Before the
Federal Communications Commission
Washington DC 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules	)	ET Docket 98-753
Regarding Ultra-Wideband Transmission	)	DA 01-171
Systems	)	

Comments of XtremeSpectrum, Inc. On Issues of Interference Into Global Positioning System Receivers

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XtremeSpectrum, Inc. hereby files these Comments in response to Public Notice DA 01-753 in the above-captioned proceeding.[1] This document comments on four studies investigating UWB interference into GPS receivers.[2] In a companion filing, also submitted today, XtremeSpectrum responds to a Qualcomm filing that discusses potential interference into PCS wireless phones.[3]

IMPORTANT: The attached *XtremeSpectrum, Inc. Technical Statement on Reports Addressing Potential GPS Interference from UWB Transmitters* is not an appendix, but an integral part of these Comments.

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

2 National Telecommunications and Information Administration Special Publication 01-45 (NTIA) (filed March 9, 2001); Stanford University (Stanford) (filed March 20, 2001) (search ECFS under "National Telecommunications and Information Administration"); Johns Hopkins University (filed March 9, 2001); Department of Transportation (filed Oct. 30, 2000).

3 *Report of Qualcomm Incorporated* (filed March 5, 2001).

XtremeSpectrum conducts research in ultra-wideband communications systems, and intends to become a manufacturer once the Commission authorizes certification of such systems. XtremeSpectrum takes no position on ultra-wideband radar applications.

A. Summary.

All four GPS studies under review provide interesting and useful measurements. But they overstate the interference from UWB emitters, because the UWB systems used for testing were badly designed and were configured specifically to maximize GPS interference.[4] Nonetheless, even the worst cases of interference documented in these reports can be successfully addressed. The Commission can (and should) refine its proposed rules to require performance characteristics that eliminate the potential interference reported in the studies. We offer specific proposals below, formulated to allow UWB manufacturers the greatest possible flexibility in choosing technologies.

Predicted interference in the four GPS studies arises entirely from two causes: excessive broadband power in the GPS bands, and spectral lines in the input band of some GPS receivers operating in the C/A code tracking mode (*i.e.*, not in the higher resolution modes). The measures proposed below bring GPS interference below the NTIA-measured threshold levels in all cases.

[4] See, for example, NTIA report 01-384 Figure 4.1.2.4. NTIA's test procedures apparently exercised a well-known vulnerability in one C/A code to one specific spectral line to guarantee an absolute worst-case result. Although not objectionable in itself, this seems to conflict with NTIA's statement, "It should be noted that no effort will be made in these measurements to intentionally align the UWB spectral lines with GPS spectral lines." *Id*. at para. 4.2

Spectral lines.[5] Passages in the Notice can be read to suggest that spectral lines are inherent to UWB systems.[6] This is not the case. In some modulations, for example, spectral lines can be eliminated simply by "whitening" the input data to ensure an equal likelihood of +1 and -1 data values, so that their average over time is close to zero. Manufacturers are free to use other methods.

To ensure that UWB spectral lines will not interfere with GPS systems, we propose a rule in addition to -- and more stringent than -- the limit on average power. At frequencies above 1 GHz, the Commission proposes measuring power over a 1 MHz resolution bandwidth.[7] XtremeSpectrum suggests, in addition, measuring average power in a 30 kHz resolution, at the sensitive frequencies associated with the GPS C/A codes, *subject to a power limit 15 dB below the 1 MHz limit*. This rule would have no effect on broadband noise-like signals, but would address the finding that some GPS radios operating in the C/A mode are up to 15 dB more sensitive to line spectra at these frequencies than to broadband noise.[8]

Combined with the emission mask discussed below, this provision would limit UWB spectral lines in the GPS band to 33 dB below the levels now permitted for spectral lines from PCs and other digital devices.[9]

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[5] Spectral lines, produced by some types of UWB emitters, are concentrations of energy at specific frequencies, at regular intervals across the spectrum. On a plot of energy vs. frequency, these show up as a comb-like pattern.

[6] *See Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, 15 FCC Rcd 12086 at paras. 36-37 (2000) (Notice).

[7] Notice at para. 50. *See* also 47 C.F.R. Sec. 15.35(b).

[8] See note 5.

[9] See 47 C.F.R. 15.109(a).

GPS-band energy. XtremeSpectrum has proposed a spectrum mask that offers GPS 18 dB of protection below Section 15.209 levels. Specifically, XtremeSpectrum proposes reducing permitted power by 6 dB below 2.7 GHz, by 12 dB below 2.0 GHz, and by 18 dB below 1.6GHz. This mask can be readily achieved by appropriately shaping the UWB signal. Manufacturers may wish to use other techniques.

Pulse repetition frequency. Contrary to study findings, pulse repetition frequency (PRF) has no direct effect on interference.[10] In the absence of spectral lines, PRF has no effect at all. If spectral lines are present, the PRF merely sets the frequency of each. Low PRFs are certain to place some lines in the GPS bands. Higher PRFs reduce that likelihood.

Rules that specifically govern limit PRF are unnecessary. The spectral lines test and emission mask will adequately control interference regardless of PRF.

Peak/average ratio. The peak-to-average ratio described in the Notice does not give correct results for all waveforms of interest. XtremeSpectrum proposes a more accurate alternative.

Aggregate effect. Because of unrealistic assumptions and modifications, the NTIA UWB-Rings study gives misleading results on the aggregate effect of multiple UWB emitters. In cases where the baseline model yielded a "fractional" closest UWB emitter to represent low interference, the study authors deliberately added a full emitter close to the victim receiver. This amplified the predicted interference for these cases. With the extra emitter removed, received interference is shown to be well below the protection criteria for all reasonable situations.

A more realistic interpretation of the study shows that interference from multiple emitters only slightly exceeds interference from the nearest emitters, so that all but the nearest can be safely ignored. This means that the aggregation effect of multiple, distant emitters will be dominated by the effects of nearby emitters. The exception arises when the victim receiver is very high above ground, as in a satellite or high-flying airplane, in which case all emitters are approximately the same distance away. Under those conditions, even though all emitters would impact the receiver equally, they are all too far away to have any interference effect.

B. Interference Into GPS From Individual UWB Emitters Can Be Reduced or Eliminated.

All cases of interference reported in the studies can be resolved with closer specification of limits on spectral lines and overall emission energy in the GPS bands.

1. Interference-causing spectral lines can be eliminated.

GPS receivers come in two main categories. C/A code tracking receivers are most sensitive to spectral lines in the GPS frequency band when they align with specific frequencies of the GPS spreading code. NTIA found these receivers are up to 15 dB more sensitive to this single-frequency interference than to broadband noise-like interference. Most of the UWB signals used for assessing GPS interference produced strong spectral lines in the GPS passband -- the direct cause of interference into these receivers.

Semi-codeless GPS receivers, on the other hand, are more sensitive to broadband noise-like interference, rather than spectral lines.

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[10] *Cf.* Notice at para. 35.

A relatively small design change can yield a major reduction of spectral lines. For example, both the NTIA and Stanford reports found interference from a particular modulation called on-off keying, a form of pulse-amplitude modulation. Here, the input to the UWB radio is a string of high and low pulses, representing 0s and 1s in the data being transmitted. This signal produces marked spectral lines. In practice, however, the spectral lines occur *only* because the pulse heights average to something other than zero. Instead, one can represent 0s and 1s with positive and negative pulses of the same height.[11] If the data is processed to make the 0s and 1s equally likely, so the average pulse height over time is close to zero, then the spectral lines can be made to disappear. The interference into GPS attributable to spectral lines likewise vanishes.

None of the UWB devices tested for GPS interference used these simple interference-reducing techniques.

XtremeSpectrum urges the Commission to consider a rule provision that sets a limit on spectral lines. Specifically, the additional rule would require additional measurement at the critical frequencies in the GPS bands with a 30 kHz resolution bandwidth, and a limit 15 dB below the 1 MHz bandwidth limits. This measurement would not require changes to noise-like signals having relatively uniform power spectral densities, but would force strong spectral lines to be reduced by about 15 dB.[12] This test applies only over the frequency range 1574.92 through 1575.92 MHz.

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[11] This is an oversimplification. For details, see the attached Technical Statement.

[12] Note that 1MHz/30 kHz = 33, or 15 dB. For a noise-like signal, the 15 dB smaller measurement bandwidth is offset by the 15 dB lower emission limit, so there is no net effect. But a spectral line taking up most of the 30 kHz measurement bandwidth would have to be reduced by about 15 dB.

Manufacturers can use any technique they wish to suppress spectral lines, so long as the emitted signal conforms to the rule.

2. Proper choice of pulse shape can eliminate most UWB energy from the GPS bands.

The UWB signal consists of a train of pulses over time. The shape of those pulses has a major effect on the interference characteristics. If the signal produces spectral lines (see above), then the pulse shape determines the relative strength of the spectral lines over different frequency ranges. If there are no spectral lines, then the pulse shape determines the shape of the signal, over different frequencies. Either way, the pulse shape governs how much energy is emitted over each range of frequencies.

The pulse shape can be controlled. As a result, the energy distribution over frequency is also controlled. An appropriate design can eliminate much of the UWB energy from the GPS bands. Many of the pulse shapes used for GPS interference testing, in contrast, represented the worst case for maximizing power near GPS bands.

