U.S. Department of Transportation
Office of the Secretary of Transportation

400 Seventh St., S.W.
Washington, D.C. 20590

October 24, 2000

Mr. Paul Withington
Vice President
Time Domain Corporation
7057 Old Madison Pike
Huntsville, AL 35806

Dear Mr. Withington:

Thank you for providing the comments of Time Domain Corporation in response to the Department of Transportation notice concerning our test plan to investigate the potential for interference to the global positioning system from the ultra-wideband transmitters. We appreciate your review of our plan.

We have prepared a brief response to your comments and are publishing in the Federal Register a notice of the availability of our response.

I am enclosing for your information a copy of our response to your comments along with a copy of the Federal Register notice.

Sincerely,

Joseph Canny
Deputy Assistant Secretary for Navigation
Systems Policy

Enclosures

DEPARTMENT OF TRANSPORTATION

Office of the Secretary

[OST Docket No. OST-2000-7538]

Test Plan for Determining Potential for Interference from Ultra-wideband Devices (UWB) to Global Positioning System (GPS) Receivers; Response to Comment

Agency: Office of the Secretary, Department of Transportation

Action: Response to Comment

SUMMARY: DOT announced a test program to begin to acquire data on the potential for interference to GPS systems from UWB signals, and sought comment thereon. Only one comment was received, which warrants additional explanation of, but no changes to, the test program.

FOR FURTHER INFORMATION CONTACT: Sally L. Frodge, Radionavigation and Positioning , P-7, (202) 366-4894

SUPPLEMENTARY INFORMATION: The Department of Transportation (DOT) became aware last year of the potential for interference to the Global Positioning System (GPS) and other communications, navigation, and surveillance systems, including actively used aviation systems, from ultra-wideband (UWB) signals. Due to the lack of technical data on interference available at that time, DOT decided to initiate a limited testing program to begin to explore the interference potential of UWB to GPS. Working with the National Telecommunications and Information Administration, the Federal Aviation Administration, the Interdepartment Radio Advisory Committee, RTCA, Inc., and others, a test plan was devised to develop data in a technically sound and controlled manner. The Department contracted with Stanford University to perform the tests. In addition, because of the potential for wide public and industry interest in this matter, the Department distributed the test plan broadly and formally solicited comment on the plan through a notice in the Federal Register. 65 Fed. Reg. 38874 (June 22, 2000). Only one party submitted comments in response to this notice -- Time Domain Corporation (TDC).

TDC criticized the test plan and concluded that it would not produce valid data about the potential for interference from UWB signals. DOT appreciates the TDC comments. Although DOT disagrees with TDC's assessment of the efficacy of the test plan, it is clear that additional clarification of certain points in the plan

description and an explanation of the rationale for the plan's basic approach are warranted. DOT remains confident that the test plan is methodologically sound and will develop data that will help support a determination about whether and to what extent UWB emissions will interfere with GPS applications.

DOT's complete response will be sent to TDC, and to other interested parties upon request. DOT will provide all data and analyses available from the test program to the FCC by October 30, 2000, the filing date for test results in FCC ET Docket No. 98-153. The test program will be incomplete at that time and further results will continue to be developed into the first quarter of 2001.

Dated: October 19, 2000

Joseph Canny,

Deputy Assistant Secretary for Navigation Systems Policy

Reply of the Department of Transportation to Comments submitted by Time Domain Corporation On a Plan For Testing Potential Interference Between Ultra-wideband Systems and Global Positioning System (GPS) Signals.

The Department of Transportation (DOT or Department) became aware last year of the potential for interference to the Global Positioning System (GPS) and other systems, including actively used aviation systems, from ultra-wideband (UWB) signals. Due to the lack of technical data on interference available at that time, DOT initiated a limited testing program to begin to explore the interference potential of UWB to GPS. Working with Stanford University, the National Telecommunications and Information Administration (NTIA), the Federal Aviation Administration (FAA), RTCA, Inc. and others, a test plan was devised to develop data in a technically sound and controlled manner. The Department contracted with Stanford University to perform the tests. The Department actively sought and received comments on the test plan through a variety of means from organizations, including NTIA and the Interdepartment Radio Advisory Committee (IRAC), Federal Communications Commission (FCC) staff, RTCA, Inc., the Department of Defense and others. RTCA, Inc. noted in a recent report that the "...Stanford Test Plan was favorably received by the RTCA study group after a few minor clarifications."[1] In addition, because of the potential for wide public and industry interest in this matter, the Department distributed the test plan broadly and formally solicited comment on the plan through a Federal Register Notice[2] on June 22, 2000.

Only one set of comments -- from Time Domain Corp. -- was received in response to the notice. The Department appreciates the comments received from Time Domain Corporation (Time Domain) regarding the test plan. The comments provide an opportunity to clarify certain points in the plan description and to explain the rationale for the plan's basic approach. In its summary comments, Time Domain asserted that the plan "...is fundamentally flawed and will not provided meaningful assessment of interference."[3] The Department disagrees with that assessment and notes that the plan was reviewed during its development by numerous other entities, both within the government and outside. None of those entities had unresolved objections and no other party submitted comments or criticisms in response to the Department's request for comments. Thus the Department remains confident that the test plan is methodologically sound and will develop data and results which will support determination of whether there are, or are not, interference effects from UWB emissions to GPS applications.

Some of the Time Domain comments appear to reflect a misunderstanding of the test plan. Others result from a lack of clarity at certain points in the plan and we attempt herein to clarify those points. The test plan was developed in anticipation of possible action by the FCC to authorize certain UWB applications. The FCC Notice of Proposed Rulemaking was published June 11, 2000. The Department will provide all data and analyses available from the test program to the FCC by the Commission's filing date for test results of October 30, 2000. The test program will be incomplete at that time and further results will continue to be developed into the first quarter of 2001.

RESPONSES TO SPECIFIC TIME DOMAIN CORP. COMMENTS: The Time Domain submission included a summary of the comments and the Department's response is keyed to the summary points.

