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The Johns Hopkins University Applied Physics Laboratory
Reply to Comments to Docket ET 98-153
10 May 2001

1.0 Introduction and Summary

On 09 March 2001, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) submitted a report as a comment to the Notice of Proposed Rule Making contained in ET Docket 98-153. That report contains a statistical evaluation of data collected by the Applied Research Laboratories University of Texas at Austin (ARL:UT). The purpose of the statistical analysis was to distill the numerous data collected by ARL:UT into a form readily interpretable by engineers. It is noted that a few minor errors were discovered in the original filing while briefing the material. These errors have been corrected in the errata in our comment filed on 24 April 2001.

Subsequent to the original filing, the FCC issued Public Notice DA No. 01-743 on 26 March 2001, which requested comments on the JHU/APL report and four other reports by 25 April 2001. Several interested parties responded to the FCC request, while other parties simply filed comments outside of the request.

This reply comment responds to both types of filings. The remainder of Section 1 summarizes three core issues that appeared in a number of the comments to the report, and provides our response. Section 2 provides detailed comment-by-comment responses to each party.

1.1 <u>The Meaning of the 3-Meter Range in the Executive Summary</u>

Comment:

Some readers took issue with our characterization of the data as showing “severe degradation” at UWB-GPS ranges less than about 3 meters. (This characterization appeared in Section 6.5 of the report, and in the Executive Summary, conclusions #4 and #5.) Complaints focused on the possible implication that there is no significant degradation beyond 3 meters.

Reply:

UWB-GPS interference ranges will vary greatly, depending on application. So while 3 meters was a subjective characterization of where severe degradation typically was observed, an examination of the report data also shows perceptible degradation at ranges as large as 25 meters and beyond, for some of the receivers tested and MOPs evaluated. At the other extreme, one of the receivers tested succeeded in maintaining a navigation fix against all three UWB modes tested, even at ranges down to 1.2 meters.

In general, the following factors will affect range:

- Scenario: The received UWB power in scenarios of interest could be significantly different from that occurring in the ARL:UT test setup, owing to factors such as mismatch between UWB and GPS polarizations, multipath, or gain of the GPS receive antenna in the UWB direction. For example, if the range is based not on the ARL:UT radiated field measurements, but calculated for an isotropic antenna with full ground bounce, it increases by a factor of about 2.
- GPS Receiver: Performance variations among the receivers tested were large. It can be anticipated that other receivers can be found whose performance lies outside the bounds observed for the receivers tested.
- Performance required: Different applications may have different MOPs of interest, or different required thresholds for the MOP. An additional margin might also be applicable. For example, if an additional 6 dB is added for safety-of-life considerations, computed ranges will increase by a factor of 2.

1.2 The Meaning of "White Noise-Like"

Comment:

Some readers took issue with the apparent implications of our description of measured UWB emissions as "white noise-like," or drew conclusions from this description in their comments which we do not agree with. (This characterization appeared in the Executive Summary, conclusions #2 and #3.)

Reply:

The term "white noise-like" was intended only to refer to the observed impact of interference on GPS receivers, i.e. that it was similar to the impact observed for white Gaussian noise, as shown in Appendix A. "White noise-like" was not intended to imply that there were no spectral lines or other form of non-white spectral energy distribution, even within the GPS band, and we agree that all of the UWB devices tested produced spectral lines. We also agree, as was stated in the Executive Summary, that only some UWB devices produce "white noise-like" impact on GPS receivers and that others can produce non-"white noise-like" effects.

Conclusion #2 of the Executive Summary was based on the fact that generally only small differences were observed between the impact of white noise and the impact of some of the UWB interference (as seen in Chapter 5 and Appendix A). Since it could be read to imply conclusions beyond that supported by the data or analysis, we wish to emphasize that we did not mean to say that the interference produced by the UWB devices tested by ARL:UT could never excite any complex interactions in GPS receivers, nor that these interactions were necessarily well-studied, only that the impact of any such interactions on the measured data was observed to be small.

1.3 The Sufficiency of the Record for FCC Decisions

Comment:

Some readers took issue with our statement that we believed there was sufficient information available to the FCC to establish criteria for regulating UWB emissions. (This characterization appeared at the end of the Executive Summary.)

Reply:

It was not the intent of this statement to judge the sufficiency of the record for FCC purposes, and we fully concur that it would be inappropriate for JHU/APL to do so.

2.0 Detailed Replies to Comments

This section contains direct replies to the comments filed in response to the FCC request. Replies to the most common and significant comments are summarized in Section 1.0.