XtremeSpectrum has recommended that the Commission step down permitted emissions by 6 dB at each of 2.7, 2.0, and 1.6 GHz, thus giving the PCS bands 18 dB of protection below Section 15.209 levels. Manufacturers can achieve that mask by controlling pulse shape, or by any other method they choose.

3. Pulse repetition frequency affects interference only if spectral lines are present.

The record includes a lot of discussion on the merits of high vs. low pulse repetition frequencies (PRFs).[13] But much of the discussion misses the mark. The GPS studies exacerbated the confusion by testing relatively few PRFs and then drawing unwarranted conclusions from those tests.

The main effect of the PRF is to position the spectral lines, if any. If spectral lines are present, the PRF determines whether any fall in the GPS bands. The lower the PRF, the more closely the lines are spaced. If the PRF is low enough, the spacing becomes tighter than the width of the GPS bands, so some spectral lines are guaranteed to fall in the bands. At higher PRF ranges, some PRFs put lines in the GPS bands, while others do not. At sufficiently high PRFs, above 100 MHz or so, most PRFs do not put any line in any GPS band.

Again, however, the PRF matters from an interference standpoint only if the UWB transmitter produces spectral lines. If the spectral lines are eliminated, then PRF has no practical bearing on interference.

Many of the UWB emitters tested for GPS interference not only had strong spectral lines, as noted above, but used PRFs that placed those lines not only in the GPS bands, but at critical frequencies shown to be GPS vulnerabilities.

XtremeSpectrum urges the Commission not to regulate PRF separately, as doing so would unnecessarily constrain system design. Rather, the provisions discussed above

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[13] As noted, a UWB system emits a train of brief pulses. The pulse repetition frequency is simply the number of pulses per second.

on spectral lines and emission mask will adequately control the harmful effects of a badly chosen PRF.

4. The test for peak-to-average ratio needs further consideration.

The Commission's proposed test for peak-to-average ratio will not give appropriate results for all of the waveforms likely to be implemented by UWB systems. The Notice observes that the Commission has used a variety of definitions and techniques for measuring peak power, for different types of equipment,[14] and requested comment on the methods proposed.[15] The attached Technical Statement sets out an alternative test for UWB peak-to-average ratio and explains why it will yield more accurate results, and hence safer UWB systems.

C. The NTIA Study Overestimates the Aggregate Effect of Multiple UWB Emitters.

Several parties to this proceeding have expressed concern that multiple UWB emitters will raise the noise floor, and thus make it more difficult for sensitive receivers, such as GPS, to detect faint signals. UWB proponents have generally responded that only the emitters nearest to a victim receiver need be considered, because the combined effect from all others is negligible.

NTIA conducted a simulation that attempted to address this question. However, NTIA made an arbitrary "correction" to its model that skewed the results to show higher interference than the model can properly justify.

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[14] Notice at para. 42.

[15] Notice at paras. 43-44.

NTIA's "UWBRings" model divides the environment into uniform rings centered on the victim receiver, rather like a target with the receiver on the bulls-eye. The model starts with a uniform distribution of UWB emitters scattered evenly over the target. Under conditions with only a few emitters and the receive antenna close to the ground, the receiver (obviously) sees little interference. To represent this case, the model "scatters" a small number of emitters over the target. But it also seeks to keep their distribution even. As a consequence, it may assign only a fraction of an emitter to the innermost ring. The concept of a fractional emitter may challenge the intuition, but it accurately reflects a case where the total received interference is very low.

The study authors had a different problem with the fractional emitter. They noted that it represents less interference than the worst case of a full emitter on the innermost ring. The authors set out to "correct" this condition by arbitrarily adding a full emitter on the innermost ring in every case where the model did not provide one.

Not surprisingly, an extra full emitter very close to the victim receiver boosts the predicted interference. This adjustment guarantees that every case is always as bad as the worst case. It rules out, in advance, any configuration in which the predicted interference is low. The adjustment invariably, and unjustifiably, skews the results to show more interference than would otherwise exist.

XtremeSpectrum has adjusted the simulation results to remove the effect of the added full emitter, but with all other settings held the same as in the NTIA study. At low emitter densities, in all cases where NTIA added the extra emitter, removing it brings the received interference below any possible violation of the protection criteria.

Even at higher emitter densities, the NTIA model still shows that the nearest emitters dominate. More distant emitters suffer proportionate propagation losses en route to the receiver. That attenuation renders them collectively negligible, compared to the nearest emitters. In other words, the much-feared aggregation of multiple UWB emitters does not occur. The only exception arises when the victim receiver is so high above ground -- as in a satellite or high-flying airplane -- as to be approximately equidistant from all emitters of interest. But under those conditions, the receiver is so far from all emitters that interference is not a serious concern.

CONCLUSION

With adjustments to the emission mask below 2.7 GHz, and to measurement bandwidth over critical GPS frequencies (to limit spectral lines), the rules proposed in the Notice yield UWB devices that do not interfere with GPS receivers. Earlier in the proceeding, XtremeSpectrum and other proponents showed that UWB devices similarly do not interfere with a variety of federal systems. In a companion filing today, XtremeSpectrum makes a comparable showing as to PCS wireless phones.

Comments on the emission mask, measurement bandwidth, and peak-to-average measurement methods were all specifically invited in the Notice.[16] The suggestions outlined here are well within the scope of the Notice. "An agency, after all, must be free to adopt a final rule not described exactly in the [notice of proposed rulemaking] where the difference is sufficiently minor, or agencies could not change a rule in response to

[16] See Notice at paras. 36-37 (spectral lines), 39 (emission mask), 43-44 (peak-to-average methods), 50 (measurement resolution bandwidth).

valid comments without beginning the rulemaking anew."[17] Even if not among the options expressly outlined in the Notice, the suggestions here are certainly a logical outgrowth of the questions raised.[18] The Commission should move expeditiously to adopt its proposed rules, modified as suggested herein.

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[17] National Cable Television Ass'n v. FCC, 747 F.2d 1503, 1507 (D.C. Cir. 1984), *quoted in* Transmission Access Policy Study Group v. FERC, 225 F.3d 667, 729 (D.C. Cir. 2000).

[18] *See* Omnipoint Corp. v. FCC, 78 F.3d 620 631 (D.C. Cir. 1996) (second round of comment not required where final rule is "logical outgrowth" of proposed rule), *citing* American Water Works Ass'n. v. EPA, 40 F.3d 1266, 1274 (D.C. Cir. 1994).

XtremeSpectrum, Inc. Technical Statement on Reports Addressing Potential GPS Interference from UWB Transmitters

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Table of Contents

1. Executive Summary

These comments are submitted in response to four separate reports concerning the effect of UWB emission on GPS receivers made available recently.[1] The tests and analyses presented in the reports examined un-modulated pulse streams (UPS), on-off keying (OOK), pulse-position modulation (PPM), a few limited forms of dithering, noise, and in some of these cases included gating of the signals at time intervals that were very long relative to the UWB pulse repetition interval. They provide results that lead to several significant conclusions that are relevant to these proceedings that are the subject of these comments.

The key fundamental items learned in the tests and analyses are:

- That some GPS C/A code tracking receivers are vulnerable to spectral lines that are aligned with the spectral lines of the GPS spreading code.
- That these C/A receivers can be up to 15 dB more sensitive to interference from such spectral lines than from noise-like signals.
- That the semi-codeless GPS receiver is not more sensitive to spectral lines.
- That aggregation is linear, and for ground-based systems the interference is generally dominated by the closest set of radiators.

Given these characteristics, the UWB waveforms used represent the worst-case possible interference potential because (1) they produce the highest amplitude spectral lines that would pass a Section 15.209 test, and (2) the GPS C/A code receiver's most sensitive vulnerability is to spectral lines. Furthermore, in virtually all cases, the geometric arrangement of emitter and victim receivers was chosen to cause maximum stress on the victim receiver. As a result, they represent a worst-case upper bound on potential interference, which, if used as the basis for regulations, would ensure that there is an extremely low likelihood of causing harmful interference.

The most important aspect of these results is that they provide a sound basis for effective rules that are a logical extension of the NPRM and that allow the safe coexistence of UWB devices and GPS and Federal systems, even for larger aggregations of UWB devices. These comments provide the FCC with UWB emission limits and measurement procedures that are formulated using the test and analysis results to ensure there is no harmful interference to GPS receivers in realistic deployment scenarios. These recommendations include: (1) a spectral mask shown in Figure 1 to regulate the noise-like characteristics of the signal; (2) a tighter resolution bandwidth test to ensure spectral lines do not fall on the identified critical frequencies of C/A code GPS receiver; (3) a combined time-domain and frequency-domain peak-to-average test to limit potential harmful interference to wider bandwidth systems; and (4) no limits on PRF or modulation types.

The UWB sources used in the test represent a class of worst-case UWB signals in terms of their interference causing characteristics (e.g. strong spectral lines in the GPS pass band). Their use

[1] NTIA Special Publication 01-45, NTIA Report 01-384, a report by Johns Hopkins University/APL, "Final Report: UWB-GPS Compatibility Analysis Project", and a report by several Stanford University researchers and others, "Interference to GPS from UWB Transmitters."

caused some to conclude that UWB could not coexist with GPS. These comments, however, show that systems can be built with UWB signals that do not share these same interference-causing properties. These alternative signals use modulation schemes and waveforms that do not lead to spectral lines in the GPS bands. They also use pulse shapes that ensure that only a tiny fraction of their energy is emitted in the GPS bands.