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[1] RTCA SC-159 First Interim Report to Department of Transportation, *Ultra-Wideband Technology Radio Frequency Interference Effects to GPS and Interference Scenario Development,* 12 September 2000.

[2] U.S. DOT/Office of the Secretary, "Notice of Test Plan for Determining Potential for Interference from Ultra-Wideband Devices (UWB) to Global Positioning System (GPS) Receivers - Review and Comment", 65 FR 38874, 22 June 2000.

[3] Comments of Time Domain, 24 July 2000.

Comment: The plan does not provide for any correlation to real world environments (e.g. ambient noise levels) nor does it compare intentional and unintentional UWB interference.

Reply: The test plan is designed to establish a quantitative equivalence relationship between UWB and white noise. By "white noise" we refer to broadband noise that is white across the GPS band. The plan seeks to develop this quantitative relationship because the analysis methods for noise impacts on GPS signals are reasonably well understood and commonly employed when the interference is white noise. Time Domain Corp. has indicated elsewhere that UWB signals are similar to noise. It is not correct to suggest that white noise cannot cause interfereance to GPS. Moreover, UWB also has other characteristics that may cause very different radio frequency interference (RFI) effects. Thus, establishing the equivalence between UWB and white noise, and identifying and quantifying the UWB parameters that impact this equivalence, are fundamental and essential analysis inputs. With this basic data, subsequent analysis of a variety of operational scenarios utilizing a wide breadth of UWB parameters can be performed. Examples include:

- analysis of scenarios with any number of visible satellites, elevation angles to those satellites, receiver powers, etc;
- scenarios placing the UWB transmitter at varying distances from the GPS receiver; and
- scenarios including the presence of other interference sources.

The Department's test plan approach allows a multitude of operational scenarios to be used to relate the test data to particular applications in the classic "source-path-receiver" analysis method. Once these three basic system components have been quantified, the final radio frequency link analyses can be performed. This provides maximum flexibility for the same data to support tests of a variety of operational scenarios including consideration of intentional and unintentional interference to the extent applicable. The test results will support the analysis of a wide variety of interference scenarios by RTCA, NTIA, the FCC, Time Domain Corp. and other interested parties.

Though of a very preliminary nature, earlier "over-the-air" tests of UWB interference to GPS, conducted by Interval Corporation and Stanford University, showed the need for controlled testing. The controlled environment of the current conducted tests also removes the anomalies and unknowns associated with "over-the-air" tests. Controlled testing is vital for the exacting analysis of any identified RFI impacts, particularly when assessing impacts on safety-of-life systems or other systems with stringent technical requirements.

Comment: The plan tries to equate all UWB signals with "white noise".

Reply: As previously discussed, the fundamental goal of the current tests is to quantify the difference between UWB and white noise. The tests quantify how this difference varies with UWB signal parameters. They will also establish how this relationship depends on a wide variety of UWB signal parameters including pulse repetition frequency (PRF), dithering, and pulse gating. It is critical to identify and quantify those UWB parameters that may cause or contribute to RFI impacts in order to establish a solid analytical base for FCC regulation of UWB.

Comment: The plan does not propose to test a signal such as that produced by Time Domain's and other's equipment.

Reply: With one possible exception, the Department believes that its proposed UWB signal test parameters span those used by Time Domain Corp. The possible exception is the modulation index of the pseudo-random pulse position modulation. The impact of the smaller Time Domain Corp. modulation index is understood and will be addressed in the test report. Time Domain Corp. is correct

in noting that the test plan does not test any individual firm's equipment. There are far too many variations in UWB equipment design and applications (as noted in the FCC's NPRM) to permit testing of them all. Rather, the Department's plan establishes a methodology and base data that can be applied to specific equipment and applications.

Comment: The plan proposes to subject the white noise signal to filtering prior to injecting it into the GPS receiver, but does not propose to route the UWB signal through the same sort of filter.

Reply: Although the plan text was unclear on this point, the test plan, as briefed at the August 4, 2000 briefing to RTCA,[4] at which TDC was represented, does send all signals through the same GPS filter.

Comment: The plan offers no justification for its one-second-reacquisition criterion for land based receivers

Reply: Based on input from the GPS Industry Council concerning receiver characteristics and GPS applications, the requirement as stated in the test plan introduction is "...may be as stringent as 1 second". This criterion is based on public safety applications involving, for example, emergency vehicles that require quick reacquisition of a GPS signal after the signal was blocked. We also understand that rapid reacquisition is key to other land applications such as location of E-911 emergency calls. In any event, the test plan is not critically dependent on the exact value of reacquisition time, because UWB interference is evaluated relative to the effect of white noise. If the reacquisition time is longer for white noise, that longer time will be used as the baseline for the UWB evaluation. The test plan is designed to provide useful data and be flexible in appropriate application of that data.

Comment: The plan fails to state that the testing will be conducted using a GPS simulator operating with a realistic constellation of satellites, giving rise to the presumption that the evaluation will examine the effect of UWB on only one satellite signal that will have been adjusted to a received power of less than 4 dB above the thermal noise – hardly a realistic scenario.

Reply: Again, the testing is directed at establishing a quantitative relationship between UWB and white noise impacts on GPS reception. The data will support analysis of scenarios with any number of visible satellites, elevation angles to those satellites, receiver powers, etc. Specifically, the test data can be used to analyze UWB impact on GPS signals with power more than 4 dB above the noise background.

Comment: The plan exhibits a clear bias by arguing that any margin has already been consumed by the –70 dBW/MHz out-of-band emissions limit applicable to mobile satellite transceivers by crippling the GPS link with high levels of noise and then testing for the impact of UWB.

Reply: The discussion about MSS is contained in the "Introduction to the Test Plan" and only serves to explain part of the motivation for current concern over UWB within the aviation community. No assumption of MSS background interference is contained in the tests themselves. However, as noted in the "Introduction to the Test Plan" testing of UWB interference impacts in the presence of other RFI sources, such as MSS emission levels in the GPS band currently authorized by the FCC must be accomplished. The total electro-magnetic interference (EMI) environment must be included in the evaluation to support regulatory decisions that will protect existing authorized services. We note that another important consideration is aggregate emitter effects since there may be multiple UWB emitters in a given area, all providing energy into the total EMI of that specific area.

