ARL

The University of Texas at Austin

LABORATORY REPORT

26 February 2001
TL-SG-01-01

FINAL REPORT
DATA COLLECTION CAMPAIGN FOR MEASURING UWB/GPS COMPATIBILITY EFFECTS

Laboratory Report under Contract UTA 00-319, “UWB/GPS Interference Test Program”

Miguel Cardoza, Douglas Cummings, and Aaron Kerkhoff

Prepared for
The Ultra Wideband Testing Consortium
Time Domain Corporation
Huntsville, Alabama

Approved for Public Release **Distribution is Unlimited**

This page intentionally left blank.

TABLE OF CONTENTS

INTRODUCTION 1

1.0 TESTING OVERVIEW 3

1.1 Test Objective 3
1.2 Testing Phases 4
1.3 Test Locations/Facilities 4
1.3.1. Conducted Test 4
1.3.2. Radiated Testing 4
1.4 Types of Tests Performed 5
1.4.1. Conducted Test 5
1.4.2. Outdoor Radiated Test 5
1.5 UWB Transmitters Tested 7
1.6 GPS Receiver Selection 8
1.6.1. GPS Receiver Selection Criteria 8
1.6.2. GPS Receiver Performance Criteria 8
1.6.3. Types of GPS Receiver Performance Measurements Made 9
1.7 Raw Data Collected For Each Test Condition 9
1.7.1. UWB Transmitter Parameters 9
1.7.2. GPS Receiver Parameters 10
1.8 Test Plan Risks 10
1.8.1. Risk One, Active Antennas 10
1.8.2. Risk Two, Lack of Broadband Noise 10
1.8.3. Risk Three, Radiated Testing 11
1.8.4. Risk Four, Data Collection Interval, Amount of Data 11

2.0 TEST APPROACH RATIONALE 13

2.1 Overview 13
2.2 Interference Impact, Loss of GPS Signal 14
2.3 Ranging Accuracy 19
2.4 Reacquisition Performance 21

3.0 TEST METHODOLOGY 22

3.1 General Overview 22
3.2 Equipment Description and Calibration Information 22
3.2.1. GPS Test Receivers 23
3.2.2. UWB Sources 24
3.2.3. GPS Simulators 26
3.2.4. Calibration of Devices 27
3.3 Conducted Testing 28
3.3.1. Spectrum Analyzer Settings 32
3.3.2. Power Meter Measurements 33
3.3.3. Conducted Test Setup Issues 33
3.4 Radiated Testing 33
3.4.1. Single UWB Transmitter and Part 15 Certified Device Tests 34
3.4.2. Aggregate UWB Transmitter Test 36

4.0 DETAILED TEST PROCEDURES 38

4.1 Conducted Interference Test 38
4.1.1. Overview 38
4.1.2. Real-World Baseline Data 38
4.1.3. Receiver Normalization Procedure 38
4.1.4. Additional Test Preparation 40
4.1.5. Conducted Baseline Data Collection 41
4.1.6. Receiver Response to Broad-Band Noise 41
4.1.7. Ranging Accuracy 42
4.1.8. Acquisition Performance 42
4.2 Single Source Radiated Interference Test 43
4.2.1. Overview 43
4.2.2. Test Preparation 43
4.2.3. Baseline Data Collection 44
4.2.4. Single Interfering Source Test 44
4.3 Aggregate Radiated Interference Test 45
4.3.1. Overview 45
4.3.2. Baseline Data Collection 45
4.3.3. Aggregate Test 45
4.4 Quality Assurance of Data 46

5.0 KEY INFORMATION FOR CONDUCTED TESTS 47

5.1 Path Loss Measurements for Test Setup – Receivers 1, 2, 3, 4 47
5.2 Path Loss Measurements for Test Setup – Receivers 6 & 7 49
5.3 GPS Signal Levels – Ranging Tests on Receivers 1, 2, 3, & 4 50
5.4 GPS Signal Levels – Acquisition Tests on Receivers 1, 2, 3, 4 51
5.5 GPS Signal Levels – Ranging and Acquisition Tests on Receivers 6 & 7 52

6.0 TOTAL DATA COLLECTED, LOCATION, AND STRUCTURE 53

6.1 Directory Structure 53
6.1.1. Conducted Ranging Accuracy Test Data 54
6.1.2. Conducted Acquisition Performance Test Data 57
6.1.3. Radiated Test Data 59
6.1.4 Aggregate Test Data 63

7.0 AUTOMATED DATA COLLECTION SOFTWARE 65

7.1 Overview of LabVIEW 65
7.2 Degree of Automation 65
7.3 Conducted Interference Test 66
7.3.1. Ranging Accuracy 66
7.3.2. Acquisition Performance 67
7.4 Radiating Interference Test 69
7.4.1. Ranging Accuracy 69
7.5 Aggregate Radiated Interference Test 70
7.5.1. Ranging Accuracy 70