2.1 Replies to Comments Submitted by the US GPS Industry Council

The following replies are directed to the comments filed on 16 March 2001 on behalf of the US GPS Industry Council, which resulted from meetings on 12 and 13 March 2001 between JHU/APL and RTCA Special Committee 159 (Working Group 6).

2.1.1 Comment:

The referenced report states that 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. Meeting participants disagreed with the arbitrary criteria used for the selection of the 3-meter separation. Data in figures from Chapter 6 of the referenced JHU-APL report contradict this conclusion.

Reply:

This summary observation was restricted by the context of the whole report to simply represent a range where the mean fitted data for the 12 measures of performance were degrading very badly. This led to the “about 3 meter” observation as a subjective characterization of the global test results. It is a fact that degradation was observed at some level for some measures of performance and some signal conditions well beyond 3 meters. The primary output of the report is the plots of all the analyzed data. The idea was that applications oriented studies could use these data to help determine their minimum standoff requirements by applying their criteria to the report plots. Naturally the receivers and UWB devices included in the test program would limit such observations, but it might be possible to extend the data somewhat with reasonable adjustment factors.

This reference to 3 meters is part of the fourth conclusion of the executive summary, which also stated these observations were “based solely on the GPS receivers and UWB devices tested by ARL:UT.” We have reviewed the 12 curves in question and still believe that the stated conclusion is correct as a means for characterizing the global test experience; in that regard, the selected range is subjective and approximate, but we do not believe that it is arbitrary. The fifth conclusion states that the “minimum separation at which degradations are acceptable depends on individual user scenarios including performance thresholds, GPS receiver and UWB device(s).” The reference to average powers for UWB devices was limited to those devices that produced white noise-like interactions with the GPS receivers tested. The importance of this characterization was the point of the first three conclusions of the executive summary. (Also 2.2.5, 2.3.5, and 2.5.1)

2.1.2 Comment:

Meeting participants observed that a device emitting at the Part 15 average power limits in the GPS frequency band result in a received power at a GPS antenna 3 meters away at a level 24.3 dB above the receiver's ambient noise level. To be consistent with commercial GPS operation, this level would have to be reduced by at least 20 dB (even more so for aviation safety-of-life), which would increase the equivalent range by a factor of 10. This observation is inconsistent with the conclusion JHU-APL report contains. Meeting participants perceived that the actual power level of the device used in the test may be less than the average power limit of a Part 15 device. The actual level for the onset of unacceptable degradation is a factor of 100 lower in power based on international standards ITU-R M.1477. Meeting participants believe that there is a discrepancy between the FCC Certification Laboratory emission levels and the actual spectrum analyzer measurements from the University of Texas, Austin, which may explain this discrepancy.

Reply:

The computation done at the meeting begins with the FCC maximum allowed field strength (500μv/m) at 3 meters, squares that number and divides by the free space impedance to calculate a power density at 3 meters. The power density is then multiplied by a theoretical expression for the GPS antenna aperture area to produce the power level indicated. That power level is about 24 dB above the typical thermal noise at the GPS preamplifier and we agree that this would cause very serious problems. However, the 500μv/m level is based on a test configuration which benefits from a 6 dB multipath response by putting the device under test above a conducting ground plane and by tuning the receiving antenna height for maximum. A more typical number and one that better represents the ARL:UT test program is 250μv/m. With this 6 dB applied, the 24 dB number drops to 18 dB.

Furthermore, most GPS antennas are circularly polarized (and they were in this test program) and the tested UWB antennas were linearly polarized. Including this factor drops the number to 15 dB. Additionally, the certification test conducted on the tested UWB device actually had its peak field strength at a frequency slightly higher than L1 and the GPS antenna gains were probably less than 0 dB over the elevation region tested. These factors would also act to reduce the interference. In the ARL:UT radiated test, all 6 GPS receivers tested continued to operate at 3 meters standoff from the tested UWB transmitter (the test elevation angle was 10.7 degrees), for all UWB modes tested. The UWB power realized at each GPS receiver's preamplifier, in the radiated test, appeared to be between 3 and 9 dB above the receiver's ambient noise levels rather than the 15 dB suggested by the above analysis.

There is an important item that can get missed when the transmit power is computed from the maximum field strength at 3 meters. If that power is subsequently converted to an equivalent transmit power into an isotropic transmit antenna by increasing it to account for the 3-meter range offset, it creates a field strength that is equal to the specified maximum value in all directions ("isotropic field strength"). In reality, because the FCC certification test is designed to include a multipath gain of 6 dB, the actual maximum transmit power that can be certified is 6 dB less than that computed from the isotropic field strength. When a transmitting device that is FCC certified is connected to a typical antenna, the region where the maximum field strength is realized is very limited relative to that for an isotropic field.