Examination of the aggregation studies in NTIA 01-43 and NTIA 01-45 confirms the FCC's initial conclusion in the NPRM that UWB interference levels are dominated by the effects of the nearest emitters.[2] This result, coupled with a set of more realistic assumptions about propagation, antenna gain, UWB activity factors, and the proposed regulatory spectral mask, shows that the aggregate effect of widespread UWB devices does not cause harmful interference to GPS or federal systems. This finding is yet another confirmation that the rules proposed in the NPRM with extensions proposed in these comments can ensure the safe coexistence of UWB and existing systems.

The test and analysis results of these GPS reports as well as the analyses in the other reports distributed in this proceeding support the NPRM. Taken together, all of the reports demonstrate that using these recommended rules, the FCC can be assured of the safe coexistence of UWB and existing systems, including GPS. At the same time, these rules will allow the nation to begin to realize many of the potential benefits of this new and exciting technology.

Together with the proposed logical extensions to the NPRM, the test results confirm that it would be prudent for the FCC to approve, without further delay, the use of UWB devices under a modified set of Part 15 rules.[3]

[2] See NPRM, paragraphs 46 and 47.

[3] NTIA Special Publication 01-45, NTIA Report 01-384, a report by Johns Hopkins University/APL, "Final Report: UWB-GPS Compatibility Analysis Project", and a report by several Stanford University researchers and others, "Interference to GPS from UWB Transmitters."

2. Specific Recommendations For FCC Action

We recommend that the FCC approve, without further delay, the use of UWB devices under a modified set of Part 15 rules. The NPRM suggested that UWB devices operate under the general emission limits contained in 47 CFR, Section 15.209, and that emissions for devices other than GPRs (and possibly through-wall devices) should be attenuated by 12 dB below approximately 2 GHz.[4] XtremeSpectrum submits the following logical extensions that are fully supported by analyses and test results provided in this proceedings:

2.1 UWB device operation under Part 15 general emission limits should be permitted at reduced levels relative to Part 15.209 limits in order to prevent interference to existing systems.

The reductions are:

-18	dB	<	1.6	GHz
-12	dB	<	2.0	GHz
-6	dB	<	2.7	GHz
0	dB	>	2.7	GHz

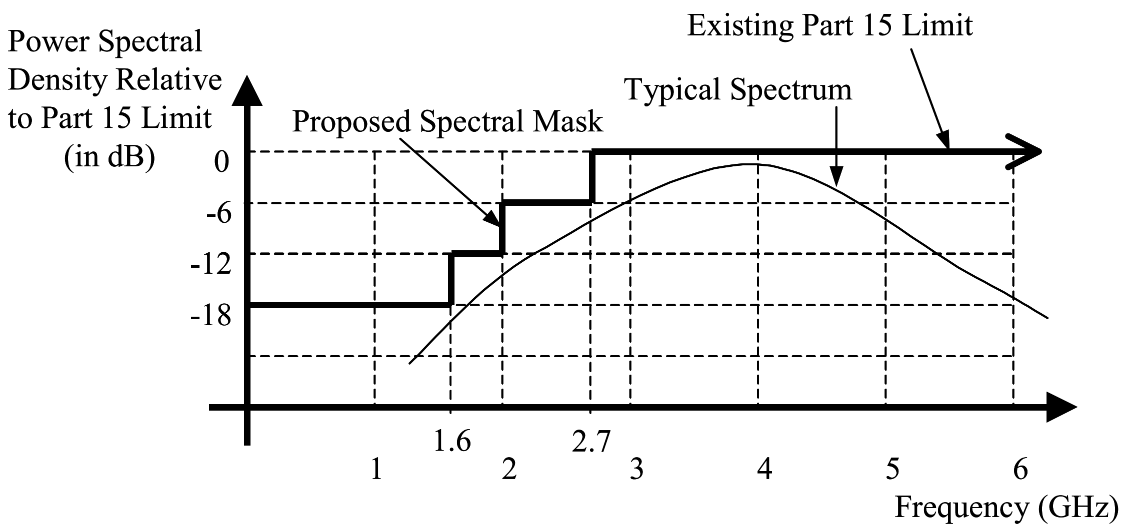

Figure 1: Proposed spectral mask for UWB operations under Part 15 limits

This extension of the FCC proposal is illustrated in Figure 1. This proposed spectral mask provides 18 dB additional protection for GPS systems relative to general Part 15 limits. This mask is specifically designed to provide protection to many existing systems, and it was effectively demonstrated in our previous filing that the mask prevents any violation of the protection thresholds for the non-GPS systems addressed in NTIA 01-43.[5] This mask is also adequate to protect GPS against noise-like UWB signals.

[4] NPRM, paragraph 39.
[5] See XtremeSpectrum comments dated March 12, 2001.

2.2 The critical frequency band containing GPS C/A code lines should be tested using a 30 KHz resolution bandwidth with a threshold of –33dB relative to Part 15.209 limits.

The recent reports demonstrated that some GPS systems are particularly sensitive to spectral lines that were present in some of the UWB signals used in the tests. This sensitivity is such that even the 18 dB attenuation of the spectral mask (measured using a 1 MHz resolution bandwidth) does not provide enough protection against spectral lines that might occur at critical frequencies within the GPS L1 band.

The possibility of this situation was anticipated by the FCC in the NPRM[6] and is attested to by the measured interference threshold results in the recently released GPS interference reports. The NTIA report on GPS interference shows that GPS receivers (operating in the C/A code tracking mode) can be up to 15 dB more sensitive to CW-like interference on specific vulnerable frequencies than to broadband noise-like interference[7].

Because the original average power test uses a measurement bandwidth of 1 MHz, the test is not able to resolve such low-level spectral lines in the presence of broadband noise-like signals. The test proposed here is better suited to limiting the amplitude of such spectral lines. Specifically, this test will require that power in the L1 band at these critical frequencies be measured using a 30 kHz resolution bandwidth (i.e. 15 dB narrower than 1 MHz) and that the limits for this measurement be 15 dB *below* the limits for the 1 MHz test as per Figure 1 according to the frequency band being measured. This test will effectively provide a total of 33 dB protection for GPS against signals with spectral lines at critical frequencies in the GPS L1 band.

It is important to note that this test is specifically designed to protect GPS receivers that are the most vulnerable to these critical frequencies against worst-case UWB signals in extreme interference scenarios. In later sections, we will show that a well-designed UWB system need not exhibit such spectral lines because there are many techniques available to avoid the intentional production of such lines. Like any digital device however, UWB emitters suffer from *unintentional* effects that could result in unwanted spectral lines. The proposed test will protect GPS even in such a case (33dB more restrictive than current limits on unintentional emitters) and will ensure that GPS can safely operate even in proximity to UWB devices.

2.3 Limitations on peak-to-average power levels for UWB signals should be measured using time and frequency domain techniques as shown in Table 1.

The existing Part 15 rules contain provisions to limit peak power levels to 20 dB above average levels. The FCC has proposed to extend this limit to as high as 60 dB in some situations[8] and

[6] NPRM, paragraphs 36 and 37.
[7] NTIA Special Publication 01-45 presents measured interference thresholds for GPS receivers. The indicated threshold for broadband noise is –134.5 dBW/MHz (or about –101.5 dBm for a GPS receiver with a 2 MHz input bandwidth). The worst-case interference threshold for CW-like signals is –146.3 dBW, or –116.3 dBm for the same receiver. These numbers show that the difference between noise-like and worst-case CW interference thresholds is 15 dB.
[8] See NPRM paragraphs 35 and 41.

specifically notes "that it is necessary to regulate both the peak and average emission levels above 1 GHz"[9] because of concerns that high peak emission levels produced by UWB devices could cause harmful interference. Unfortunately, the proposed test to limit the ratio of peak power to average power in paragraphs 42 and 43 of the NPRM does not completely accomplish this purpose.

The only difference between a high peak to average waveform and a low peak to average waveform is its phase versus frequency. A chirp and an impulsive wavelet can have identical spectra, for example, but the impulsive wavelet phase has a constant phase slope whereas the chirp has a quadratic slope. The fundamental problem is that a spectrum analyzer is unable to measure phase, it only measures the power spectrum. It cannot, therefore, be used to measure peak to average ratios.

We concur with the findings in Appendix D of NTIA Special Publication 01-43 (D.4) and shown in figure D-1 that points out one case (e.g. lines versus no-lines) that shows the breakdown of this tests ability to measure peak power. But there are an infinite number of cases that would make it fail since there are an infinite number of phase responses.

We suggest, as per the NPRM (¶44), that the FCC consider requirements that use time domain and frequency domain measurements of UWB signals to measure the ratio of peak power to average power. One method to implement such a test is given in Table 1. In this test, a spectrum analyzer is used to find the –10 dB signal bandwidth, a very high bandwidth sampling oscilloscope is used to find the true peak-to-peak signal voltage, and a power meter is used to measure the average power. This setup makes it easy to perform the test without any triggering requirements and can be done through the air. Alternatively, if the spectrum analyzer is capable of providing digitized outputs, then the power meter could be replace by using Parseval's rule and integrate the spectrum to find the average power. Similarly, if a real-time digitizing oscilloscope is available with adequate bandwidth, sample rate, and memory[10], then by backing out the impulse response of the oscilloscope, all of the measurements could be made from the digitized data.