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[4] Attachment 1 is a briefing on interim results of the testing at Stanford, presented at the August 4, 2000 RTCA WG 6 meeting.

The discussion about Mobile Satellite Services ("MSS") contained in the "Introduction to the Test Plan" was included to provide some understanding to how one critical transportation community -- the aviation community -- looks to this analysis method. The Department anticipates that this concern will be echoed in other communities to varying degrees. There may be no margin left for additional EMI if we are to preserve safety-of-life systems in the 1559-1610 MHz band because prior FCC actions allows MSS emissions levels in that band such that the entire interference margin is consumed. The Department must use worst-case conditions as its analysis basis in order to assure there is no interference with aviation safety-of-life systems.

Summary

The Department considers that UWB is a promising and singular technology worthy of further exploration. Like any other technology, however, it must not interfere with vital safety-of-life communication, navigation, and surveillance systems that have become critical in the transportation sector. The Department's test plan will provide technical data that will support regulatory decisions necessary to preserve existing systems dependent upon GPS.

UWB Interference Test Preliminary Results

Ming Luo, Dennis Akos, Sam Pullen, Per Enge, *Stanford University*

Sally Frodge, *Department of Transportation*

research funded by the Department of Transportation (DoT)

August 4, 2000

The data contained herein is preliminary and has not been subject to independent validation. Moreover, the views expressed are those of the authors and do not necessarily express the views of any other organization or individual.

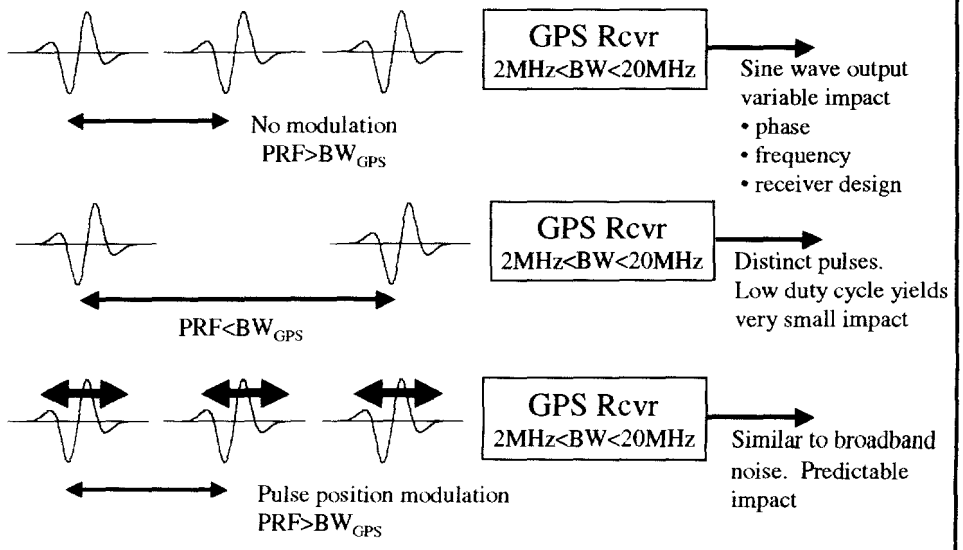
Contents

- Test philosophy & setup
- Measurement duration
- Receiver test and normalization
- UWB test data
  - different PRF (100Kpps-20Mpps)
  - different burst duty cycle (10%-100%)
  - different burst on-time (10us-10ms)
  - no modulation and random PPM
- Summary

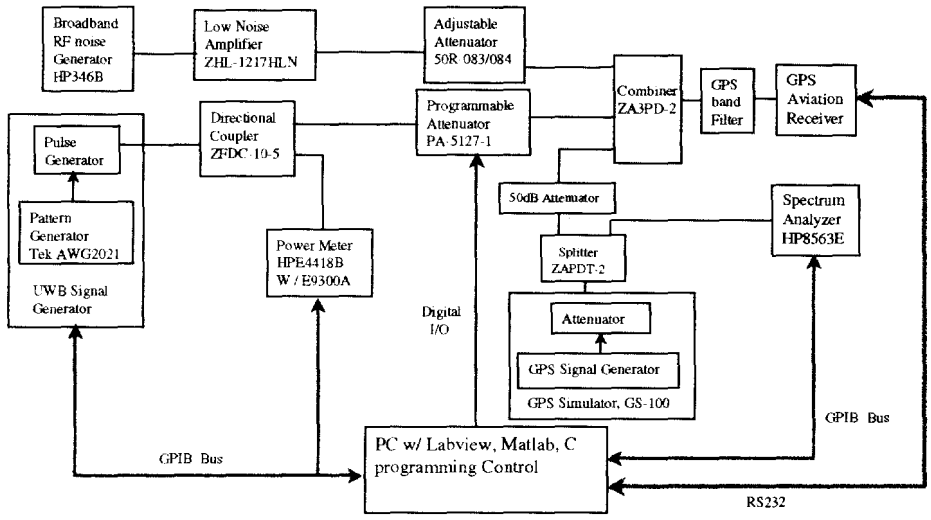
Overview of Test Philosophy

- **Quantify UWB to random noise equivalence to support the analysis of any operational scenario with or without other interference sources.**
- **Quantify sensitivity to UWB signal parameters. Attempt to span the space of anticipated parameters.**
- **One channel simulator for controlled & repeatable tests**
- **Interference criteria:**
  - **accuracy for aviation (LAAS reqm't of 15 cm.)**
  - **reacquisition time for land (E-911 reqm't of 1 s)**
- **Aviation rcvrs of DO229/253 interference quality.**
- **Normalize receivers under test to DO229/253 interference masks.**