The UWB device used in the ARL:UT test program is a good example. It produced a field strength at 3 meters that was just compliant in the FCC certification test with a transmit power that is 6 dB lower than what would be calculated from the isotropic field strength calculation. This is important because, while the effective radiated power is the product of the transmit power and transmit antenna gain, the transmit power is scenario-independent, which is not the case for transmit antenna gain. Not all scenarios will experience significant multipath, but if the power is assigned to the transmitter it becomes a part of all scenarios.

We offer no comment with regard to the reference to ITU-R M.1477. Nothing within the APL study was intended to define or comment on specific user's requirements. Our intended purpose was to report observations of UWB interference based on an analysis of the data provided by the ARL:UT test program.

The concern with regard to actual power level of the UWB used in the radiated test was the result of a misunderstanding between ARL:UT and JHU/APL that unfortunately caused an error in intermediate calculations in Appendix B. It was our original understanding that the UWB device used in the conducted test was reduced by 6 dB before it was used in the radiated test (see the first sentence at the top of page B-6). ARL:UT has now corrected our understanding: There were no modifications made to the UWB device between the two test phases. Furthermore, the UWB device as used in the radiated test was configured exactly as it had been for the FCC certification testing. As a result of the appendix B error, the range equations on pages B-7 and B-9 have the wrong constants. While this changes intermediate values, the final adjustments to conducted data analysis for each receiver (i.e., the equations on page B-15) were based on a fit to the radiated test data. Therefore, only the fitting parameters changed, and the resulting equations remain correct. Details of the required corrections were provided separately in a report errata filing.

2.1.3 Comment:

Meeting participants believe that:

- *Improper factors were used in the conversion of attenuator settings from the test range values reported in the results.*
- *Introduction of a range relationship implies that a scenario dependent link budget was employed when, in fact, it was not.*
- *The criteria used for severe degradation is not consistent with safety-of-life applications that demand high GPS availability, continuity of service and integrity. These applications should require an additional 10 dB; E911 deserves further consideration.*

Reply:

Apart from the above-acknowledged minor correction needed in appendix B, the factors used to compute equivalent range for the attenuator values used in the conducted tests are proper. The first value that was derived from a theoretical description of the radiated test configuration did include the 6 dB error noted, but the equations used to compute equivalent range for the conducted data were based on the fit to the actual radiated test data. The summary data reported for the 12 measures of performance were based on the fitted equivalent range. (Also see 2.3.7)

The only scenario relevant to our study was the radiated test configuration. We did analyze that link configuration in appendix B. The purpose of that analysis was to provide a comparison with the results obtained from the radiated tests to use as an indication of reasonableness. The theoretical equivalent range factor (i.e., the range represented by a 0 dB setting of the UWB variable attenuation, using 0 dB UWB antenna gain and –3 dB GPS antenna gain) for the Holloman test configuration was 0.62 meters. The fitted values of the four receivers varied between 0.31 and 0.69 meters. These values were considered to be in reasonable agreement.

The use of “severe degradation” in the report makes no reference to any regulatory criteria. To have done so, the report would have had to apply performance criteria for specific applications, and that was not within the scope of the study. The application of margins for safety-of-life or E911 services is also beyond the scope of this report.

2.1.4 Comment:

From the Executive Summary of the referenced report: “Based on this report and the inputs from other organizations, JHU/APL believes that sufficient information is available for the FCC to establish criteria for regulating UWB emissions. Methodologies such as those presented in this report can be used to help the FCC *evaluate the application of these criteria." RTCA SC-159 (Working Group 6) observes that it is inappropriate for JHU-APL to judge the sufficiency of the record in the UWB proceeding.*

Reply:

It was not the intent of this statement to judge the sufficiency of the record for FCC purposes, and we fully concur that it would be inappropriate for JHU/APL to do so.

2.1.5 Comment:

The JHU-APL analysts were repeatedly requested by the participants to correct both the stated power and distance errors. The JHU-APL analysts stated that they would not publish any changes and that their report stands as is.

Reply:

A report errata document has been submitted to correct all known technical errors.

2.2 Replies to Comments Submitted by ARINC and ATA

The following replies address comments submitted by the Aeronautical Radio, Inc. (ARINC) and the Air Transport Association (ATA) dated 25 April 2001. The specific comments are contained in section II. C.

2.2.1 Comment in first paragraph, third sentence:

… pro-UWB "spin" contained in the executive summary of the JHU analysis …

Reply:

We were surprised by this assertion; the APL analysis team believes itself to be neutral with regard to the applications of this technology.