[9] See NPRM paragraph 36.
[10] 3 db bandwidth out to at least the upper – 10 dB cutoff frequency of the signal, a sample rate of 5 times the – 10 dB high frequency cut-off, and enough digitizing memory to provide 5 us. of record length

Test Procedure for Peak-to-Average Power Limits[11]
1. Measure on a spectrum analyzer the –10dB points F_{hi}, and F_{lo} and compute the bandwidth $B = F_{hi}-F_{lo}$, and the center frequency $F_c = (F_{hi}+F_{lo})/2$. 2. Apply the test for the device qualifying as a UWB device: $B/F_c > .25$ or $B > 1.5$ GHz 3. Measure peak-to-peak voltage (V_{p-p}) into a 50 ohm load using a high bandwidth sampling oscilloscope and compute peak power. Note that this measurement can be done without a trigger signal and long persistence display mode to get a peak-to-peak voltage measurement: $P_p = \frac{\left(\frac{1}{2} V_{p-p}\right)^2}{50 \text{ Ohms}}$ 4. Measure average power (Pa), using a power meter [12,13] 5. Compute the peak-power to average-power ratio in dB, i.e. Pr = 10 $\log10(P_p/P_a)$. 6. Compute the dB ratio between 50 MHz and the bandwidth B (in MHz) of the equipment under test (EUT), i.e. R = 10 log10(B/50). (we propose using 10 log instead of 20 log since bandwidth is proportional to power, not volts.) 7. Apply limit as proposed in the NPRM, but correcting for the 10 log instead of 20 log so that instead of 60 dB the limit is 40 dB, the limit becomes: Pr - R < 20dB and Pr<40dB

Table 1: Test procedure for time domain peak-to-average power limit.

2.4 The FCC should decline to mandate *specific types of modulation or PRFs of systems that operate under these rules.*

Such a ruling would tend to limit potential advances in UWB technology that might improve performance or further reduce interference effects. Rather, the rules should be limited to easily measurable performance characteristics such as spectral masks, total power, and peak to average time domain power as proposed above.

[11] If the output signal is not directly observable, non-dispersive antennas such as bi-cones, TEM horns, ridge horns can be used. An example is the Farr Research FRI-IRA-2.
[12] HP436A with HP8481A (10MHz-18 GHz) or HP8485A (50 MHz – 26.5 GHz) sensor.
[13] Gigatronics 8650A with 8033A (.01-18 GHz) sensor.

3. Technical Overview Of Test Results, NTIA's Conclusions, and Characteristics of UWB Signals

3.1 Core Test Results

The tests and analyses presented in the reports examined un-modulated pulse streams (UPS), on-off keying (OOK), pulse-position modulation (PPM), a few limited forms of dithering, noise, and in some of these cases included gating of the signals at time intervals that were very long relative to the UWB pulse repetition interval. Most produced signals containing strong spectral lines but others were noise like. The Stanford report documents testing UPS, random PPM, and OOK. All of these exhibited strong spectral lines in the spectral plots shown in the report. The NTIA testing used UPS, OOK, 50% absolute random dithering (ARD), and 2% relative random dithering (RRD). Spectral plots show strong lines for both UPS and OOK, analysis below confirms that this is to be expected. Even the 50% absolute dithered signal is shown to have spectral lines using theoretical analysis.

The three key results of these tests are:

- The test results show that the worst cases of interference resulted from spectral lines landing on critical vulnerable frequencies within the GPS pass band—frequencies associated with spectral lines of the C/A codes.[14]

- The tests show that some C/A code tracking GPS units are 15 dB more sensitive to spectral lines at these critical frequencies than they are to noise.[15]

- The signal set used in these tests represents the class of worst possible UWB signals for GPS interference,

Several of the reports arrive at the conclusion that severe GPS interference will result from widespread use of UWB devices. A more accurate conclusion, however, is that the various reports have succeeded only in identifying a class of undesirable UWB signals that contain spectral lines which, if they are on critical frequencies, can cause interference to GPS.

3.2 UWB modulation does not inherently cause spectral lines

In contrast to this bleak picture, the real situation is much more positive. Understanding the spectral characteristics of communications signals is an essential step in good UWB system design. Communications theory provides many tools to analyze UWB signals and understand what types of modulation might be appropriate to reduce concerns about interference. There are

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[14] For example, the PRF for some NTIA testing was set to target a specific GPS code spectral line at 1575.571 MHz as described in NTIA 01-384, page 4-8.
[15] See footnote 7.

a number of different signal design techniques that will eliminate or greatly reduce the magnitude of the spectral lines in the UWB signals.

Consider, for example, the case of OOK, a signal determined to cause interference in both the Stanford and NTIA reports. In one form of OOK, each pulse is weighted with either a one or zero to transmit a data bit. This is one example of a more general form of modulation known as pulse-amplitude modulation (PAM), where the pulse weights are chosen from some small set of values (according to the data bits to be transmitted) and used to modulate the pulse sequence:

$$s(t) = p(t) \otimes \sum_{k=-\infty}^{\infty} a_k \delta(t - kT_b) = \sum_{k=-\infty}^{\infty} a_k p(t - kT_b) \qquad \textbf{(1)}$$

Here *s(t)* is the transmitted signal, T_b is the bit interval and *p(t)* is the basic pulse, and a_k is the data sequence containing the information. The power spectral density of this signal ($\Phi_{SS}(f)$, assuming random uncorrelated data) has the general form:

$$\Phi_{ss}(f) = \frac{\sigma_a^{\,2}}{T_b}\left|P(f)\right|^2 + \frac{\mu_a^{\,2}}{T_b^{\,2}}\left|P(f)\right|^2 \sum_{m=-\infty}^{\infty} \delta\left(f - \frac{m}{T_b}\right). \qquad \textbf{(2)}$$

Here, *P(f)* is the Fourier transform of a single pulse *p(t)*, and σ_a^2 and μ_a are respectively the variance and mean of the information sequence a_k. Although equation (2) seems rather intimidating, it is similar to those derived in a number of the reports and is worth repeating because it highlights the fact that communications theory can be used to very accurately model UWB signals and their spectra. Equation (2) shows that the signal's PSD has both a continuous part (to left of + sign) as well as discrete spectral lines (to the right of + sign). This result (or similar) is derived in several of the reports and is then used to show that for OOK (where $a_k \in \{0,1\}$) the spectrum will still contain strong spectral lines.[16] Similar exercises can be done for other signals, such as the UPS, PPM and the 50% dithered signals.[17]

A more useful result, however, can be found in most texts on digital communications. This is the case where the expected value of a_k is forced to be zero (e.g. a zero-mean set where all values are equally probable).[18] In such a case the discrete parts of the spectrum (the lines) vanish and all that remains is the continuous spectrum with no spectral lines:

$$\Phi_{SS}(f) = \frac{\sigma_a^{\,2}}{T_b}\left|P(f)\right|^2 \qquad (3)$$

[16] See NTIA 01-43 and JHU/APL reports.
[17] Even a 50% dithered signals does contain discrete spectral lines, as indicated in NTIA 01-384, page 2-2. Also see complete derivation in R. Fontana, "A Note on Power Spectral Density Calculations for Jittered Pulse Trains," Germantown, MD, Multi-spectral Solutions, Inc., http://www.multispectral.com/presentations.html, 2000.
[18] See for example, John G. Proakis, Digital Communications, McGraw-Hill, Inc. 1995.

There are numerous examples of this, such as binary phase-shift keying (BPSK, where $a_k \in \{\pm 1\}$), or any PAM scheme with zero-mean constellation. This result is well known and virtually all digital communications systems designed today use zero-mean constellations and consequently do not produce spectral lines when the data bits are assumed to be random and uncorrelated. In fact, it is easily demonstrated that a zero-mean symbol set is often the best choice when the desire is to build a power-efficient communications system.[19]

This discussion about modulation schemes also highlights a significant difference between unintentional emitters and potential UWB systems. When digital electronics devices are built, there is little regard for the specific spectral properties of the emission since they have no impact on system performance. For a communications system, however, the spectral properties of the signal are a key part of the system design and any well-designed system will have a controlled spectrum to improve both performance and power-efficiency.

In addition to using appropriate modulation techniques, spreading functions plus data whitening or scrambling prior to modulation can also used to control spectral characteristics, as previously noted in the NPRM. In conclusion, we have shown that a UWB system can easily be designed to have no spectral lines, thereby significantly reducing concerns about interference to GPS.

3.3 Pulse Repetition Frequency

3.3.1. Reported conclusions concerning PRF

The range of PRFs for the signals analyzed were 0.1, 1, 5, and 20 MHz. Most of the UWB signals tested had strong spectral lines, and only a few were more noise-like. Unfortunately, there was little attempt to distinguish between the two when conclusions were drawn about the effect of PRF on interference effects. The end result of this situation is that conclusions drawn in the reports about PRF were often due to the specific combination of PRF *and* a modulation format that results in spectral lines.

For signals with strong spectral lines (such as the un-modulated pulse stream), the system PRF determines the frequencies at which spectral lines occur, and thus in large part the interference effect of the UWB signal. This is because some PRFs result in spectral lines in the GPS input filter passband, while others would place the spectral lines in the filter stopband. A clear example of this occurs in the Stanford report where the 20 MHz PRF is compared to the 19.94 MHz PRF signal in Figures 16 and 17. Vastly different effects are noted when the PRF is lowered slightly to place a line at a critical frequency in the GPS passband. A similar effect occurs in the NTIA report where many of the signal PRFs are chosen to place a spectral line in close proximity to the lines of the GPS C/A code to maximize the interference effect.[20]

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[19] See for example, E.A. Lee and D.G. Messerschmitt, Digital Communications, Kluwar Academic Publishers, 1996.
[20] NTIA report, Table C.1.1 in Appendix C, page C-2.