8.0 REFERENCE DOCUMENTS 72

LIST OF FIGURES

Figure 3-1 Conducted Test Laboratory Setup for Receivers 1, 2, 3, and 4. 30
Figure 3-2 Conducted Test Laboratory Setup for Receivers 6 and 7 31
Figure 3-3 Side View of Radiated Setup.. 35
Figure 3-4 Field Layout UWB, GPR, Digital Devices Radiated Interference Test.... 36
Figure 3-5 Field Positioning Layout UWB/GPS Aggregate Radiated Interference Test 37
Figure B-1 PAD Non-Burst Mode E.I.R.P. Spectrum at 3 m.....................................B-3
Figure B-2 PAD Non-Burst Mode E-Field Strength Spectrum at 3 m.......................B-3
Figure B-3 PAD Transmitter Block Diagram...B-4
Figure B-4 UWB Signal Generator Non-Burst Mode E.I.R.P. Spectrum..................B-7
Figure B-5 UWB Signal Generator Non-Burst Mode E-Field Strength Spectrum....B-7
Figure B-6 Signal Generator Transmitter Block Diagram...B-8
Figure B-7 Output Spectrum of GPR Device 1, Sensors and Software Noggin 1000...B-9
Figure B-8 Output Spectrum of GPR Device 2, Sensors and Software Noggin 250...B-9
Figure C-1 GPS Simulator Calibration Output Example 1..C-1
Figure C-2 GPS Simulator Calibration Output Example 2..C-1
Figure C-3 GPS Simulator Calibration Output Example 3..C-2
Figure C-4 GPS Simulator Calibration Output Example 4..C-2
Figure F-1 Radiated / Aggregate Test Site F-1
Figure F-2 Time Domain Corporation PAD UWB Device F-2
Figure F-3 Single PAD UWB Device Radiated Test at 4 meters F-3
Figure F-4 Single PAD UWB Device Radiated Test at 2 meters F-4
Figure F-5 Aggregation Test at 8 meters F-5
Figure F-6 Aggregation Test at 3 meters F-6
Figure F-7 Aggregation Test at 1 meter F-7

LIST OF TABLES

Table 1-1 Types of Tests Conducted. 6
Table 1-2 Number of Separate Setup Configurations for Each Type of Test........ 7
Table 1-3 Ultra Wideband Devices Tested. 7
Table 1-4 GPS Receivers Used in Test Effort........ 8
Table 3-1 Data Parameters Collected from each GPS Receiver 23
Table 3-2 Time Domain PAD Operational Modes........ 25
Table 3-3 Spectrum Analyzer Settings........ 32
Table 3-4 UWB Source Heights for Each Test Range........ 35
Table 5-1 Fixed UWB Path Losses for Receivers 1,2, 3, & 4 47
Table 5-2 Fixed GPS Path Losses for Receivers 1, 2, 3, & 4 47
Table 5-3 Fixed UWB to Spectrum Analyzer Path Losses for Receivers 1-4 47
Table 5-4 Variable UWB Path Losses with Programmable Attenuators, Receivers 1-4........ 48
Table 5-5 Fixed UWB Path Losses for Receivers 6 & 7 49
Table 5-6 Fixed GPS Path Losses for Receivers 6 & 7 49
Table 5-7 Variable UWB path losses with Programmable Attenuators, Receivers 6 & 7........ 50
Table 5-8 “Live Sky” GPS Signal Strengths for Ranging Accuracy Tests with Receivers 1-4 51
Table 5-9 “Min” GPS Signal Strengths for Ranging Accuracy Tests with Receivers 1-4 51
Table 5-10 .... Acquisition "Min" GPS Signal Strengths for Receivers 1-4 51
Table 5-11 ...."Live Sky" GPS Signal Strengths for Receivers 6 & 7 52
Table 5-12 ...."Min" GPS Signal Strengths for Receivers 6 & 7 52
Table A-1 Characterization Data Files for Test Setup 1........A-2
Table A-2 Characterization Data Files for Test Setup 2........A-3
Table B-1 PAD Emission Modes........B-2
Table B-2 Noise Generator Emission Modes B-5
Table D-1 FCC Compliance Test Report Data Files........D-1
Table E-1 Test Procedure Data Files........E-1

LIST OF EQUATIONS

(2-1) 13
(2-2) 15
(2-3) 15
(2-4) 17
(2-5) 18
(2-6) 18
(2-7) 18
(2-8) 19
(2-9) 19
(2-10) 19
(2-11) 19
(2-12) 20
(2-13) 20

LIST OF APPENDICES

APPENDIX	TITLE	Page
A	Characterization of Conducted Test Setup	A-1
B	Characteristics of the UWB Signal Sources	B-1
C	GPS Simulator and GPS Receiver Specifications	C-1
D	Test Equipment Calibration Criteria and Data	D-1
E	Test Procedure Documentation and Log Data	E-1
F	Photos	F-1
G	List of Parties Providing Comments on Test Plan	G-1
H	ARL:UT Test Team Members	H-1

Introduction

The Applied Research Laboratories is the single largest research unit at the University of Texas at Austin. Formed in 1945 as the Military Physics Research Laboratory, ARL:UT is a University Affiliated Research Center (UARC) working almost exclusively for the Department of Defense (DOD). ARL:UT has been involved with satellite-based navigation and positioning systems since the inception of TRANSIT in 1964 (a system which ARL:UT now maintains for ionospheric research). With the advent of the Global Positioning System (GPS), ARL:UT increased its level of expertise. These early GPS efforts included the specification and acquisition of the first commercially available geodetic quality survey receiver (the TI 4100) and the development and fielding of the global Monitor Station Network for the Defense Mapping Agency (DMA), used in the development of precise ephemeris for the GPS system. Since that time, ARL:UT has designed, developed, and fielded many GPS-based systems, including tactical systems, for our Department of Defense customers. ARL:UT has a vested interest in the integrity and viability of the GPS system.

Recently, ARL:UT began investigating Ultra Wideband (UWB) technologies for use as an adjunct to GPS to meet geo-positioning requirements that could not be met by GPS alone. In order to fully support its traditional base of DOD sponsors, ARL:UT created the Center for Ultra-Wideband Research and Engineering (CURE) to study and integrate UWB solutions for these sponsors and to further the knowledge regarding Ultra Wideband systems and solutions.