2.2.2 Comment in second paragraph, first two sentences:

JHU concedes that the choice of time coding parameters in the UWB device can have a significant impact on the performance of GPS receivers. JHU contends that time coding that produces 'non-white noise-like" signals will have greater impact on GPS receiver performance than UWB emissions that are "white noise-like".

Reply:

Actually, impact of time coding on interference is more than a concession; it was a stated conclusion. The greater impact condition is also more than a contention; it has been demonstrated by the DOT/Stanford University test results and the JHU/APL analysis provided in chapter 5.

2.2.3 Comment in second paragraph, third sentence:

JHU failed to define the term "white noise-like", or explain whether "white noise-like" transmissions have discrete spectral lines on the same order as noise.

Reply:

This is a valid criticism; we had intended the "white noise-like" commentary to be understood in relationship to the data and analysis discussions in the body of the report, but didn't explicitly make that connection. With regard to spectral lines, the time code used in the test program did have discrete lines (unlike white-noise). The line spacing was equal to the pulse rate divided by 1000. That is, depending on UWB mode, the lines were separated by 1, 5, or 10 KHz. Within the 20 MHz GPS bandwidth, the lines have nearly equal amplitudes. The "likeness" terminology is related to the similarity of performance-degradation between a white noise source interferer and the tested UWB interference, normalized to equal average powers. This similarity was observed in the test results (since an actual white noise source was included with similar power levels as in Figure A-14) and in the simulated results presented in chapter 5 (Figure 5-21). (Also see 2.4.2 and 2.6.1)

2.2.4 Comment in second paragraph, last two sentences :

JHU's conclusions about "non-white noise-like" coding schemes must be qualified. It is possible that UWB coding schemes other than the limited ones measured by UT ARL may significantly affect GPS performance more than the schemes tested."

Reply:

We do not understand the comment since the Executive Summary specifically stated, "there exist coding schemes that can produce non-white noise-like UWB signals that may have a greater impact on GPS performance than those effects shown herein." Note that the report only considered one specific "non-white noise-like" code and that was done analytically, the only UWB time codes included in the test program were "white noise-like."

2.2.5 Comment in third and fourth paragraphs:

These ARINC/ATA paragraphs discuss an interpretation of the "about 3 meter" terminology from the report executive summary in relationship to specific applications and referenced standards of performance for those applications.

Reply:

These ARINC/ATA paragraphs and their associated footnotes incorrectly extended report conclusions to specific application scenarios. The scope of the report was limited to analyzing the nature of interference observed within the data sets collected by ARL:UT. The report includes no content with regard to standards of performance for any application. There are no typical or worst-case scenarios evaluated to determine performance criteria relative to any application. "Severe degradation" does not have a regulatory definition within the report context. To identify such terms in a regulatory sense would have required examination of the kinds of things rightly noted in the commentary, but these are not addressed by the report. They were outside the objectives and scope of the study. (Also see 2.1.1, 2.3.5, and 2.5.1)

2.2.6 Comment in fifth paragraph, last two sentences:

For white noise-like signals, the JHU report recognizes that such interference accumulates as added average power. However, the JHU Report fails to remark on the increased interference potential from multiple UWB [device] even from so called "white noise-like" devices."

Reply:

As noted in the comment (and addressed in Appendix G of our report) we agreed with others that these powers added.

2.3 <u>Replies to Comments Submitted by Sirius Satellite Radio</u>

These replies address section I.B of the Sirius comments submitted on 25 April 2001.

2.3.1 Comment in first sentence:

This is the only report from the five considered in this Comment cycle that has been prepared on behalf of a UWB proponent (Time Domain Inc.).

Reply:

The foreword of the JHU/APL reports more correctly indicates the nature of the JHU/APL relationship with the Time Domain Corporation. "While this work has been conducted under a contract with Time Domain Corporation, a proponent of

UWB technology, JHU/APL has conducted an independent evaluation and this technical report does not make advocacy statements or policy recommendations with regard to UWB technology or Time Domain Corporation."

2.3.2 Comment in item I.B. (i), first paragraph:

The findings of the report are very limited in scope and certainly do not address the potential interference that could occur to GPS receivers from all UWB devices. Two aspects of the Johns Hopkins University (JHU) report demonstrate this conclusion:

(a) The data on which this report is based was gathered using only two UWB device types, both from the same manufacturer, Time Domain, Inc. Because UWB devices vary significantly and only two types were tested, the report provides only a limited assessment of the potential interference situation.