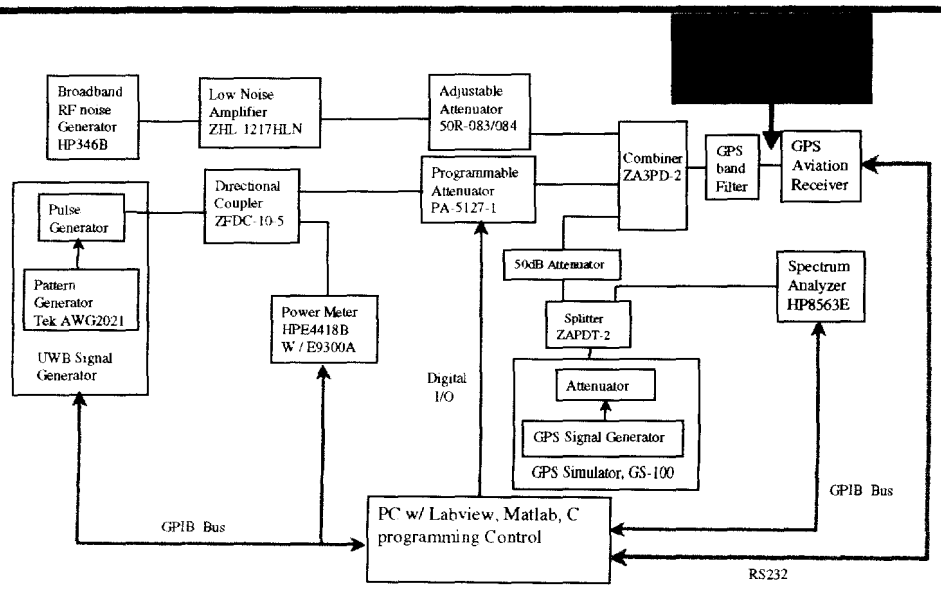
Sensitivity to UWB Signal Parameters



UWB Test Setup

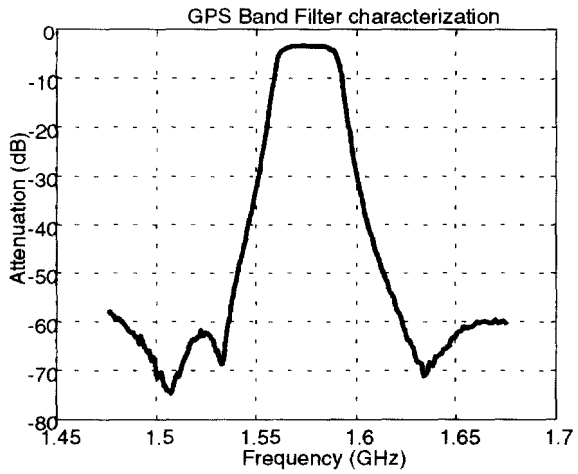


Power Measurement



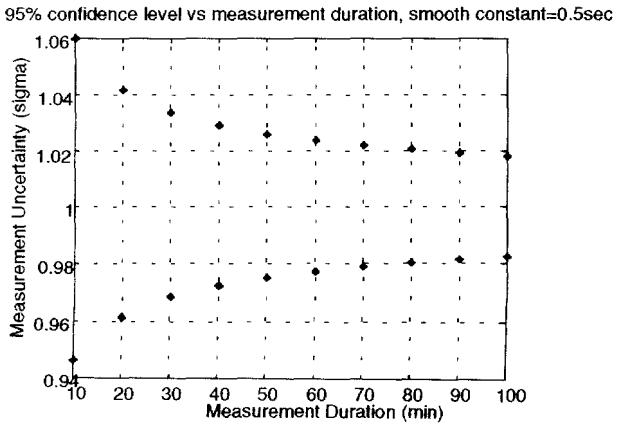
GPS Band Filter

Both broadband noise power and the UWB power were measured through the GPS L1 band filter. The filter characteristic was shown as below.

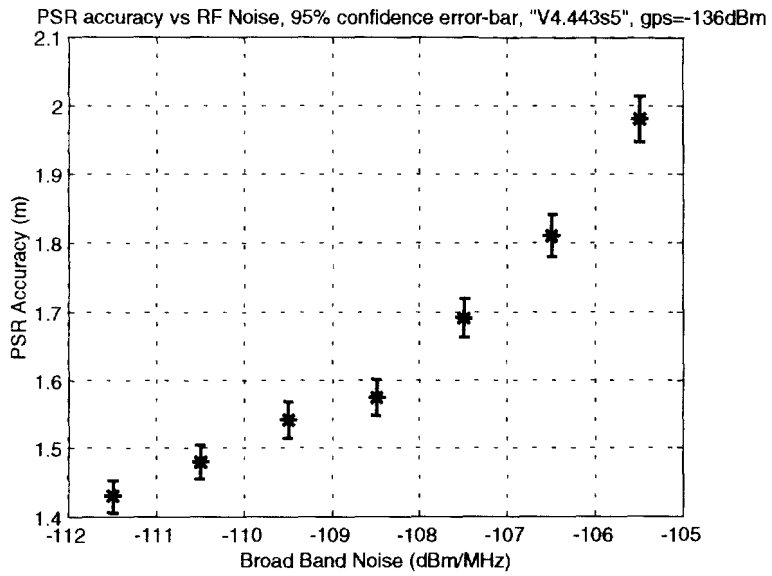


Test Duration Consideration

There is a tradeoff between measurement certainty and test duration. We decided to take 1 hour of data (~ 3600 independent samples when smooth time constant is 0.5 second) for each accuracy measurement setup. The uncertainty is about +/- 2.4% for 95% confidence level.



Is 1dB of RF Separation Distinguishable?