Because of ARL:UT's expertise in both technologies, ARL:UT was asked by Time Domain Corporation to conduct testing of the susceptibility of GPS receivers to UWB emissions. As a UARC, however, ARL:UT must adhere to the UARC Management Plan, which places restrictions on the relationships that can be established between private companies and UARC laboratories. As such, ARL:UT and Time Domain came to the following understanding regarding this effort:

- The testing should be impartial. ARL:UT would "own" the test plan and be completely responsible for the conduct of the data collection effort.
- Third parties would be allowed to review and critique the test plan and when feasible observe testing.
- ARL:UT would not analyze the data or draw inferences from the data. It would only capture the data, reducing it to the degree necessary to ensure quality.
- ARL:UT would make the data and any associated documentation available to the public so that it could be analyzed by the entire GPS/UWB community.

- ARL:UT would make every effort to accomplish this within a time frame that allowed the data to be used during the Federal Communication Commission's Notice of Proposed Rule Making (NPRM) on Ultra Wideband, which was released May 10, 2000.
- Provide opportunities for other Ultra Wideband equipment manufacturers to participate in the testing.

This document describes the methods, procedures, and data collected by ARL:UT in support of this GPS/UWB compatibility data collection campaign.

1.0 Testing Overview

1.1 Test Objective

The objective of the testing prescribed in this test report was to measure the behavior of GPS receivers in response to UWB emissions in highly controlled environments. From the raw data collected, it is possible to determine, for separately defined operational scenarios, representative minimum operating distances between specific UWB transmitters and GPS receivers such that the GPS receiver would experience no harmful interference. Additionally, from the data collected, it is possible to derive potential effects on GPS receivers from an aggregation of UWB transmitters in a given locale.

Although some proposed analysis methods are outlined in this test plan, it was not the objective of this project to extensively analyze the collected data. The analysis discussed in this report only represents a rationale for why specific data was collected. Neither was it the purpose of this project to attempt to predict the impacts of UWB emissions on GPS receivers in any operational scenario. The primary intent of this project was to acquire data that would allow anyone with the appropriate technical background, and a thorough quantitative understanding of operational scenarios of interest, to estimate the impact of the measured UWB emissions on GPS receivers.

The UWB and GPS devices used in this data collection campaign are representative of available technology and were operated according to the manufacturers' specifications.

The key limitations in this test effort were:

- Only a limited number of UWB technologies were tested. While the UWB emissions tested represent the dominate waveforms of interest to the FCC, they do not represent every potential UWB device or technology in existence today.

- Only a limited number of GPS receivers were tested. The chosen receivers were intended to be a representative cross-section of modern, good-quality, commercially available GPS receiver technologies. The chosen receivers do not represent the lower quality GPS receivers available in the market today, nor do they represent military receivers due to the classified nature of the data from such receivers. The use of classified data would have prohibited the publication of the data for public record.

Nevertheless, despite these limitations, ARL:UT strongly believes that this measurement program will allow for the quantification of the compatibility of UWB and

GPS receiver technologies with sufficient precision to serve as a basis for FCC decision-making.

1.2 Testing Phases

This test program consisted of nine phases:

1. Prepare the test plan;
2. Acquire and calibrate test equipment and develop automated measurement software;
3. Certify the UWB sources in both conducted and radiated modes at an approved FCC measurement facility;
4. Determine GPS receiver characteristics;
5. Make conducted UWB interference measurements;
6. Make single UWB device radiated interference measurements;
7. Make part 15 certified, intentional and unintentional radiator interference measurements[1];
8. Make aggregate UWB interference measurements
9. Post test results on password protected Web server
10. Prepare final test report.

ARL:UT wanted this entire process to be a transparent test program. For this reason, every effort was made to make the test plan, the testing itself, and the subsequent data collected readily accessible to the general public. For example, ARL:UT organized a number of tele-conferences with interested parties and participated in recent RTCA meetings in order to receive feed-back on the test plan. Also, all data and documentation collected during the test effort have been posted on a web site that is freely available to the public.

1.3 Test Locations/Facilities

1.3.1. Conducted Test

The first phase of the conducted interference testing was performed at a DOD approved test facility, the 746th Test Squadron at Holloman AFB, New Mexico. This facility provided all GPS simulator instrumentation and the trained personnel required to operate the simulator. This support was acquired through a purchase/contract between ARL:UT and the USAF. The second phase of the conducted testing was performed at ARL:UT facilities using a GPS simulator on loan from Holloman AFB.

1.3.2. Radiated Testing

[1] Part 15 devices refer to readily available commercial electronic devices that either intentionally or unintentionally radiate a permissible amount of RF energy according to CFR Title 47 Part 15.

Radiated interference testing was performed in a vacant field adjacent to ARL:UT. ARL:UT is located at the Pickle Research Campus in northwest Austin, Texas. The research campus has numerous surveyed field sites where extensive GPS data collection projects have been performed. A continuously operating GPS monitor ground station, operated for the National Imagery and Mapping Agency (NIMA), was used as the GPS performance baseline during the radiated interference testing.

1.4 Types of Tests Performed

This GPS susceptibility testing program consisted of two major classes of tests, laboratory conducted tests and outdoor radiated tests. Each of these types of tests are described in the following sections.

1.4.1. Conducted Test

In the laboratory conducted tests, GPS simulator signals were mixed with UWB signals in a controlled laboratory environment in which both signals were “conducted” to the GPS receiver through a calibrated cable connection. Conducted tests provide the most conservative estimate of the impact of UWB emissions on GPS since there were no other sources of noise and there was a complete absence of typical GPS signal errors (such as signal multipath and atmospheric errors). Moreover, simulator tests allow for the repetition of scenarios such that for each test case (or UWB operational mode), the GPS receiver under test ‘sees’ the identical GPS constellation. This is important in retaining consistency across the all of the GPS and UWB test cases under consideration.