(b) The JHU Report is in fact limited to a study of those UWB devices least likely to cause interference to licensed systems. …
The JHU Report makes clear that other UWB devices can exist that produce significantly greater interference in GPS receivers, while still complying with the FCC proposed technical parameters.

Reply:

The above statement is correct in regard to test data analysis. This was an admitted limitation of the report. Indeed the total objective of the study was to analyze the data collected by a previously conducted test program and was explicitly limited to the hardware used in those tests. However, the findings were extended some by additional theoretical analysis. Without that extension the report would not have included the final comment in (b) above.

2.3.3 Comment in item I.B. (i), last three paragraphs:

Furthermore, the JHU Report acknowledges that the structure of the UWB signal affects the impact on the victim receiver. Both the NTIA and DOT reports indicate further that certain signal characteristics, particularly the Pulse Repetition Frequency (PFR), make greater difference than others. In particular, the NTIA and DOT reports show that, the higher the PRF, the stronger the interference effect. For this reason, The NTIA Report separately analyzed the effect of signals at several PRF rates up to 20 MHz.

Nevertheless, the UT:ARL tests and the JHU analysis only studied PRF up to 10 MHz. One of the two devices tested operates with a nominal PRF from 1 MHz to 10 MHz; no separate results are given for the operation of this device at different PRF levels, and thus the effect of this device is not clearly explained. The second *type of UWB device tested operates with a nominal PRF of 5 MHz. This device would be expected to show relatively less interference than a device with a PRF of 10 or 20 MHz.*

In short, the JHU report shows the interference effect of UWB devices, which, by their very nature, are less harmful to licensed systems, and does not analyze the variable interference effects that even those devices may have.

Reply:

These comments do not accurately reflect the test conditions or the findings of the JHU/APL report. The UWB device type used for all the conducted tests and most of the radiated tests were operated at a 1, 5, and 10 MHz PRF, and results were reported for all pulse rates. Within the acknowledged limitation of the single time-coding technique used by the tested UWB devices, PRF was not a strong factor when the signals were normalized to a common average power. This was shown to be true in both the test data and the theoretical analysis. The theoretical analysis of this waveform type was extended to 20 MHz. The analytic results of the 20 MHz case showed the same characteristic. The theoretical analysis also showed that the PRF could be very significant when the UWB device spectrum has strong widely distributed and/or substantially non-uniform spectral line content.

2.3.4 Comment in item I.B. (ii)

The JHU Report is self-contradictory and simply incorrect when it states that the current record is sufficiently complete to support Commission action.

Reply:

It was not the intent of this statement to judge the sufficiency of the record for FCC purposes, and we fully concur that it would be inappropriate for JHU/APL to do so.

2.3.5 Comment in item I.B. (iii)

The JHU Report's conclusion that GPS receivers exhibit "severe degradation when the separation between the GPS receiver and the UWB devices is less than about 3 meters" is arbitrary and misleading because it understates the danger of interference.

Reply:

The danger of interference depends on specific users' applications, which are beyond the scope of the report. (Also see 2.1.1, 2.2.5, 2.5.1)

2.3.6 Comment in item I.B. (iv)

The tests reported by [The] John[s] Hopkins University do not take into account the fact that the GPS receiver will likely be already operating in a background noise environment before the UWB interference is encountered.

Reply:

Within the conducted tests, the background noise environment is set by the noise contribution of the amplifier connected to the GPS simulator output and the noise contribution of the first amplifier of each receiver. In some cases, the first receiver amplifier is the normal GPS preamplifier, in other cases, it is the first amplifier following the cable connector where an antenna-preamplifier cable would normally be connected. Therefore, it should be expected that each receiver in the conducted test setup actually had a somewhat different background noise environment.

The conducted test concept was based on setting independent attenuator values between each receiver and the GPS signal simulator. The attenuators were adjusted (with UWB interference off) so that each receiver reported the C/N_0 that it had reported while operating at the field test site on an earlier day. The GPS simulator was configured to repeat the constellation geometry for the day corresponding to the C/N_0 settings. This test setup was called the "live-sky" test. In this test the background noise was approximately representative of the conditions of the field test site. Reducing the GPS simulated signals by 13 dB created a more stressing condition, called the "min-level." From a receiver performance perspective, this would be equivalent to operating in a background noise environment 13 dB worse than the "live-sky" condition. In this environment, the GPS receivers were operating so near threshold that even without any UWB interference some of them were unable to reliably reacquire satellites once they were lost.

In the radiated tests, the background noise environment was exactly that provided by its geographic location over the many days of testing at that location. Therefore, the sum of the data analysis is representative of the background environment associated with the ARL:UT test site. To extend the results to other environments would require an adjustment to account for the differences in the background environments.