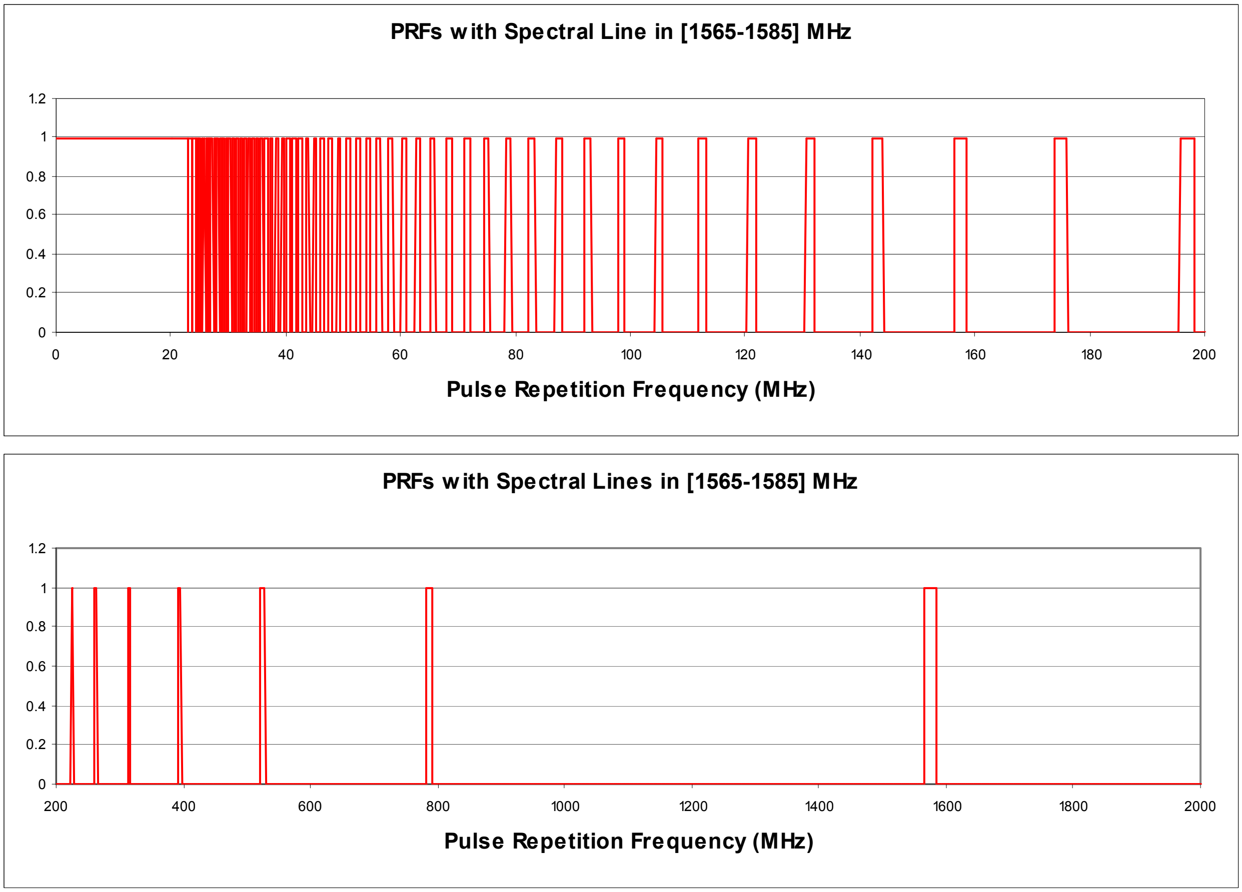

Figure 2: Pulse repetition frequencies for which at least one spectral line will occur in the GPS input passband (1565-1585 MHz). On vertical axis, a value of one indicates at least one spectral line in the GPS L1 band for a given PRF. The GPS L1 band can be seen in the rightmost band of the lower plot.

The tests did not cover any situations where the PRF was actually greater than the operating band for GPS. Figure 2 shows those PRFs that result in a spectral line between 1565 and 1585 MHz. At low PRFs (< 20 MHz) *all* PRF values result in a line in the passband. At higher PRFs, the vast majority of PRFs do not result in spectral lines in the passband. In fact, there are only seven small ranges for PRFs above 200 MHz that place lines in GPS L1 passband.

3.3.2. *With spectral-line free modulation, PRF is immaterial*

All the discussion about PRFs is only relevant to modulation formats with lines. When no lines are present (as in BPSK) the spectrum is continuous so there are no values of the PRF what would result in CW-like interference to the GPS receiver. This is clear from the PSD shown in Equation (3) that does not depend on the PRF (through T_b) like the PSD shown in equation (2).

Some reports and comments have claimed that high PRF systems produce *inherently worse* interference than low PRF systems.[21] This statement is misleading for two reasons:

[21] Refer to MSSI reports, any other comments that misrepresent the effect of high PRFs

1. First, there is no *inherent* reason that a UWB system must produce spectral lines. If a modulation format is selected that has no spectral lines, then the PRF does not affect the spectrum.

2. Even if the modulation scheme does produce spectral lines, the PRF can be chosen to control the placement of the lines to protect GPS. This is especially easy to do at high PRFs (above 100 MHz) because the spectral lines are sparse relative to the GPS input bandwidth.

The conclusion reached in some of the reports and comments, that low PRFs are desirable, is *actually* a demonstration that the spectral lines themselves are undesirable. For the limiting case of low PRF (i.e. the PRF going toward zero) the period of any pattern in the signal tends to infinity and the result is a continuous spectrum, where the spectral lines become vanishingly small and infinitely dense. But a modulation format that has no spectral lines accomplishes the same thing—a continuous spectrum.

Given these facts, we recommend that the FCC *decline to mandate* specific types of modulation or PRFs of systems that operate under these new rules.

3.4 The critical factor of the UWB pulse shape

In addition to the modulation format and the PRF, the pulse shape of the UWB transmitter also has a significant impact on the amount of energy available to cause GPS interference. This characteristic is critical for all UWB systems and is very likely to change as the technology matures, but was only mentioned in passing in the reports.[22]

It was noted that UWB systems typically use a basic pulse that is modulated by data for communications. As we saw in equations (2) and (3), this pulse shape has a fundamental effect on the spectrum of the signal and therefore the interference effects of the UWB signal. The spectrum of the signal is determined by the Fourier transform of the basic pulse:

1. For systems with spectral lines (such as UPS, OOK, etc.), the pulse determines the envelope of the spectral lines.

2. For systems with continuous spectra, the pulse directly determines the actual shape of the power spectral density.

In several of the reports, the pulses shown have a frequency response that places the maximum amplitude of the PSD at or near the GPS input filter passband, maximizing the interference effect. For example, the report by Johns Hopkins University shows a plot of the spectrum of the pulse used in their analysis that has maximum magnitude at approximately 1.5 GHz, which is again a worst-case scenario for GPS interference. The combined result of this choice for the

[22] See, for example the Stanford University report, page 4.

pulse shape, in addition to the modulation and PRF, is that in many cases the spectral lines that are deliberately placed in the GPS passband are also the highest magnitude lines of all those present in the UWB signal spectrum.

It is important to realize that the pulse shape of the UWB system is completely controllable in the design process. When the system is designed properly, the pulse can be selected so that only a tiny portion of the emitted energy is in the GPS frequency bands.

As noted above and in previous comments, XtremeSpectrum, Inc. has proposed a spectral mask that requires emissions in the GPS bands (in fact, any band below 1.6 GHz) to be 18 dB *below* the current limit for Part 15 devices.[23] This limit provides a substantial amount of additional protection for all of the GPS frequency bands. This additional protection is provided both against systems with continuous PSDs and against systems with spectral lines.

4. Specific Comments about Interference Results from the GPS Reports

4.1 NTIA Special Publication 01-45

In the NTIA 01-45 report, a number of interference scenarios are described where analysis showed that UWB signals operating at the existing Part 15 limits would exceed interference thresholds for GPS. These scenarios are classified under five different categories based on the nature of the GPS application under test: terrestrial, railway, maritime, surveying and aviation applications. For each category, a number of "typical" scenarios were developed as a basis for determining which might lead to GPS interference.

The results of these scenarios are presented in two different ways in the original report. First, Tables 1 through 4 of NTIA 01-45 present the worst-case results for each of the various scenarios. The final result was a comparison between the current Part 15 limits and the maximum allowable UWB device EIRP to prevent interference to the GPS device in the given scenario. The same results are then presented in a different way in Figures 1 through 4 of the report. In these figures, the results are arranged according to the characteristics of the UWB signal and the GPS receiver architecture.

[23] See XtremeSpectrum comments dated March 12, 2001.