Two types of tests were completed in the conducted environment, ranging tests and acquisition tests. Ranging tests were performed to assess the impact of UWB emissions on GPS receiver pseudorange, carrier phase, and Doppler frequency measurements, as well as its impact on GPS receiver positioning accuracy. Similarly, acquisition tests were conducted to assess the impact of UWB emissions on a GPS receivers ability to acquire satellites. Throughout these tests, the GPS receivers were maintained in a fixed operating condition set by the ARL:UT test team, while the level and type of UWB emissions were varied. In addition, for each type of test, a baseline test where no UWB signals were injected, and white noise test where a broadband white noise signal was injected in place of the UWB signal, were conducted to provide a basis for comparison to the UWB test cases. A summary of the conducted tests completed in this effort is included as Table 1-1.

1.4.2. Outdoor Radiated Test

In the outdoor radiated tests, GPS receivers were operated in a manner set by the ARL:UT test team while potentially interfering UWB signals were radiated at discrete distances. The field location site was selected in order to minimize potential site-dependent test anomalies that may cause uncontrolled or unpredicted local field interference (such as GPS signal multipath). Although considered to be more realistic by some, such tests have the disadvantage of being less controllable than conducted tests. By including radiated tests, a basis for comparison can be drawn between the laboratory conducted and outdoor radiated tests, thereby ensuring that no large systematic errors or biases exist in either case.

There were four unique types of devices included in the radiated testing. Each device utilized the same testing structure, equipment, and location. These tests were designed to gather data sets for a variety of unique situations encompassing different models, modes, and locations of UWB transmitters. These devices included a single UWB RF transmitter, two different UWB ground penetrating radars (GPR), two electronic devices that fall under the FCC Part 15 rules, and multiple UWB RF transmitters used to conduct aggregate tests. For each of these tests, the GPS receiver was operated to provide only ranging performance data as there was insufficient time to conduct acquisition testing in the radiated environment. A summary of the tests conducted in this effort is included as Table 1-1. Table 1-2 lists the number of setup configurations tested for each test type.

Table 1-1 Types of Tests Conducted.

Type of Test	GPS Mode	Baseline Test	White Noise Test	UWB Device
Conducted	Ranging Test	X	X	Single UWB RF Transmitter
	Acquisition Test	X	X	Single UWB RF Transmitter
Radiated	Ranging	X		Single UWB RF Transmitter
	Ranging	X		Single UWB GPR Device
	Ranging	X		Single part 15 Device
	Ranging	X		Multiple UWB RF Transmitters

Table 1-2 Number of Separate Setup Configurations for Each Type of Test

Type of Test	Setup Configurations
Conducted Ranging Accuracy (UWB)	2520
Conducted Ranging Accuracy (White Noise)	240
Conducted Acquisition Performance(UWB) *	648
Conducted Acquisition Performance(White Noise) *	108
Radiated Ranging Accuracy (UWB)	540
Radiated Ranging Accuracy (Ground Penetrating Radar)	40
Radiated Ranging Accuracy (Part 15 Devices)	40
Aggregate Radiating Ranging Accuracy (UWB)	120
Total	**4256**
* 30 individual trials were run for each setup configuration	

1.5 UWB Transmitters Tested

Table 1-3 lists the in-band signal sources that were used as the transmitting devices during the testing specified by this report. Note that although two Time Domain PulsON Applications Developer (PAD) devices were available for testing, only one device was actually used for any of the single UWB RF transmitter test cases. In addition, the Time Domain PAD devices were tested in up to eighteen different operational modes consisting of both continuous and bursted modes, depending upon the test being run. For the aggregate testing, the Time Domain signal generators were operated in two different operational modes consisting of a continuous and a bursted operational mode. This limitation was imposed by design so that sixteen of the devices could be fabricated in time to support this effort. The Part 15 certified devices and GPR devices were operated in their normal operating modes. The part 15 devices tested were a Motorola Radius SP10 Walkie-Talkie, and a Gateway Model GP7-450, Mini-Tower, Personal Computer (PC). The GPR devices tested were the Sensors and Software Noggin 250 and Noggin 1000 models.

Table 1-3 Ultra Wideband Devices Tested.

Device	Quantity
Time Domain PulsON Applications Developer (PAD) (single UWB RF transmitter test)	2

Part 15 Certified Devices	2
Time Domain Signal Generators (aggregate UWB tests)	16
Sensors & Software Ground Penetrating Radars	2
Total devices tested	22

1.6 GPS Receiver Selection

1.6.1. GPS Receiver Selection Criteria

The GPS receivers chosen for this test effort were recommended by interested parties and by ARL:UT. Additionally, a variety of receivers were selected to provide some ability to analyze the impact on different manufacturer's implementations of GPS receiver technology, especially aviation grade receivers. Table 1-4 lists the make, model, and type of the receivers used in the test effort as well as reference name used by the testing team throughout testing. The tests described in this test report were intended to acquire data sets that could be used in extrapolating the potential impacts of specific UWB technologies on representative GPS receivers .