2.3.7 Comment in item I.B. (v)

In a March 16, 2001 ex-parte submission, the US GPS Industry Council reports that there appear to be errors in the JHU report, including the use of improper factors for the conversion of attenuator settings from the test to the range results reported in the results, and other significant errors in measurements. These referenced errors have not been corrected.

Reply:

The US GPS Industry Council comment is addressed in Section 2.1.3.

2.4 Replies to Comments Submitted by Conexant Systems

The following replies address the comments submitted by Conexant Systems on 25 April 2001.

2.4.1 Comment in second and third paragraphs:

We are especially concerned with the impact to GPS because of the low signal levels, wide bandwidth, and interference scenarios that could exist. It is in this regard that we make some observations on the report by the John Hopkins University / Applied Physics Laboratory (JHU/APL) where they have performed relevant data analysis on the data generated by the [Applied] Research Laboratories, University of Texas (ARL, UT). …
The report makes a conclusion that the interference capabilities of UWB devices are dependant on the characteristics of the UWB signal. The only UWB devices that were used in the test analysis are the two devices provided by Time Domain Corporation: a PulsON Application Developer and a Signal Generator/ Noise Emitter. The signal structure of UWB devices of other corporations differ from those of the devices used in the tests. Since there are presently no guidelines on the specific nature of the UWB pulse and its characteristics in the current Part 15 regulations, it remains to be seen whether results with UWB devices not used in the tests behave in the same manner.

Reply:

The limitations of the tests were acknowledged. The supporting analysis clearly indicates that there are waveforms that would definitely not behave in the same manner.

2.4.2 Comment in fourth paragraph, first two sentences:

The JHU/APL report states that it is possible to design a properly time-coded UWB waveform that has a white-noise like spectrum. The report also state[s] that improper time coding of the UWB waveform can result in non white-noise characteristics which can cause deleterious influence to GPS systems.

Reply:

The comment regarding UWB white noise-likeness refers to UWB signals that interferes with GPS receivers in a manner like a white noise source of the same average power within the GPS signal bandwidth. (This is less constraining than producing a white noise-like spectrum.) The tested devices generally worked that way and an analysis of the signal structures confirmed the observed test results. The study also analyzed a UWB waveform previously reported that demonstrates a waveform that produces interference with GPS that is non-white noise-like. (Also see 2.2.3 and 2.6.1)

The remainder of the fourth paragraph relates to matters outside the scope of the JHU/APL study. Development of controlling criteria will require additional study and such a study can not be completed without applying definitive GPS performance criteria set by usage scenarios that bound acceptable UWB operating conditions.

2.4.3 Comment in sixth paragraph, first two sentences:

The interference effects of UWB are dependent on a number of variables including the type of signal structure, the operating scenarios and the type of receiver. These parameters have not been properly addressed by the report in sufficient depth and detail.

Reply:

The JHU/APL report addressed only the test results obtained for the specific UWB devices and GPS receivers that were part of the ARL:UT test program. An analysis of the involved waveforms was also completed to enhance the understanding of the nature of the interference being observed in the test data. The analysis and test results support the conclusions reached in regard to characterizing the test observations and when combined with specific scenario constraints can be used to assess performance degradation as a function of range in the subject scenario. The JHU/APL report did not analyze any GPS application, or consider standards of performance for any application, or provide scenario analysis in support of the development of application-dependent standards of performance.

2.5 Replies to Comments Submitted by Multispectral Solutions

The comments submitted by Multispectral Solutions on 16 March 2001 addressed perceived "myths" in regard to UWB interference. The following replies are identified by the myth number.

2.5.1 Comment:

"Myth #1" (*UWB is non-interfering*). Regarding values in the table.

Reply:

The table provided in this discussion incorrectly attributes "Min Range," "Max Range," "Average," and "Criteria" entries to the JHU/APL report. The JHU/APL report did not establish criteria for the assessment of an acceptable standoff range for UWB devices. The 3 meters in the JHU/APL report was only to identify the approximate standoff range where the performance degradation is severe. (Also see 2.1.1, 2.2.5, and 2.3.5)

2.5.2 Comment:

"Myth #3" (*High UWB Pulse Rates Have Little Impact on UWB Interference Potential*)

- *NTIA, Stanford University, and The Johns Hopkins University/Applied Physics Laboratory have each demonstrated that, for UWB pulse repetition frequencies (PRFs) exceeding the bandwidth of a victim receiver, the interference level increases as the* <u>*square*</u> *of the PRF ratio.*

Reply:

The JHU/APL report does not demonstrate this characteristic. The report analyzed test results for 1, 5, and 10 MHz PRFs and showed approximately equal impact for equal average powers. The report also included a theoretical analysis that demonstrated this same conclusion and extended it to include a 20 MHz PRF. These results were restricted to the specific time-dithered pulse trains used in the UWB devices tested. The figures referred to (pp 5-20 to 5-22) have different amplitudes only because they have different average powers. A single alternate case operating at 19.94 MHz without dithering did not behave this way (see the figure on p 5-23). The primary issue with the alternate case was the existence of a spectral line at the GPS L1 center frequency (see the figure on p 5-24, where the dithering used in the other cases was applied to the 19.94 MHz PRF).

