB increase in the noise floor. In its decision, the Commission stated that "[w]e find Motorola's assumption that a 1 dB increase in the noise floor will result in objectionable interference to be unreasonable and overly restrictive."[45]

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42 *See* Qualcomm Report at 7.

43 *See* TDC Comments (Feb. 23, 2001) at 6.

44 *See* 47 C.F.R. § 2.1; NTIA Manual § 6.1.1

45 *See* Service Rules for the 746-764 and 776-794 MHz Bands, and Revisions to Part 27 of the Commission's Rules, *Second Memorandum Opinion And Order,* WT Docket No. 99-168 at ¶ 6 (rel. Jan. 12, 2001) ("700 MHz Order").

B. The Signal Type Used by Qualcomm Included Harmful Spectral Features Instead of Using PPM to Ensure the Signal is White-Noise-Like.

Qualcomm used a 250 MHz arbitrary waveform to generate UWB trigger pulses at integer multiples of 4 ns (i.e., 1/250 MHz), and so probably created a non-white noise-like UWB signal[46]. White noise-like UWB signals cause less interference than signals with spectral features. In the case of GPS, experiments and analysis by Stanford University, NTIA and Johns Hopkins University Applied Physics Laboratory have shown that UWB signals with spectral features that fall in the passband of the receiver can cause interference even when these signals are 10 dB to 20 dB weaker than white noise-like UWB signals. Unfortunately, Qualcomm's documentation does not provide sufficient detail for TDC to evaluate the spectral characteristics of their UWB signal generator, other than to reiterate that it apparently did not utilize the sort of sophisticated time coding techniques that Time Domain and other UWB manufacturers use to make their signals white noise-like.

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[46] Qualcomm Report at 19. In order to decorrelate (make white noise-like) the spectrum of a UWB pulse train, the time coding circuitry must divide time into increments that are at least 1/10th of the length of a single cycle at a given frequency. At a frequency of 1.85 GHz, a single cycle is 540 ps long. Thus, the timing system must divide time into 54 ps increments if the signal is to be noise-like within the PCS band. TDC's systems trigger pulse generation at integer multiples of 3 ps; an arbitrary waveform generator would have to operate at a frequency of 333.3 GHz to have equivalent timing capabilities.

C. Contrary to What Qualcomm Argues, the Analyzed UWB Signals Did Not Exhibit a Large Peak-to-Average Ratio.

Qualcomm stated the UWB signals will have peak powers that greatly exceed average power, but failed to note that the testing conducted by Sprint and Time Domain showed that time modulated UWB was white noise-like in the PCS receiver bandwidths and so did not exhibit a large peak-to-average ratio[47]. The UWB signal source for that testing had a 5 MHz pulse repetition frequency and would have had a peak-to-average ratio of approximately 7 dB corresponding to the statistical peak-to-average ratio of random white noise within the 5 MHz bandwidth of the PCS victim receiver.

D. The Device Modeled by Qualcomm Probably Emitted More Power than the FCC Would Allow.

Qualcomm calculated the field strength based on a reading of the Part 15 Class B rules, but did not use a device that had undergone FCC laboratory certification testing and as such, the device as described by Qualcomm probably emitted more power than would be certifiable (if the UWB signal generator was an unintentional emitter).[48] The FCC measurement technique for Part 15 devices requires a 3 meter separation distance, which introduces an additional 6 dB of signal into the receiver due to reflected components of the incident signal off the ground plane. Therefore, if one wanted to comply with existing Part 15 power levels and measurement techniques, a device subject to a 54 dB uV/m power limit at 3 meters would have to have an actual output of -47.25 dBm/MHz instead

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[47] *See* Qualcomm Report at 1.

[48] *See* Qualcomm Report at 5, 7.

of -41.25 dBm/MHz in order to meet the 54 dB uV/m field strength limit at 3 meters as measured on an open area test site covered by a reflecting ground plane. Unfortunately, Qualcomm did not document its UWB signal sufficiently to allow one to determine whether the signal they used would be certifiable under Part 15 of the Commission's rules while using its measurement technique, so their experimental data may have overstated the impact that a UWB device that DID comply with Part 15 power levels using the current measurement technique would have on the cellphone.