Table 1-4 GPS Receivers Used in Test Effort

Receiver Ref. Name	Make and Model of Receiver	Receiver Type
RCVR 1	Novatel, 3151	Survey Receiver
RCVR 2	Ashtech, Z12	Survey Receiver
RCVR 3	Garmin International, GPS 150 XL	Aviation Receiver
RCVR 4	Ashtech, Z-Sensor	Survey Receiver
RCVR 5	Allen Osbourne, TR SNR-8000 (Not tested)	Survey Receiver
RCVR 6	Novatel, Millennium	Aviation Receiver
RCVR 7	Trimble, 4700	Survey Receiver

1.6.2. GPS Receiver Performance Criteria

The determination of the effects of UWB signals on a given GPS receiver can be based upon the impact of UWB emissions on a receiver's:

1. GPS measurement or ranging accuracy,
2. GPS satellite acquisition, and
3. GPS tracking performance.

The majority of the GPS receivers selected for testing were able to provide the raw measurement data necessary to gather these performance measurements. It should be noted that the Garmin 150XL, an aviation grade receiver used in this effort, was not designed to produce raw measurement data, and thus other more indirect means of assessing impact on this receiver will have to be chosen by the analyst.

1.6.3. Types of GPS Receiver Performance Measurements Made

A variety of GPS receiver performance measurements were available, dependent upon receiver type. All such data available from the receiver was extracted and archived to support post-test analysis. These measurements included (where possible):

1. Errors in pseudorange measurements,
2. Errors in carrier phase measurements
3. GPS signal reacquisition performance,
4. GPS receiver cycle-slip and loss-of-lock performance, and
5. GPS receiver signal-to-noise ratios.

1.7 Raw Data Collected For Each Test Condition

The following raw data was collected or identified, where possible, for each UWB device and GPS receiver tested, according to the procedures defined by this test report. Table 3-1 describes the information that was actually collected from each receiver. For each conducted test case, the GPS simulator generated a log file that tracked its raw measurement output. This log file was saved for each test.

1.7.1. UWB Transmitter Parameters

A. Spectrum analyzer measurements
   1. UWB spectral content in 2 MHz and 20 MHz bands around both L1 and L2 GPS Frequencies.
   2. UWB average power in 2 MHz and 20 MHz bands around both L1 and L2 GPS frequencies.
   3. UWB instantaneous power 2 MHz and 20 MHz bands around both L1 and L2 GPS frequencies.

B. UWB device modes
   1. Pulse repetition frequency (PRF),
   2. Code mode
   3. Burst mode
   4. Power level

1.7.2. GPS Receiver Parameters

A. Unsmoothed L1 pseudorange and carrier phase
B. Unsmoothed L2 pseudorange (or L1-L2 codeless) and carrier phase
C. L1 carrier-to-noise ratio
D. L2 carrier-to-noise ratio
E. Estimated receiver position and position variance
F. L1 and L2 cycle-slip flags
G. Pseudorange and carrier phase variance
H. Receiver noise figures
I. Receiver front-end bandwidths

1.8 Test Plan Risks

1.8.1. Risk One, Active Antennas

One major outstanding technical issue had to do with by-passing the active antennas used with some GPS receivers during conducted testing. It had been suggested that the GPS receivers that require active antennas be tested in such a way as to incorporate the receiver's active antenna. This would have required the re-radiation of the signal from the simulator in a shielded area such as an anechoic chamber, with the GPS receiver antenna inside the shielded area. The test facilities at Holloman AFB did not support the ability to conduct such a test. The test plan attempted to mitigate the risk of fully - conducted testing by only selecting receivers that could be tested on a simulator such as the GSS STR4760.

1.8.2. Risk Two, Lack of Broadband Noise

Opinions were expressed that the conducted testing should incorporate a broad band white noise source similar to the Department of Transportation (DOT) / Stanford test plan [1]. In that plan, a broad band white noise source is injected into the test setup, where it is combined with the UWB signal and both are presented to the GPS receiver. The reasoning given for this approach is that broad band noise is always present and should be accounted for in the test setup.

Although ARL:UT agrees that broad band noise is always present in the environment, the use of a white noise source in the conducted test was based on several apparent assumptions that ARL:UT does not agree with. First, an apparent assumption had been made that all communities-of-interest agree that testing GPS receivers in such a manner was appropriate. Second, an apparent assumption had been made that UWB signals are similar to broad band noise. Third, an apparent assumption had been made that broad band noise and UWB signals have an additive effect that is linear across the bandwidth of interest. Fourth, an apparent assumption had been made about the amount of broad band noise power currently existing in the GPS frequency bands.

As many of these assumptions could not be quantified, ARL:UT chose not to implement the broad band white noise source in the manner described in the DOT / Stanford test plan. However, ARL:UT did conduct a procedure similar to the normalization procedure described in the DOT / Stanford test plan. For one set of tests, broad band white noise source replaced the UWB transmitter and measurements were taken that provided data on each GPS receiver's response to a broad band noise source. This data can be utilized to make comparisons against the effects of individual UWB modes of operation and the effects of broad band noise at similar power levels.

1.8.3. Risk Three, Radiated Testing

Opinions were expressed that radiated testing of GPS receivers in real-world environments would produce no valuable data and may be "confusing" to personnel not familiar with the operational constraints of the GPS system. It had been suggested that aggregate system errors such as those from multipath and ionospheric effects would mask the impacts of UWB signals on GPS receivers in such an environment.

ARL:UT fully understands that GPS-based error sources (such as signal multipath and atmospheric effects) could potentially mask any UWB interference present. To address this concern, ARL:UT took precautions to mitigate the occurrence of GPS signal multipath and made efforts to quantify the RF environment prior to, during, and immediately following each radiated test case. The intent of the radiated testing was for it to serve as a validation of the conducted testing.