2.5.3 Comment:

"Myth #6" (*Filtering will significantly increase the cost to manufacture UWB devices*)

- *… The recent JHU/APL report highlighted the use of a high-pass differential-type filter by Time Domain Corporation in the Pulson Applications Developer (PAD) and Signal Emitter/Noise Generator used in the UWB-GPS compatibility tests.*

Reply:

Characterizing the JHU/APL reporting of a high-pass filter in the test configuration as highlighting its use seems to imply an importance not intended. JHU/APL made no recommendations with regard to filtering the UWB device under test and offers no opinion on this technique.

2.6 Replies to Comments Submitted by RTCA

The RTCA Second Interim Report dated 27 March 2001 and filed by NTIA on 03 May 2001 offers several comments regarding the conclusions presented in the executive summary of the JHU/APL report.

2.6.1 Comment:

RTCA disagrees with the characterization of "white noise-like" for the individual UWB devices tested. It appears from Joint Spectrum Center analysis of the same UT data set that these signals actually contain spectral lines spaced at PRF/1024 Hz. For example, a 5 MHz PRF yields a line spacing of 4.88 kHz. The effect on the receiver cycle slip rate appears to be associated with aligning of these 4.88 kHz lines with the C/A code spectral lines, thereby producing effects that are time varying and only weakly correlated with UWB interference power.

Reply:

The reference to "white noise-like" was based on comparisons of GPS receiver performance in tests conducted using a white noise source with those using the UWB sources. The UWB spectrum does have a line structure related to the time code. The time codes used actually contain 1000 "chips" rather than 1024. The lines are located at PRF/1000 Hz and their amplitudes are relatively flat over the GPS frequency band. The intent of the white noise-like characterization can be seen in the data plots shown in Appendix A and in the analysis results shown in chapter 5.

The conducted test MOP results for all receivers are shown beginning at page A-12. Each page shows the MOP results for four different interference sources: a white noise source (lower right), UWB mode 1 (lower left), UWB mode 7 (upper right), and UWB mode 13 (upper left). The white noise source average power was set to be equal to the UWB mode 13 average power. The mode 7 power was about 4 dB lower and the mode 1 power was about 10 dB lower. Examination of the 4 plots indicates a strong similarity between the white noise result and the mode 7 and 13 results. Recognizing the statistical nature of the tests and the natural variations in the test setups, the likeness of results between the white noise and the mode 13 test results motivates the white noise-like characterization. Examination of all the remaining data will expose differences of detail, but most of the data supports this characterization.

In chapter 5, the same four test conditions were analyzed using the same power levels. GPS C/A signals were simulated for six satellites all at the same power level along with an interfering signal at a varying power level. The power levels were set to match the conditions used in the conducted test setup.

Figure 5-15 shows the correlation results for the interference produced by an analytic white noise source having the same average power as the mode-13 simulated interference, shown in figure 5-18. The top plot in each of these figures is a cross correlation between the simulated signal group and a single C/A signal that matches one of the six simulated satellites. The bottom plot uses a single C/A signal not included in the six simulated satellites.

There is no significant off-center correlation until the attenuation setting gets below 20 dB. Below 10 dB there are many regions where the interference is greater than twice the central correlation peak (i.e., the red areas). Comparing figures 5-15 with 5-18 shows the similarity between the mode 13 and the white noise source correlation outputs. The other UWB modes show less impact because of their reduced average power.

These results are consistent with the test results observed in Appendix A. In contrast to these results, figure 5-20 shows an undithered UWB device set at 19.94 MHz. In this case, once the L1 line achieves a sufficient level (at around 30 dB), the interference dominates the correlation. Figure 5-21 computes the C/N_0 that would be estimated by outputs from the correlation processes of figures 5-15 through 5-20. It should be remembered that the average powers for each line shown here is different, except that the white noise source and the mode 13 powers were set equal. The white noise source and the mode 13 lines are therefore overlaid in the figure. If the other dithered modes were all set to the mode 13 average power level, they would also overlay the mode 13 line. However, even after power normalization, the undithered UWB line would continue to show far greater degradation.