GPS Application	Class of scenario within each application	Comparison with the current Part 15 level (dB) (from NTIA 01-45 Table 1)	Spectral Mask Factor	Corrections due to spectral lines or other factors	Resulting UWB excess margin below GPS interference threshold (dB)
Terrestrial	Single outdoor UWB with modulation of None, OOK or 50% ARD	-5.7 to 35.6	18 db	15 dB (due to spectral lines) 4.5 dB (antenna, see note 1)	43.2 to 1.9
	Single outdoor UWB with modulation 2% RRD	20.3	18 db	3 dB (geometry) 4.5 dB (antenna)	5.2
	Multiple indoor UWB emitters	14.2 to 20.2	18 db	15 db (due to spectral lines) 6 dB (activity factor, see note 2)	24.8 to 18.8
	Multiple outdoor UWB emitters	18.9 to 24.7	18 db	15 db (due to spectral lines)	14.1 to 8.3
Maritime	All scenarios	-1.7 to 10.5	18 db	15 db (due to spectral lines)	34.7 to 22.5
Railway	All scenarios	11.7 to 20.2	18 db	15 db (due to spectral lines)	21.3 to 12.8
Surveying	Both single and multiple emitter scenarios	21.3 to 22.9	18 db	9 db (building/ propagation losses, see note 3) 3 dB (antenna, see note 3)	8.7 to 7.1
Aviation	All scenarios (both NPA and ER)	5.3 to 15.3	18 db	(none)	12.7 to 2.7

Table 2: Application of spectral mask factor and other correction factors to interference scenarios presented in Table 1 of NTIA-1-45 for PRFs of 1, 5, and 20 MHz. Scenarios for the 100 kHz PRF are not included in this analysis because in no case did the comparison with existing Part 15 limits exceed the margin provided by the spectral mask alone (18 dB).

Notes:

(1) An additional 4.5 dB was included because the 3 meter UWB emitter height is inconsistent with previous NTIA studies that used a typical 2 meter height for outdoor UWB emitters on the ground. When the emitter is lowered by one meter, the GPS antenna gain is reduced by 4.5 dB.

(2) In this scenario, four UWB emitters are assumed to be co-located 5 meters from the GPS unit. Assuming a 100% activity factor for each of four co-located emitters is unrealistic, so a 6 dB adjustment is made.

(3) In this scenario, a UWB emitter at 30 meters range is considered to be 10 meters in elevation. This is unreasonable unless either the emitter is inside a building or on the ground, where additional propagation loss relative to free-space is more realistic. A more reasonable UWB height also reduces GPS antenna gain by 3 dB.

An examination of the results from Table 1 of NTIA 01-45 is presented in Table 1 above. This table addresses all of the scenarios for which the report indicated that interference would result from a UWB device operating under the existing Part 15 rules. For each group of scenarios this table lists the original range of the values for indicated maximum UWB EIRP relative to existing part 15 limits. This range of values is then adjusted to account for several different factors. First, we adjust all of the EIRP values to account for the 18 dB attenuation of the proposed spectral mask. We also provide an adjustment of 15 dB for those cases where the limiting UWB waveforms would contain strong spectral lines that would result in additional attenuation of the signal to meet the guidelines proposed in these comments for UWB emissions. This 15 dB adjustment is made for the cases where the modulation used for the UWB signal is none, OOK or 50% ARD.[24] The analysis also includes a number of additional adjustments where the assumptions about the geometry of the scenario were determined to be unrealistic. These are described in the notes below the table.

It is important to note that the original analysis also contains additional margin to account for variability in GPS performance due to different manufacturers, as well as margin for other sources of interference, device activity factor (always 100%) as well as an additional safety factor of 6 dB for the aviation scenarios. All of these additional factors are still included in the above analysis, except where clearly indicated in the table notes.

From the results in Table 1, it is clear that the logical extensions to the NPRM rules proposed in these comments are effective in preventing any interference to GPS receivers. The final column of Table 1 shows that in every case the maximum EIRP permitted by the proposed rules will not result in exceeding any of the GPS interference thresholds.

4.2 Johns Hopkins University and University of Texas (Austin) reports on UWB-GPS compatibility[25]

For this report, the Applied Research Laboratory of the University of Texas at Austin (ARL:UT) carried out the actual testing while Johns Hopkins University Applied Physics Laboratory (JHU/APL) performed analysis of the data.

The UWB sources for this study were provided by TDC and consisted of two PulsON Application Developers (PAD) and 16 UWB Signal Emitter/Noise Generators. When operated through its "diamond" antenna, the PAD center frequency is about 2 GHz, with a 10 dB bandwidth of 1.2–3.0 GHz, which means it is a pretty severe test of the GPS L1 frequency at

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[24] Although there is some confusion about the spectral line content of the 50% ARD signal in the report (its signal is sometimes referred to as "noise-like"), it is clear that such a signal would contain lines and not be entirely noise-like. This can be understood from the discussion on page 2-2 of NTIA 01-384 as well as from the spectrum plots for the 50% ARD signal in Figure C.2.2 in Appendix C of NTIA 01-384, which shows strong spectral lines in the 50% ARD signal that would be detected by the modified test proposed in these comments.

[25] ARL:UT "Final report - Data collection campaign for measuring UWB/GPS compatibility effects" (TL-SG-01-01, 26 Feb 2001) and JHU/APL "Final Report – UWB-GPS Compatibility Analysis Project" (8 March 2001).

1575.42 MHz, being about 2 dB off its peak amplitude. The PAD has a pseudo-random sequence generator of length 1024, which can lead to closely spaced spectral lines when it is operated at any of its internal (1,5, and 10 MHz) PRFs. Outdoor tests elevated the sources 5° above the GPS antenna, which guarantees good coupling into the GPS antenna, but is not representative of most victim receiver encounters, and certainly not airborne scenarios.

JHU/APL developed a number of measures of performance (MOP) that they converted and plotted as separation distances between the transmitter and receiver. Although UT:ARL did testing at a number of transmitter activity factors, JHU/APL used the 100% duty cycle tests as they seemed to be most indicative of effects on the MOP, and were the severest tests. Their observations and the data show:

a) At distances less than 3 meters, GPS performance is severely affected
b) GPS receiver response is more variable unit-to-unit than due to the operating modes of the UWB emitters.
c) The MOP asymptotically approach interference free performance levels as the UWB sources are moved away, reaching reasonable values in 10–20 meters, depending on the MOP.

Conclusion: *By applying the spectral mask proposed in these comments, we see an additional attenuation for the UWB emitters of 18 dB below the level of the PADs. Assuming* $1/R^2$ *propagation at these close distances (i.e. a 8x reduction in range), there should be no adverse effects on GPS performance until separation distances are less than 3 meters.*

Aggregate tests were also performed and resulted in no surprises. The UT:ARL test sequence consisted of 1, 2, 4, 8, and 16 generators arranged in circles of radius 1, 2, 3, 4, 5, and 8 meters and confirmed that interference power added linearly.

4.3 Stanford University report on UWB-GPS compatibility

The report was based on work carried out at Stanford to measure the interference effects of UWB transmitters on GPS receivers. Unlike the NTIA report, no attempt was made to extrapolate the measured UWB power levels to ranges or specific interference scenarios. The primary conclusion of the Stanford report is that the interference impact of UWB signals is largely determined by the location of the UWB spectral lines relative to the GPS L1 band and the power of those lines. This conclusion is certainly consistent with the results of the NTIA reports, where the most severe interference results were noted as a result of spectral lines occurring at critical frequencies in the GPS passband.

As noted in an earlier section, the Stanford report presents a pessimistic picture of the effects of UWB signals because there were no tests made on UWB signals that did not exhibit spectral lines. All of the plots in the report clearly show strong spectral lines in the UWB signals under test. Even the signal employing pulse-position modulation (PPM), which can be considered a form of random dithering, showed strong spectral lines in the spectral plots shown in Figures 23, 23, 26 and 27 of the report.

5. Interpretation of the Aggregation Studies of the NTIA 01-43 and 01-45

The models produced to date in connection with these proceeding provide a good basis to understanding the issue of UWB aggregation. Several conclusions can be made based on these studies:

- UWB interference power seen by a victim receiver is additive for multiple devices. This conclusion is supported in detail in section 6.1.
- The nearest UWB emitters in an aggregate scenario will dominate the overall interference. This fact occurs because the propagation losses from the more distant emitters overwhelm most of their contribution to the power seen by the victim receiver (even with the very conservative propagation models used by the NTIA). As a result, an analysis which considers only close emitters is a very good approximation to a more exhaustive analysis that includes even the most distant emitters. A thorough examination of the data supporting this conclusion is provided in section 6.2.
- The modification to the UWB-Rings model to force a whole emitter onto the first ring produces overly pessimistic interference levels. Section 6.3 examines the impact of this addition on the systems it influences most.
- Additional propagation and antenna factors will further reduce interference due to aggregation, as shown in Section 6.4.
- UWB devices will exhibit intrinsic limitations on emitter density because they share a common RF channel. Section 6.5 describes the usage restriction inherent in UWB systems.

5.1 A basic conclusion is that noise-like signals always add linearly

The NTIA report demonstrates that interference power from UWB emitters is additive. This is clearly seen in the curves for high-altitude receivers (such as Figure 5.5.1 in NTIA 01-43), where straight lines with a –10 dB/decade slope indicate a linear increase in interference power with density. More relevant, however, is that this also happens to indicate a linear increase in the number of *nearest emitters*.

These results are not surprising in light of the linearity of the density assumption made as part of the UWB-Rings model for aggregation analysis. In the NTIA model, there are a number of simplifications made to reduce the computational complexity of the simulation. In particular, the model places "fractional emitters" on uniformly spaced rings around the victim receiver, instead of placing individual emitters at random locations. At low to moderate emitter densities, this simplification results in very small fractions of an emitter on the nearest ring used for analysis. This simplification is easily seen to lead to the resulting behavior of proportional increase in interference power with emitter density. Any increase in density will simply be reflected in a proportional increase in the fractional value of the emitters on each ring.