1.8.4. Risk Four, Data Collection Interval, Amount of Data

1.8.4.1. Measurement Accuracy

Opinions were expressed that the duration of a testing interval needed to approach 60 minutes in order to obtain enough statistically independent samples to properly evaluate the impact of UWB signals on GPS receivers. These opinions were based primarily upon the DOT/Stanford test plan and the concerns of the aviation community members of the RTCA.

According to RTCA/DO-229B [2], 50 independent samples of pseudorange data are needed to make an initial determination of interference impact on measurement accuracy. The time frame needed to collect 50 independent samples is based on the GPS receiver's use of carrier phase smoothing and the integration interval used in that smoothing. The sampling interval is required to be at least twice the integration time for the carrier phase smoothing. An example provided in this document used a carrier phase integration time of 100 seconds. Thus the sampling interval would have to be 200 seconds. With 10 pseudorange measurements collected per sample, 50 independent samples would require a data collection period of 1,000 seconds or just under 17 minutes. ARL:UT used a data collection period of 20 minutes for all ranging accuracy tests.

1.8.4.2. Acquisition Accuracy

According to RTCA/DO-229B, the number of trials necessary to make a determination of impact from interference on the GPS receiver's ability to acquire satellites in a warm start mode may approach 30. The criteria outlined in this section indicated an iterative approach where initially 10 trials are conducted, the data evaluated, and a pass/fail determination made. If the receiver does not pass the test criteria, an additional set of 10 trials is conducted and a new determination of pass/fail is made. If the receiver does not pass this criteria, a final set of 10 trials is conducted.

In order to support analysis from the aviation community, ARL:UT conducted 30 acquisition trials on each receiver for specific attenuation settings. The data sets provide enough data for aviation communities-of-interest to make a determination of the impact of UWB technologies on GPS receiver acquisition performance.

2.0 Test Approach Rationale

2.1 Overview

UWB emissions occupy an unusually large portion of the spectrum. The typical –26 dB bandwidth for a Time Domain FCC radar is approximately 441 MHz to 7.17 GHz. The Time Domain Corporation (TDC) UWB FCC Radar source, which has a similar output spectrum as the TDC devices evaluated in this effort, has a fractional bandwidth on the order of 65%, where fractional bandwidth is defined as:

$$Fr_{BW} = \frac{BW_{3db}}{F_{pk}} \cdot 100\,\% \qquad \textit{(2-1)}$$

With a peak frequency, $\mathbf{F_{pk}}$, of 1.775 GHz and a –3 dB bandwidth ($\mathbf{BW_{3dB}}$), of 1.15 GHz, the fractional bandwidth is 64.79%. Although the UWB spectral power density is very low, UWB energy is spread across both of the GPS L1 and L2 bands (1.575 GHz and 1.227 GHz, respectively). This has raised concern that UWB emissions may possibly interfere with GPS reception.

The potential impact of UWB signals on GPS receivers spans three different broad categories. First, UWB signals have the potential to cause a loss of GPS signal. This means that the UWB signal has the potential to reduce the signal-to-noise ratio of a given satellite signal to such an extent that the GPS receiver can no longer de-correlate that signal and thus loses lock with the satellite.

A second potential impact of UWB signals on a GPS receiver is that they could cause errors in the range measurements provided by the receiver. Also, through potential impacts on the carrier and code tracking loops, the UWB signal could cause errors to propagate through the GPS receivers position location algorithms and cause the GPS receiver to miss-interpret its location.

The third potential impact of UWB signals on GPS receivers is the degradation of GPS receiver acquisition times. UWB signals could increase the acquisition times, both from a “cold start” acquisition in which the receiver is trying to acquire the constellation with no prior knowledge stored, and from a “warm start” acquisition in which the receiver was previously tracking the constellation, but lost the signals from any or all satellites and is attempting to reacquire them.

This test program employed three different methodologies designed to assess the potential impacts of UWB transmissions on GPS receivers. The first test methodology was designed to ascertain, under controlled laboratory conditions, the effects UWB emissions have on typical GPS receivers. Through this approach, UWB emissions were conductively mixed with simulated "live-sky" GPS signals, and presented to representative GPS receivers. The second methodology tested the impact of a single

UWB source radiating near a GPS receiver under live field conditions. The final methodology tested the impact of multiple UWB sources radiating near a GPS receiver under live field conditions.

Specific test criteria were chosen for these testing methodologies in order to quantify the potential impact that UWB emissions have on GPS receivers. These test criteria consisted of GPS receiver ranging accuracy, tracking performance, and acquisition performance. The subsequent sections present a justification of how the data collected in this test effort will be useful in determining receiver interference behavior using these test criteria.

2.2 Interference Impact, Loss of GPS Signal

The first potential impact of UWB emissions on GPS receivers investigated was loss of GPS signal. If an interfering signal has enough power within the GPS bands, that signal has the potential to reduce the carrier to noise ratio of satellites that the receiver is tracking to the point where the receiver can no longer de-correlate some of the satellite signals. Depending on the strength of the interfering signal, the range at which it may potentially interfere with a GPS receiver will vary. Therefore a test was designed to determine, in a controlled laboratory environment, the potential range at which the loss of GPS signal would take place.

It is important to note that conducted testing represented the absolute worst-case scenario for interference, and as such, the measured range of interference may not be representative of that of a “live-sky”, radiated measurement. This is due to the fact that, in the conducted scenario, both the GPS signal and the UWB signal are bypassing potential effects that would normally be introduced by the GPS antenna and preamplifier, and the UWB antenna. Mismatches between the circularly polarized receiving GPS antenna and the transmitted UWB signal might significantly reduce the interference effects introduced by the UWB signal in a radiated scenario. Additionally, the pre-amplifiers used in active GPS antennas might interact with the UWB signal. This interaction could possibly lead to additional attenuation of the UWB signal as it is injected into the GPS receiver front-end or generation of additional interfering signals due to inter-modulation components created within the preamplifier.