E. Qualcomm Used an Unrealistic Propagation Model.

Qualcomm did not incorporate a real-world propagation model for UWB signals, since it conducted all of its tests in an anechoic chamber using cables as opposed to in an outdoor, radiated environment.[49] As TDC discussed in its Reply Comments, the real world can be far more harsh than an anechoic chamber, and devices intended to be used in the real world must be designed accordingly. During TDC's joint testing with Sprint PCS[50], PCS cellphone performance in anechoic chambers was dramatically better than in an open field from which the base station was clearly visible and the propagation path was unobstructed. The model developed by Telcordia and discussed in TDC's Reply Comments to the NPRM predicted that in an anechoic chamber, IS-95 cellphones should not experience frame error rates exceeding 2% down to a signal level of –105 dBm.

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49 *See* Qualcomm Report at 8.

50 *See* TDC Comments (Oct. 27, 2000), Appendix A.

However, in the open field testing even when the signal was 20 dB higher (i.e. up to –85 dBm), the frame error rate would jump up momentarily to as much as 8%.

F. Qualcomm Used Unrealistic PCS Signal Levels.

Qualcomm calculated a requirement for a separation distance of 35 meters (which is incorrect, see below) between an UWB emitter and a PCS phone receiving a –105 dBm signal, but failed to note that a call cannot be maintained at this level in the real-world and would probably be dropped even in an anechoic chamber.[51] By using this signal level in its analysis, Qualcomm implied that an analysis of the impact of UWB on a PCS cellphone at this power level is meaningful; however, because these cellphone power levels are only useful in an anechoic chamber, TDC believes the Qualcomm analysis to be of very limited utility or significance.

Qualcomm also used an incorrect value in equation (3.9), which should read: $L_p = 20Log(d) + 20Log(f) + 32.4 + L_{adjust}$. This error, repeated in Table 3, makes Qualcomm's prediction of theoretical range of interference erroneous.[52] If one believed that a –105 dBm PCS phone power level was useful anywhere but in an anechoic chamber, and that a 1 dB increase in the thermal noise floor was the appropriate metric to use for harmful interference in the first place, then Qualcomm's predicted range could be mathematically corrected by reducing itby a factor of 1.64, *i.e.,* the interference range would not be 140 feet, but rather 85feet.

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[51] *See* Qualcomm Report at 8.

As discussed in the Telcordia Model, Qualcomm's CDMA system constantly monitors frame error rate (FER) and adjusts the transmitted power levels to achieve a 2% frame error rate. If the FER is better than 2%, the system directs the transmitter to reduce its emitted power; if the FER is worse than 2%, then the system directs an increase in transmitted power. The Qualcomm Report submission does not document the impact on FER of the UWB emitter in a real-world environment. Rather, Qualcomm ran its tests over cables, thus isolating the PCS system from the real-world. All its results were extrapolations from these unrealistic tests.

The joint testing conducted by TDC and Sprint PCS utilized a device that had been measured by an EMC compliance laboratory, which determined that, were the device an unintentional radiator, it would have qualified as a Part 15 Class B emitter. This same testing showed that the theoretical model developed by Telcordia was inadequate to predict phenomena measured in an open field. Extrapolation from that testing suggests that the impact of UWB might be observable when the PCS signal is marginal (-95 dBm) and the UWB emitter is continually transmitting and within 1.5 meters. However, even this is probably a conservative estimate, since during this testing a PCS phone operating in the open field with a signal level that fluctuated between –92 and –96 dBm did not show any impact from UWB until the continuously transmitting UWB emitter was less than 1 meter away.

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[52] *See* Qualcomm Report, Fig. 3.2

By contrast, the Qualcomm test did not ensure that its UWB signal generator complied with Part 15 Class B limits; use a UWB signal that was properly time-coded to behave in a white noise-like manner; use a realistic (or accurate) propagation model; use an appropriate metric for harmful interference; or attempt to verify their indoor testing under "real world" conditions. Accordingly, the Qualcomm Report does not provide a realistic characterization of the effect of UWB on CDMA systems, and does not offer any new insight.

IX. Conclusion

The Commission's experience shows that the general Part 15 limits – based on the prevailing digital device limits – have worked particularly well in preventing harmful interference. The FCC's regulations clearly define harmful interference as the result of signals in the passband of a victim receiver that seriously degrade or repeatedly interrupt the service. Each of the reports analyzed herein offers the basis for authorization of UWB operations on a Part 15 basis when they are read with an accurate understanding of harmful interference, the real-world signal propagation environment, and the operational characteristics of GPS, PCS, and UWB equipment.

Respectfully,
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