Unfortunately, these simplifications also lead to *unrealistic* behavior in some situations. In the baseline NTIA model, the closest emitter to the victim receiver at lower densities is only a small fraction of an emitter on the innermost ring. In the real world, the closest emitter would instead be a “whole” emitter with a range that is a random value depending on the density of the emitter distribution. For low densities, the *expected* range to closest emitter is larger, and it decreases with increasing density (assuming uniform random distribution of emitters). The NTIA approach instead leads to a “smooth” distribution that does not model this lumpiness.

To “correct” for this effect (of close, fractional emitters), the NTIA model introduces a modification that forces a whole emitter to be placed on the innermost ring that is specified in the simulation analysis. This additional emitter changes the nature of the aggregate interference because it dominates the interference seen by the victim receiver in most of the critical cases analyzed and presented in NTIA 01-43, Chapter 5. This domination of the nearest emitters will be examined in the next section, and its implications will be described.

5.2 Interference effects are dominated by the nearest emitters in most realistic situations

As described above, the expected results for each case analyzed in NTIA 01-43 using the unmodified UWB-Rings mode would be straight lines with slope of –10 dB/decade as density increases. This simple result requires no complicated simulation, and is expected based on assumptions used to produce model. However, when we look at the actual results shown in Figures 5.5.1 through 5.5.16, we see a different situation entirely. There are many cases where the curve representing maximum UWB EIRP versus density is a straight sloping line, as expected, but there are also many cases where the curve is actually flat for low densities and then begins to curve downward only as density increases to 100s or 1000s of emitter per km^2.

This flattened curve effect occurs because of the specific modification to always place one whole emitter on the innermost ring. This modification is indicated by the notation “I_{agg}+I_{single}” in the report and it is used for all of the figures shown in the report. The reason that this modification is included in the simulations is given in Appendix B:

> “The purpose of this control is to allow the user to ensure a worst-case aggregate interference calculation. Under low emitter density and low receive antenna height the RINGS topology may assign less than a single emitter to the innermost ring(s). In such cases, it is possible that the entire aggregate power level (I_{agg}) may be less than the power received by a single emitter placed on the worst case ring.”[26]

So we see that the model is deliberately modified so that at low densities the indicated maximum allowable UWB EIRP will never be higher than the “worst-case” of a single “whole” emitter on the innermost ring. This modification prevents the simulation from showing what the true effect of low emitter densities might be in any case where the model would have resulted in less interference than the “worst-case”.

It is not clear why the report’s authors felt that this would produce a realistic interference analysis, but it clearly gives a worst-case bound. For the case of low densities, the closest emitter could very easily be further than the innermost range chosen for analysis and thus it clearly does not represent reality. It skews the results to indicate *worse interference* than the model should produce for densities up to several hundred emitters/km^2. The resulting curves for many of the

[26] NTIA SP 01-43, page B-20.

systems show that the single emitter added to the nearest ring dominates the interference seen by the victim receiver.

This modification is thus seen to skew the UWB-Rings results to indicate more interference in some case than would really occur for uniform emitter distribution. In spite of this limitation, the modification does help to show how a nearby emitter (the additional one included by the modification) can easily dominate the effect of a large number of UWB emitters distributed over a wide area.

Table 2 was constructed from the plotted results shown in Figures 5.5.1 though 5.5.16 in NTIA report 01-43. For each system analyzed in that report, Table 2 shows in the sixth column the effect on interference power seen by the victim system as UWB emitter density is increased from 1 to 100 emitters/km^2.

For a large number of the cases, the difference between the maximum allowable EIRP for a single emitter per km^2 and for 100 emitters per km^2 is only a few dB, not 20 dB as we would expect if there were a strict linear relationship between UWB density and interference power. For those cases where there is a full 20 dB increase, the reason is that the receiver height (and therefore the range) is very large (e.g. SARSAT uplink or airborne receivers). In this case, many emitters are essentially “nearest emitters” since the propagation loss is nearly the same to all of them.

Clearly for the most relevant systems analyzed using UWB-Rings model (i.e. those with ground-based receivers which had negative margin in column 4 of table 2) the effect of increasing emitter density by 100 seems to be only a few dB increase in interference power seen by the victim receiver. The determining factor for these cases is the distance from the receiver to the location of the single whole emitter added to the inner analysis ring. For those receivers located near the ground, the result of large increases in UWB emitter densities is much less than the expected linear increase in received power. It was only those receivers at high altitudes that saw the full 20 dB increase in power for 100x emitters. In fact, this trend is clearly seen by looking at those systems for which multiple altitudes were analyzed. For example, the radar altimeter results clearly show that the effect of increased emitter density is negligible for low altitudes (30 meters) and linear only at high altitudes.

System	Freq. (MHz)	Proposed Limit on UWB Emissions dBm/MHz	Margin for 1 emitter/ km^2 (dB)	Receiver Height	Interference power increase for 100x density (dB)	Reduction in UWB EIRP due to the I_{agg}+I_{single} mode (at 1 km^{-2})
SARSAT Uplink	**406**	**-59.3**	**+22**	**850 km**	**20**	**0 dB**
ATCRBS (Airborne)	**1030**	**-59.3**	**+15 +32 +39 +47**	**10 m 80 m 200 m 12.2 km**	**2 14 20 20**	**24 dB 7 dB 0 dB 0 dB**
ATCRBS (Grnd)	**1090**	**-59.3**	**+28**	**22 m**	**3**	**22 dB**
DME (Ground)	**1150**	**-59.3**	**-5**	**10 m**	**1**	**20 dB**
DME (Airborne)	**1213**	**-59.3**	**+13 +30 +32 +34**	**30 m 1200 m 3000 m 5500 m**	**5 20 20 20**	**16 dB 0 dB 0 dB 0 dB**
ARSR-4	**1250**	**-59.3**	**0**	**22 m**	**7**	**12 dB**
SARSAT LUT	**1544**	**-59.3**	**-9**	**12 m**	**2**	**16 dB**
ASR-9	**2700**	**-47.3**	**+3**	**17 m**	**4**	**16 dB**
NEXRAD	**2700**	**-47.3**	**+7**	**28 m**	**14**	**6 dB**
Marine Radar	**3050**	**-41.3**	**-16**	**20 m**	**1**	**22 dB**
FS ES 5° elev.	**3750**	**-41.3**	**-8**	**3 m**	**1**	**26 dB**
FS ES 20° elev.	**3750**	**-41.3**	**+7**	**3 m**	**1**	**27 dB**
Radar Altimeter	**4300**	**-41.3**	**+40 +50 +52 +54**	**30 m 150 m 300 m 1520 m**	**1 2 10 20**	**0 dB 15 dB 17 dB 26 dB**
MLS-1	**5050**	**-41.3**	**-5 +10 +11 +12**	**30 m 500 m 3000 m 6100 m**	**6 20 20 20**	**13 dB 0 dB 0 dB 0 dB**
MLS-2	**5050**	**-41.3**	**-10 +5 +6 +7**	**30 m 500 m 3000 m 6100 m**	**6 20 20 20**	**14 dB 0 dB 0 dB 0 dB**
TDWR	**5600**	**-41.3**	**+5**	**27 m**	**17**	**3 dB**

Table 3: Results for aggregation analysis taken from NTAI 01-43 with additional derived results to show effect of the Iagg+Isingle modification to UWBRings model.

This effect is also very clear from a visual examination of the plots in the report. In many of the Figures 5.5.2 through 5.5.13, the curves are relatively flat as emitter density increases from 1 to 100 emitters per km^2. It is only when the density exceeds 1000 and approaches 10,000 per km^2 in some cases that the curves begin to slope downward. In contrast, the curves that correspond to high-altitude receivers are seen to have a -10 dB/decade slope over the entire range of densities.

The clear cause of this anomalous behavior is that for the high-altitude receivers, the additional UWB emitter on the inner ring is at essentially the same range as a large number of the other emitters on the earth's surface. For a receiver on the ground, the additional emitter on the inner ring is much closer than most of the other emitters and hence it dominates the interference seen by the victim receiver. This dominating effect is only overcome at high emitter densities where the number of emitters placed on the inner circle begins to increase above one so that the interference effect is dominated by the *linearly increasing* number of emitters on the nearest rings.

5.3 The modification to the UWB-Rings model to force a whole emitter onto the first ring produces overly pessimistic interference levels.

In addition, the table also shows that the only systems which do experience a full 20 dB interference power increase are those that are *least affected* by the UWB interference. The column labeled "Margin for 1 emitter/km^2" lists the margin for each system with respect to the proposed emission limits for UWB devices. These values clearly show that systems for which the aggregation effect is linear are also the *least likely* to experience UWB interference (because of their high altitude, as we expect). We can finally begin to see the full effect of this modification when we compare these margin values with the values in the final column, the "Reduction in UWB EIRP due to the $I_{agg}+I_{single}$ mode (at 1 $km^{-2)}$". A negative value for the margin value would indicate that the particular system would exceed the protection threshold at the lowest emitter density. When we remove the effect of the extra emitter, however, by adding back the reduction due to the $I_{agg}+I_{single}$ mode, we see that for every system the proposed emission limits would prevent any violation of the protection criteria at the lowest emitter density.