In order to make a determination of the potential interference impact of UWB signals on GPS receivers, it is important to utilize an analysis method appropriate to the task. The following analysis method is taken from Kaplan [3], and can be used in determining the potential interference effects on a GPS receiver from external in-band sources such television transmission sites.

In order to determine an equivalent “live-sky” interference range using a conducted test setup, a relationship must be established between the ratio of the in-band signal level to the GPS signal level measured in the setup, J/S, and the expected free space path loss. Given the J/S measured at the receiver and the output power level of the GPS simulator used in the conducted setup, the power level of the in-band signal can be derived. The power density of the in-band signal at the receiver input can be computed using Equation 2-3, which is derived from Equation 2-2. The Carrier to Noise Ratio neglecting any in-band signals, C/N, given by Equation 2-4, is based upon a number of parameters which include antenna gain and the noise figure of the antenna pre-amplifier when included in the receiver design. By bypassing the antenna and pre-amplifier, the conducted test will determine any impact that the in-band signal may have due to other receiver parameters that influence the receiver's perceived C/N. These parameters include the type of carrier loops and discriminators used, the type of code loops and discriminators used, and the carrier and code loop filters used. These parameters each contribute differently to the overall noise floor of the receiver and vary between different receiver implementations.

Once the J/S causing loss of GPS signal is known, the range at which the in-band signal causes GPS receiver impact can be calculated using Equation 2-5. Solving for d, the range to the in-band signal source for receiver impact, in the expression for L_p results in Equation 2-6. It should be noted that if included in the receiver design, the noise figure of the pre-amplifier will have an impact on the range equation.

It is also important to note that both Equations 2-5 and 2-6 assume that the in-band signal source is intentionally utilizing a circularly polarized antenna in order to obtain maximum impact on the GPS receiver. In the case of Ultra-Wideband signals, this is not generally so.

$$\frac{c}{n} = -10 \cdot \log\left[10^{\frac{-\left(\frac{C}{N}\right)}{10}} + \frac{10^{\frac{\left(\frac{j}{s}\right)}{10}}}{Q \cdot R_c}\right] \qquad \textbf{(2-2)}$$

$$\frac{J}{S} = 10 \cdot \log\left[Q \cdot R_c \cdot \left[\frac{1}{10^{\frac{\left(\frac{c}{n}\right)}{10}}} - \frac{1}{10^{\frac{\left(\frac{C}{N}\right)}{10}}}\right]\right] \qquad \textbf{(2-3)}$$

$\frac{J}{S}$ = the ratio of the in-band signal level to the GPS signal level

$\frac{c}{n}$ = Equivalent carrier-to-noise power power density ratio, after injection of in-band signal

$\left(\frac{C}{N}\right)$ = carrier-to-noise power in a 1-Hz bandwidth expressed as a ratio (with no in-band signal present)

$$N = N_o + I_{ocochannel}$$

$I_{ocochannel}$ = the co-channel- (or self-) interference of the GPS C/A-codes which are present at the GPS receiver

$\left(\frac{j}{s}\right)$ = in-band signal-to-GPS signal power expressed as a ratio

R_c = GPS PRN code Chipping rate (chips/sec)

Q = spread spectrum processing gain adjustment factor (dimensionless)

= 1 for a narrowband in-band source

= 1.5 for wideband spread spectrum in-band source

= 2 for wideband Gaussian noise in-band source

In order to represent a more accurate “real-world” representation Equation 2-5 must be modified as shown in Equation 2-7. Rearrangement of Equation 2-7, and substituting terms leads to Equation 2-8; for a conducted test, G_t, G_j, L_f, L_M, G_{AAA}, and L_{Other} equal zero. The modified expression for the range of receiver impact is given by Equation 2-9.

In a conducted test, the J/S ratio at the point where the in-band signal first impacts the receiver can be determined using the measured path loss in the test setup between the in-band signal source and the receiver. J_t and S_r are assumed to be known. Substituting the free-space wavelength (λ_j) corresponding to the appropriate GPS frequency, L1 or L2, into Equation 2-9 leads to a determination of the worst-case range at which an in-band signal source will impact the GPS receiver. By varying the path loss in the test setup, and hence the J / S, the full extent of the impact of in-band signal source on the receiver can be determined.

$$\frac{C}{N} = S_r + G_a + G_{preamp} - 10 \cdot \log\left(kT_o\right) - N_f - L \qquad \textit{(2-4)}$$

$\frac{C}{N}$	= Carrier to Noise ratio with no in-band signal present
S_r	= received GPS signal power (dBw)
G_a	= antenna gain toward SV (dBic)
G_{preamp}	= preamplifier gain (dBw)
$10 \cdot \log\left(kT_o\right)$	= thermal noise density (dBw-Hz) = -204 dBw-Hz
k	= Boltzmann's Constant (watt-sec/K) = $1.38 * 10^{-23}$
T_o	= thermal noise reference temperature (K) = 290 K
N_f	= noise figure of receiver including antenna, preamplifier, and cable losses (dB)
L	= implementation losses plus A/D converter loss (dB)