The APL summary conclusions fully support the following RTCA report section A.4 conclusions that UWB interference depends on pulse sequence and that random-sequences can be treated like white noise interference:

From the responses shown above, it is very clear that the effect of UWB pulse sequences on a GPS receiver is much like random wideband noise, CW interference, and anything in-between, depending upon the pulse sequence (random, constant PRF or mixture of the two). Thus the response to UWB emission can be treated like any other GPS interference. That is, the random sequences can be treated like white-noise and the constant PRF sequence can be treated like CW interference – treated as though it were 10 times worse than white noise. Any semi-random sequence would fit somewhere in-between. Thus, because the signal structure[s] of UWB devices are unknown, [they] must be treated as the worst case CW interference at a 10 dB penalty with respect to interference.

(Also see 2.2.3, and 2.4.2)

2.6.2 Comment:

RTCA notes that other testing efforts have shown coding schemes that actually do produce non-white-noise-like effects.

Reply:

This seems to be a restatement of what was intended by conclusion 3. The first two conclusions were acknowledging, based on experimental observations and analysis, that UWB time code modulations could produce interference with GPS receivers that acted like white noise interference having the same average power (above discussion). The third conclusion was added to indicate that this was not a property of all UWB time coding schemes. The same point appears in the RTCA report section A.4 noted above.

2.6.3 Comment:

RTCA disagrees with the arbitrary selection of 3 meter separation for the onset of "severe degradation" for several reasons. (1) Report data (Figures 6-4, -5, -6, -9, -11) contradict the conclusion that 3 meters is an appropriate distance separation for GPS effects analysis. (2) An emitter at the Part 15 average power limit (-71.3 dB W/MHz) produces a signal into an isotropic antenna 3 meters away which is over 200 times the internationally accepted standard for unacceptable interference to the GPS receiver (ref ITU-R M.1477). (3) Improper factors were used in the conversion from attenuator setting to equivalent range. Examination by RTCA of the basic ARL:UT measurements suggests that the performance degradation actually takes place at power levels consistent with the international standards (see also Sec. 3.1 and 3.4 of this RTCA report). (4) The introduction of a range relation implies that a scenario-dependent link budget was employed when, in fact, it was not.

Reply:

Refer to the replies in section 1.1 and the first three comments of section 2.1. These same points of contention were contained in the comments submitted by the US GPS Industry Council.

2.6.4 Comment:

RTCA notes that the 3- meter value is unrealistic (see RTCA comment above). Also, there is no explanation of "nominal level."

Reply

See the 3-meter discussion in the response to the third point of contention. "Nominal level" meant that the MOP being observed would return to a value typical of its performance when no interference was present.

2.6.5 Comment:

RTCA notes that the measures of performance are inadequate for many GPS applications. For example, cycle slip occurrence is a critical measure for survey receiver performance, and for aviation precision approach.

Reply:

The measures of performance selected for the JHU/APL study were those that seemed most appropriate. There was no purposeful omission in this regard; cycle slip occurrence was simply not within our originally selected group. (Note that the actual occurrence of cycle slips cannot be inferred from the receiver-generated flags.)

2.6.6 Comment:

RTCA believes that it is very inappropriate for JHU/APL to judge the sufficiency of the FCC record in the UWB proceeding. This final conclusion is inconsistent with and unsupported by the certain results in the body of their work as pointed out above. The conclusion is far to general and sweeping in relation to a study of only GPS L1 band RFI effects (see, for example, the discussion of the NTIA study in section 3.3 of this RTCA report).

Reply:

It was not the intent of this statement to judge the sufficiency of the record for FCC purposes, and we fully concur that it would be inappropriate for JHU/APL to do so. The limitation in regard to GPS L1 RFI is implied with regard to all observations and conclusions by the limited nature admitted for the study. (Also see 2.1.4 and 2.3.4)

2.7 Replies to Comments Submitted by Time Domain Corporation

The following replies to comments in the 25 April 25 2001 submission by Time Domain.

2.7.1 Comment in Section IV, second paragraph:

… UWB random PPM signals appear in the passband of a GPS as white noise – which is well understood impact, and is also the UWB signal type that TDC plans to implement.

Reply:

This statement goes beyond the conclusion drawn regarding this form of UWB signals. The “white noise-like” refers to approximate effect on the GPS receiver. It does not mean the UWB signal is the same as white noise nor that its impact on every GPS receiver will be same as white noise in all respects. (Also see 2.2.3, 2.4.2, and 2.6.1)