5.4 Additional propagation and antenna factors will further reduce interference due to aggregation

The original results of the NTIA's study of aggregation effects for UWB emitters were reported in chapter 5 of NTIA Special Publication 01-43. One of the fundamental problems with this study was that no effect was made to compensate for real-world propagation effects for RF signals. This same chapter includes a lengthy discussion of numerous factors that can significantly affect propagation. For example, the chapter reports that foliage, terrain and building losses can significantly increase propagation losses computer by their model and would thus result in reduced interference levels seen by the receiver.[27] The report includes specific values for many of these losses that have been determined through extensive propagation studies. In addition, many of the comments filed by other parties noted that the failure to account for real world propagation losses was very troubling.[28]

The report also indicated that there were a number of other specific propagation models that could have been used in the aggregation study that might have resulted in more realistic path loss values. For example, the report shows a comparison of path loss values given by the NTIA's model (the irregular terrain model, ITM) and the Okamura-Hata model, which is specifically

[27] NTIA report 01-43, chapter 5.
[28] See for example the comments of Fantasma, Inc, and Time Domain Corp. in repose to NTIA 01-43.

designed to account for real-world propagation effects found in urban and suburban environments. In every case compared, the ITM model showed that it was consistently underestimating the path loss by 25-40 dB.[29]

All of these issues were noted in earlier comments, but it is important to point out that these omissions by the NTIA are directly relevant to the results of the aggregation study discussed in the sections above. We have shown that the specific modification to add an additional emitter to ensure results no better than the "worst-case" single emitter case resulted in unrealistic levels of interference. When that effect is removed, in every case the systems analyzed indicate no interference for low emitter densities. When we take the additional step of including more realistic path loss estimated for each of those cases, we would find that there is even less reason to believe that widespread distributions of UWB devices will lead to harmful interference levels or the excessive rise in background noise levels feared by some parties.[30]

When we include the fact that many UWB devices are anticipated to be deployed where people live and work, that is in buildings located in suburban and urban areas, the reality of much higher propagation losses than the NTIA estimated is inescapable. Clearly, any realistic interpretation of the aggregation study will lead to the conclusion that effective regulation can allow UWB devices to safely coexist with current systems.

One final point about interference level estimates for the aggregation study pertains to the analysis of the airborne application in NTIA 01-45. In this analysis, although the pattern of the GPS antenna seems to be included in calculations, it is once again assumed that all UWB transmitters are aimed at the victim receiver. While it is likely that most UWB antennas will be omnidirectional (uniform azimuth coverage), that does not mean that they will be isotropic (uniform in all vertical directions). A more reasonable antenna model would be that of a vertical dipole whose elevation pattern is depicted below in Figure 3. The gain of this antenna is reduced by approximately 40 dB to 4 dB respectively by elevation angles from the vertical down to 45°. This reduces the signal strength at the aircraft to the strongest of these emitters (45°) by not only the 4 dB, but also by the increased distance to those emitters squared (assuming only free-space propagation losses), or an additional 3 dB. Closer emitters (directly below the aircraft) suffer from larger antenna losses that offset the decreased range to the victim receiver.

5.5 UWB devices will exhibit intrinsic limitations on emitter density because they share a common RF channel

One of the final points to address in our discussion of aggregation is to understand what densities to expect for eventual deployment of UWB devices. Although the NTIA study presented results for densities as high as 10,000 emitters per km^2, each with 100% activity factor at the highest power levels permitted, this upper limit is certainly an unrealistic level for typical situations. To see why this must be we must simply understand that UWB device density will be *inherently self-limiting* because the devices share a common RF channel.

[29] NTIA report 01-43, chapter 5.
[30] See for example, the Qualcomm report on UWB-PCS interference or Sprint in comments date Feb. 23, 2001.

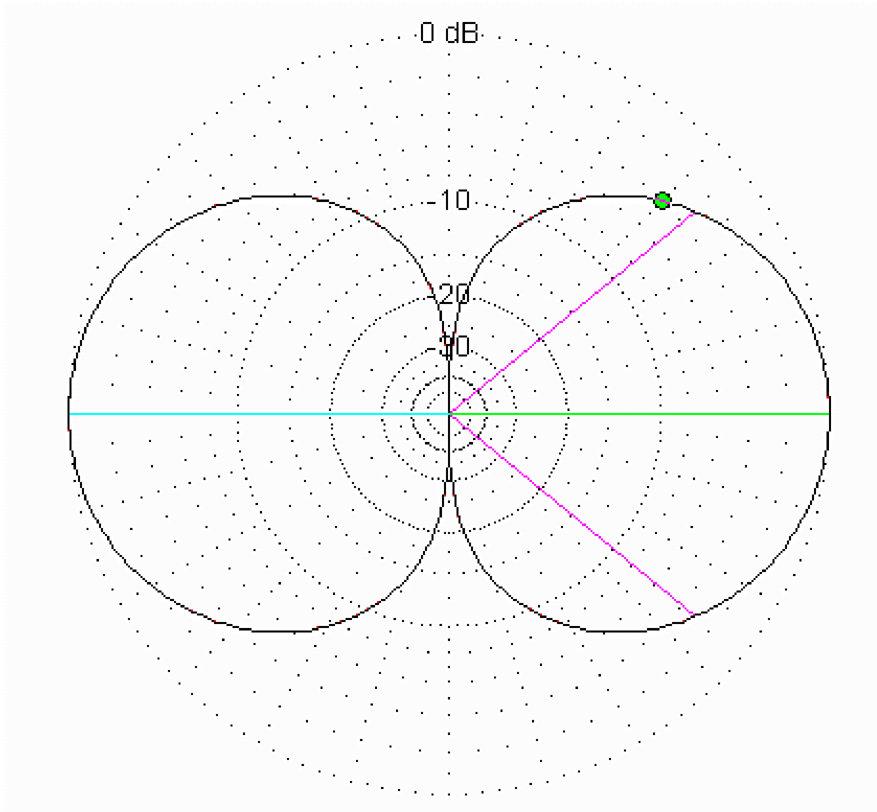

Figure 3: Realistic antenna pattern for UWB emitter used in the aggregation studies for aviation applications.

Obviously most communications applications require that UWB devices are closely grouped to enable communications between them. This is particularly true for wireless network applications that might link multiple devices in a home, for example. In modeling the aggregate emissions of such group, however, we should treat them as a single emitter, at most, because they must coordinate emissions to share the common channel. Although there are different medium access control approaches that can be used to share a common channel, all must provide a way to ensure that devices do not interfere with each other or else effective communications cannot occur. This need for coordination will therefore result in either reduced duty cycles, reduced power levels, or both, whenever devices are operating together as a network. The logical result of this effect is that as device densities increase, beyond some level there must be a corresponding decrease in per-device emissions or else the combined effect will be to render all of the UWB devices inoperable. This situation is well understood by system designers and is one of the fundamental concepts underlying cellular telecommunications today.

Although it is difficult to predict what levels of UWB deployment density will ever occur, it is clear that it will not increase indefinitely. In earlier comments, one company provided an estimate of several hundred devices per km^2 for a populated area.[31] Although some may question this estimate, it is certainly hard to understand how this could low by more than an order of

[31] Comments by Fantasma, Inc., dated February 23, 20001.

magnitude. At such levels, we have seen that the effect of nearby emitters will still dominate the interference seen by victim receivers in many cases of the NTIA aggregation study and therefore that regulations based on such results can be safe and effective.

5.6 Aggregations of UWB emitters can be well understood using existing techniques

As a result of the aggregation analysis reported by the NTIA and the additional interpretations offered above, we now see that although UWB interference power does add linearly for a victim receiver, distant emitters experience propagation losses that significantly attenuate the amount of their contribution to the aggregate interference seen by the victim receiver. This is demonstrated by the NTIA results where the additional emitter placed on the inner ring in all of the simulations had a dominating effect whenever the receiver was close to the ground. This is also in agreement with prior analytical studies that indicated the dominant effect of nearby emitters in the aggregate interference. These studies are noted in the NRPM where the FCC indicates that their initial conclusions are that the noise floor for victim receivers is determined by the closest UWB transmitters.[32]

In summary, we see that the aggregate effects of multiple transmitters can be understood through the same techniques used to model single emitters or small groups of emitters throughout these proceedings. We have demonstrated in these comments and in earlier comments that the guidelines proposed above for UWB operation are sufficient to ensure that UWB devices in small number will be able to safely coexist with existing telecommunications systems, including federal systems, PCS, and GPS. We have further demonstrated that aggregation effects will not lead to any unpredictable phenomena, but can be effectively analyzed and understood using existing models and techniques. As a result, we can safely conclude that there is no reason to believe that the aggregate effect of widely distributed UWB emitters will lead to significant interference problems under any realistic assumptions about emitter densities or deployment scenarios.

6. Conclusion

The data presented in these reports provides an adequate basis for understanding the nature and severity of the potential interference that may be caused by a UWB device to a GPS receiver. Logical extensions to the NPRM were proposed that would allow UWB devices to coexist with GPS and other radio services with little potential to cause harmful interference. All of the test results and analyses examined in this proceeding have been shown to support this fact. Therefore, XTREMESPECTRUM recommends that the FCC approve, without further delay, the use of UWB devices under a modified set of Part 15 rules.

[32] See NPRM, paragraphs 46 and 47.

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