Choose Operational Point

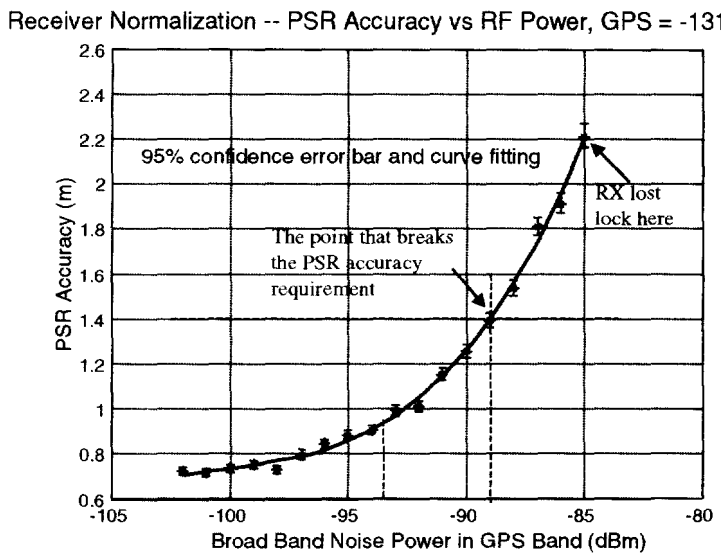
- Consider:
  - Linear region
  - Test duration
  - 1 dB of RF distinguishable
  - Accuracy requirement

=> Set GPS power = -131dBm

=> Set broadband RF region: -93.5 to -89dBm (in GPS L1 band)

=> Use unsmoothed (raw) pseudorange accuracy measurements (see next slide)

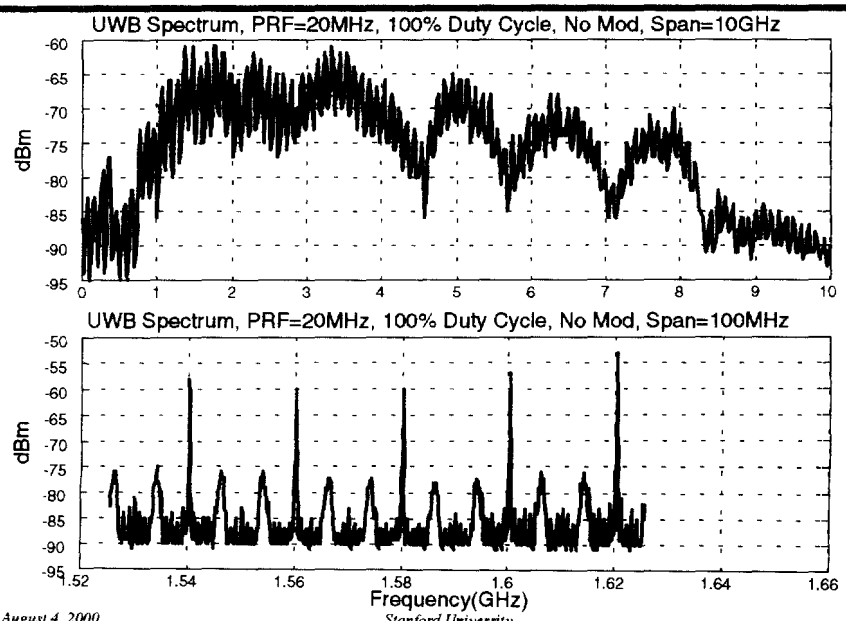
GPS Receiver Normalization



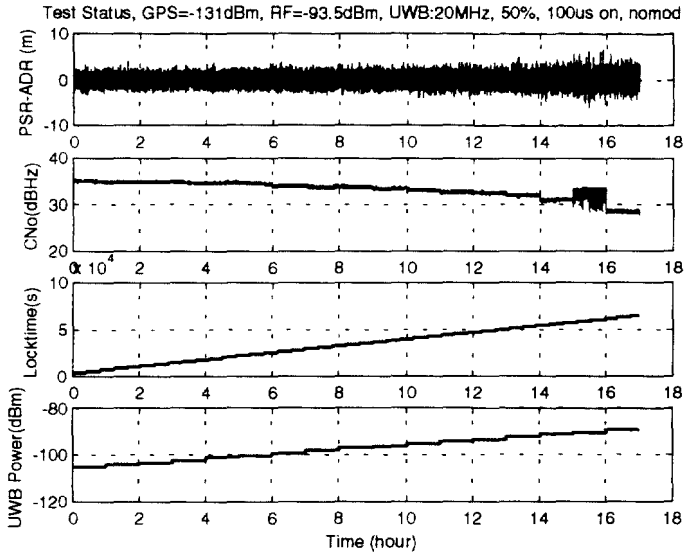
Note:

Based on variance measurements from raw PSR and from 100-sec carrier smoothed PSR, we found that 1.4 m of raw PSR accuracy is equivalent to 15 cm of carrier-smoothed PSR accuracy.

UWB Spectrum, PRF=20MHz, No Mod

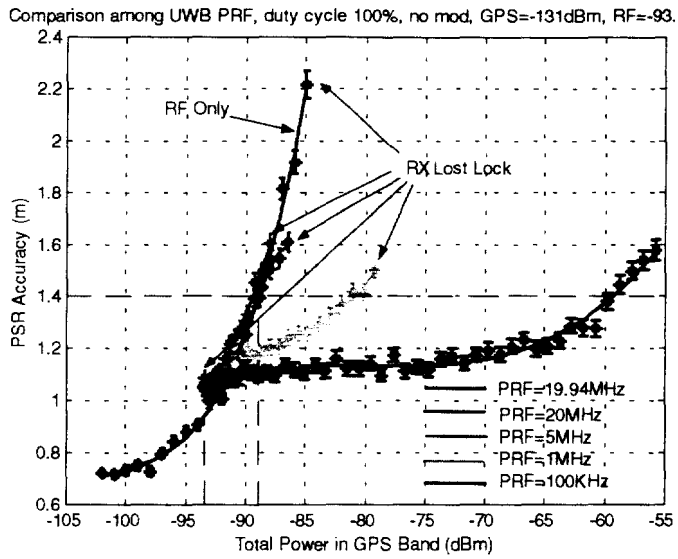


Test Status During UWB Power Sweeping (a typical run)



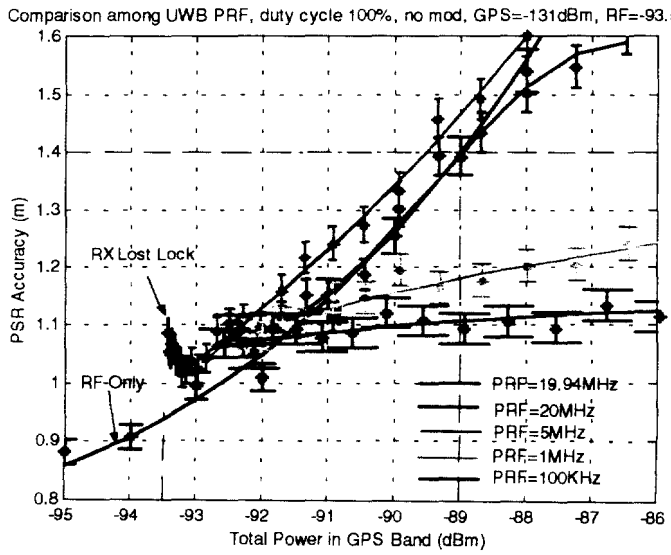
Comparison of PRF

Comparison among PRFs, 100%duty cycle, no modulation



Notes:
Only 1 GPS Receiver
Only 1 UWB transmitter
No aggregation

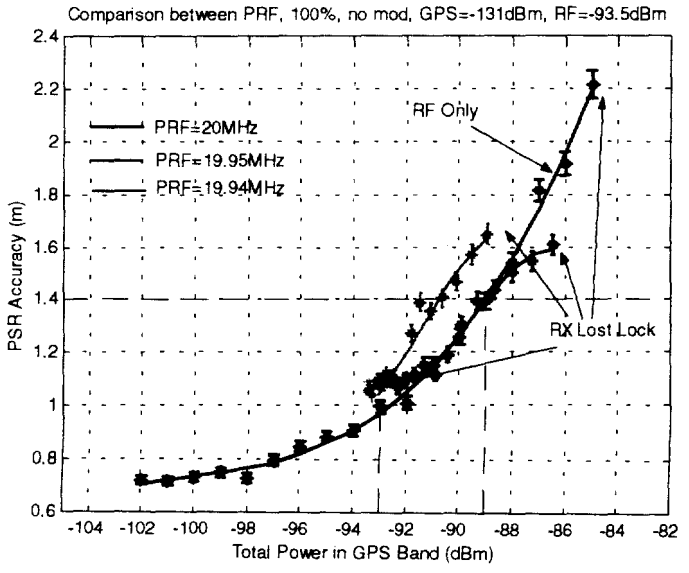
Comparison among PRFs, 100%duty cycle, no modulation (zoomed)



Notes:
Only 1 GPS Receiver
Only 1 UWB transmitter
No aggregation

Spectral Line Sensitivity

Comparison among PRF=20MHz, 19.95MHz, 19.94MHz, 100%, no mod



Notes:
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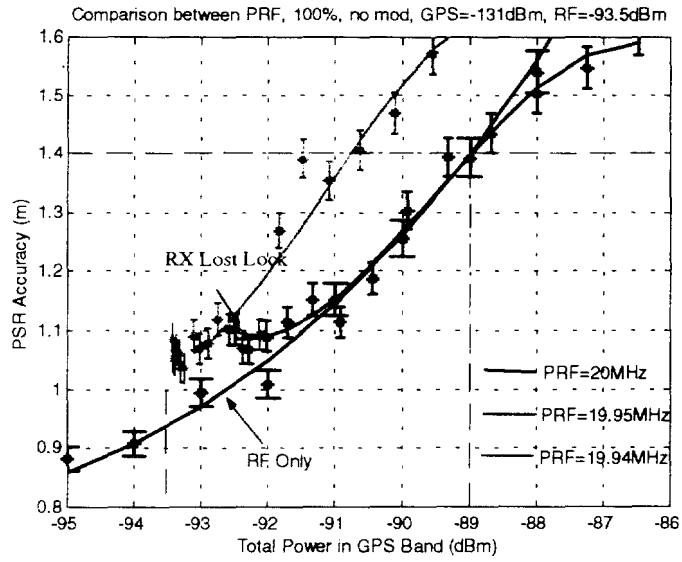
No aggregation

Comparison among PRF=20MHz, 19.95MHz, 19.94MHz, 100%, no mod (zoomed)



Notes:
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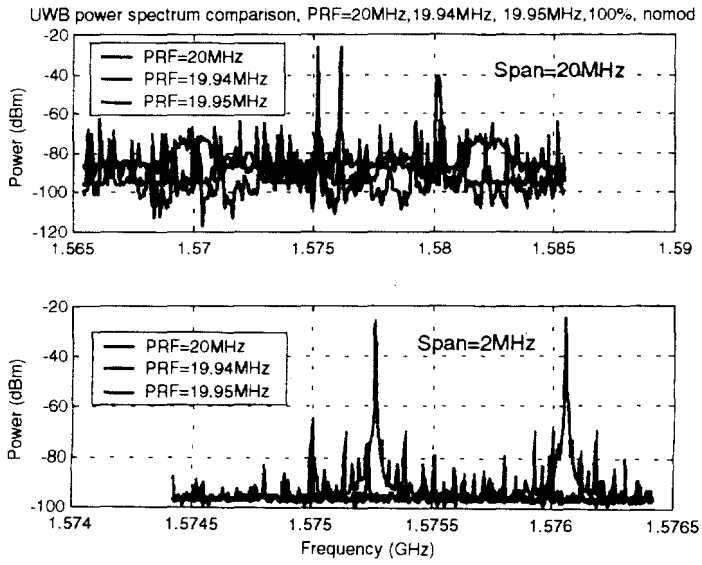
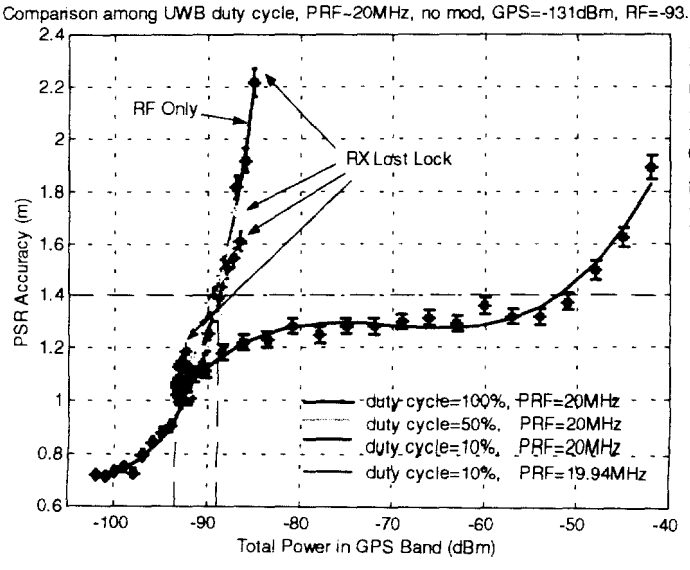
No aggregation

UWB spectrum comparison between PRF=20MHz ,19.94MHz, 19.95MHz



Comparison of Duty Cycle

Comparison among UWB burst duty cycle, PRF~20MHz, no modulation



Notes:
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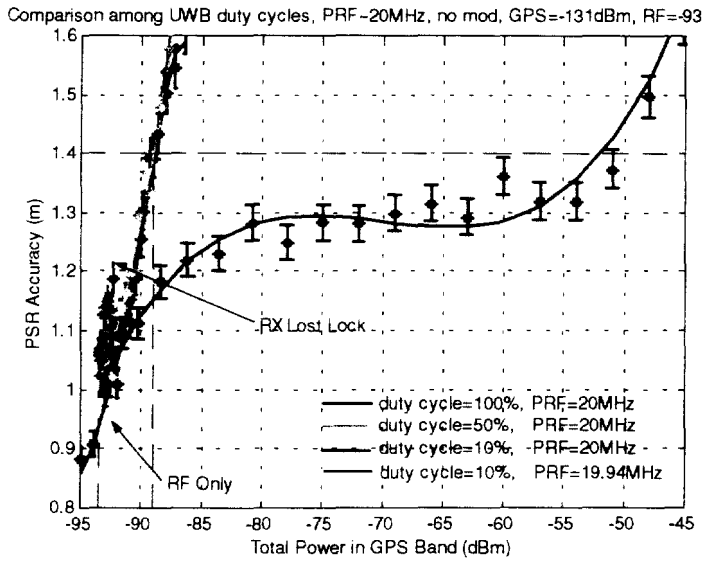
No aggregation

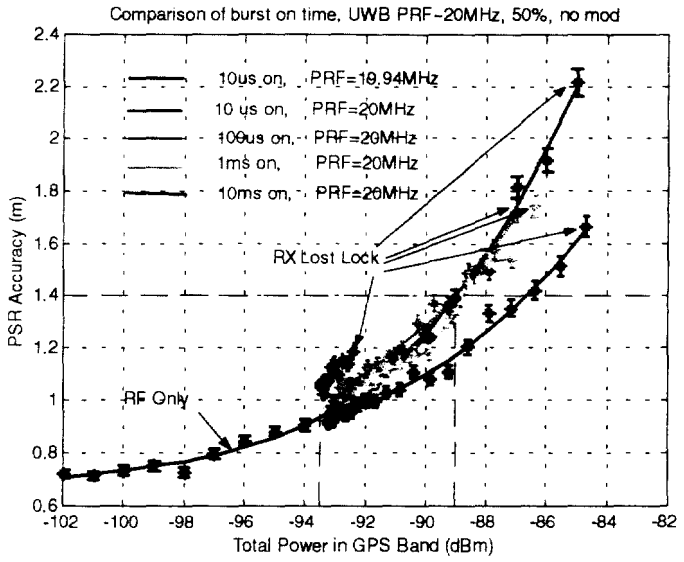
Comparison among UWB burst duty cycle, PRF~20MHz, no modulation (zoomed)



Notes:
Only 1 GPS Receiver
Only 1 UWB transmitter
No aggregation

Burst on-Time Comparison

Comparison among Burst On-Time, PRF=20MHz, 50%, no mod



Notes:
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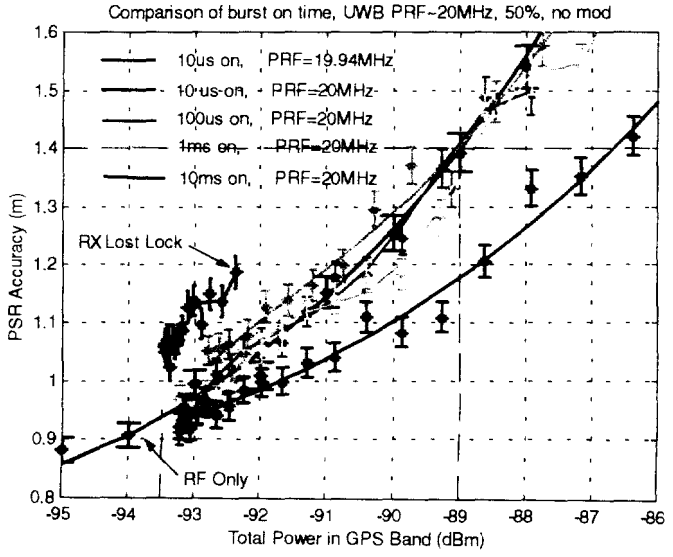
Only 1 UWB transmitter
No aggregation

Comparison among Burst On-Time, PRF=20MHz, 50%, no mod (zoomed)



Notes:
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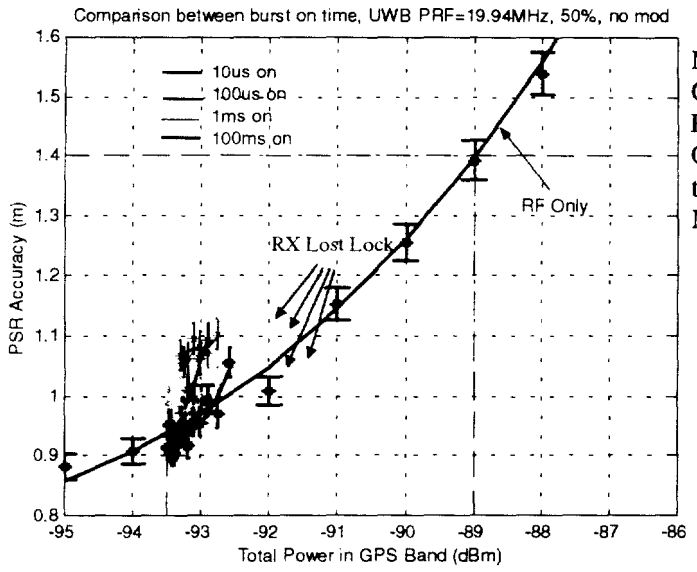
Only 1 UWB transmitter
No aggregation

Comparison among Burst On-Time, PRF=19.94MHz, 50%, no mod



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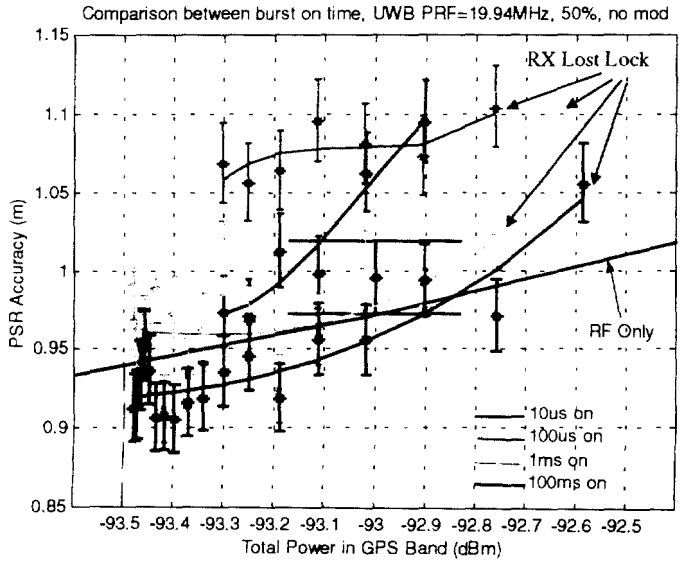
Comparison among burst on-time, PRF=19.94MHz, 50%, no mod (zoomed)



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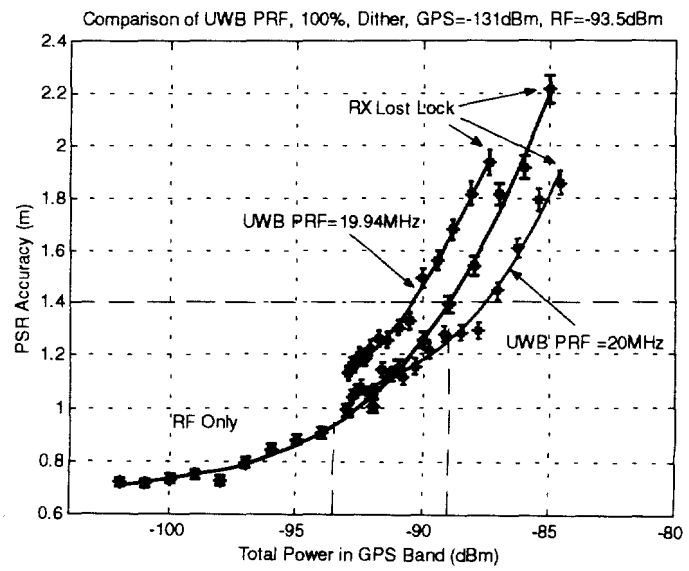
Random PPM Cases

Comparison of UWB PRF, 100%, Dither



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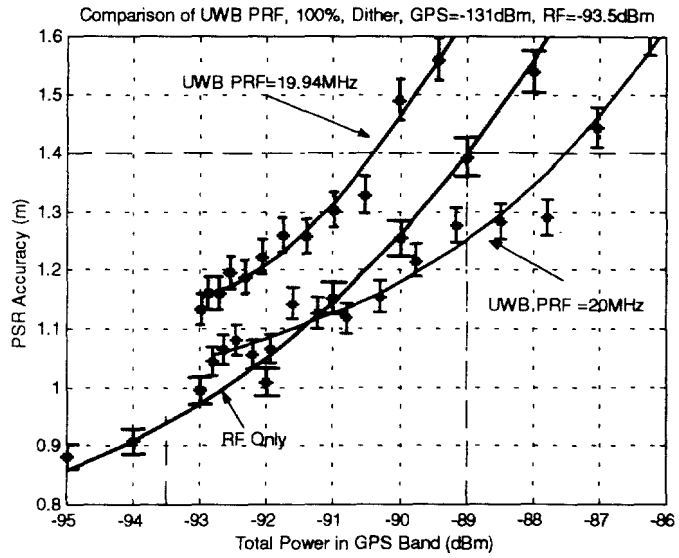
Comparison of UWB PRF, 100%, Dither (Zoomed)



Notes:
Only 1 GPS Receiver
Only 1 UWB transmitter
No aggregation

Summary

- **For this first receiver, we have demonstrated the expected dependence on UWB parameters:**
  - **location of spectral lines relative to GPS**
    - **important for all PRFs, duty cycles, on-times & modulation**
  - **PRF (lower is better)**
  - **duty cycle (lower is better)**
  - **burst on-time (longer is better)**
  - **modulation (modulation is worst)**
- **Near term plans:**
  - **finish aviation test matrix (40-50% done)**
  - **begin land receiver test**
  - **understand connection between results and potential rules**