$$ERP_j = J_r - G_j + L_p + L_f \qquad \textbf{(2-5)}$$

$ERP_j = J_t + G_t$	= Effective radiated power of in-band signal
J_t	= in-band signal source transmit power into its antenna (dBw)
	= 10 log (j_t) (j_t expressed in watts)
G_t	= in-band signal source antenna gain (dBic)
$L_p = 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d}{\lambda_j}\right)$	= free-space propagation loss (dB)
d	= range to in-band signal source (meters)
λ_j	= wavelength of in-band signal (meters)
G_j	= GPS receiver antenna gain toward in-band signal source (dBic)
L_f	= in-band signal power loss due to receiver front-end filtering
$J_r = \frac{J}{S} + S_r$	= incident (received) in-band signal power (dBw)
	= 10 log (j_r) (j_r expressed in watts)
S_r	= received GPS signal power

$$d = \frac{\lambda_j}{(4 \cdot \pi)} \cdot 10^{\left[\frac{1}{20} \cdot \left(J_t + G_t - J_r + G_j - L_f\right)\right]} \qquad \textbf{(2-6)}$$

$$ERP_j = J_r - G_j + 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d}{\lambda_j}\right) + L_f + L_M + G_{AAA} + L_{Other} \qquad \textbf{(2-7)}$$

L_M = Losses due to Antenna Mismatches and mismatches in Antenna Polorizations

G_{AAA} = Gains (or losses) from the effects of the Active Antenna Amplifer in some GPS antennas

L_{Other} = Gains (or losses) from the other effects such as multipath, antenna noise figure, and preamplifier noise figure

$$\frac{4 \cdot \pi \cdot d}{\lambda_j} = 10^{\left[\frac{1}{20} \cdot \left(J_t + G_t - \frac{J}{S} - S_r + G_j - L_f - L_M - G_{AAA} - L_{Other}\right)\right]} \quad \textbf{(2-8)}$$

$$d = \frac{\lambda_j}{(4 \cdot \pi)} \cdot 10^{\left[\frac{1}{20} \cdot \left(J_t - \frac{J}{S} - S_r\right)\right]} \quad \textit{\textbf{(2-9)}}$$

2.3 Ranging Accuracy

The formulation of pseudorange and carrier phase measurements by a GPS receiver is not an exact process. As the name implies, a pseudorange measurement is only an estimate of the range between the receiver antenna and the satellite transmit antenna, due to a number of error sources in the satellite, in the propagation path, and within the receiver itself. The errors associated with this process can be expressed as elements of time (given that the range measurement is the time of flight of the signal converted to a distance by multiplying the time of flight by the speed of light, which is assumed constant in this case). The total time offset or error in any particular range measurement can therefore be described as [2]:

$$\delta_{tD} = \delta_{tSV} + \delta_{tATM} + \delta_{tRCV} + \delta_{tSA} + \delta_{tMP} \quad \textit{\textbf{(2-10)}}$$

where,

δ_{tD} = total error in the pseudorange in units of time,
δ_{tSV} = satellite orbit and clock errors,
δ_{tATM} = delays due atmospheric errors (ionospheric and tropospheric effects),
δ_{tRCV} = timing errors due to receiver hardware (noise, phase center migration, etc.),

δ_{tSA} = intentional induced errors (such as Selective Availability), and
δ_{tMP} = signal multi-path delays.

In developing a testing philosophy for this effort, an additional term is added to this expression to account for the unknown impact of UWB emissions. Thus equation 2-10 is now expressed as:

$$\delta_{tD} = \delta_{tSV} + \delta_{tATM} + \delta_{tRCV} + \delta_{tSA} + \delta_{tMP} + \delta_{tUWB} \qquad \textbf{\textit{(2-11)}}$$

where,

δ_{tUWB} = timing error due to UWB emissions.

Given the testing process chosen (where discrete intervals of UWB emissions would be injected over a 20 minute period), in reviewing equation 2-11, several terms cease to be relevant when considering those error terms which are due to long period bias errors. These terms include first order effects due to satellite orbit and clock errors, delays due to atmospheric errors, and any receiver hardware biases. In addition, at the time of this effort, Selective Availability (SA) was no longer active on the GPS system. Thus the ranging error sources of principal concern for this testing effort are reflected by equation 2-12,

$$\delta_{tD} = \delta_{tMP} + \delta_{tUWB} + \Delta\delta_{tSV} + \Delta\delta_{tATM} + \Delta\delta_{tRCV} \qquad \textbf{\textit{(2-12)}}$$

where,

δ_{tD} = total error in the pseudorange in units of time,
$\Delta\delta_{tSV}$ = higher order satellite clock errors,
$\Delta\delta_{tATM}$ = higher order atmospheric errors (principally ionospheric variations),
$\Delta\delta_{tRCV}$ = higher order timing variances in receiver hardware,
δ_{tMP} = signal multi-path delays, and
δ_{tUWB} = timing error due to UWB emissions.

Of these remaining parameters, the two most significant are signal multi-path (which can have an amplitude greater than one meter in a period less that 20 minutes) and UWB emissions (which are unknown and therefore cannot be eliminated from the equation).

For the conducted test configuration, GPS constellation errors on the simulator were set to zero (which implies that $\delta_{tMP} = \Delta\delta_{tSV} = \Delta\delta_{tATM} = 0$), and an additional error source is added (that of the signal simulator itself). Therefore equation 2-12 reduces to,

$$\delta_{tD} = \Delta\delta_{tSIM} + \Delta\delta_{tRCV} + \delta_{tUWB} \qquad \textbf{(2-13)}$$

where,

δ_{tD} = total error in the pseudorange in units of time,
$\Delta\delta_{tSIM}$ = higher order timing variances in the signal simulator hardware,
$\Delta\delta_{tRCV}$ = higher order timing variances in receiver hardware, and
δ_{tUWB} = timing error due to UWB emissions.

Thus, although there is the potential for higher order hardware timing variances to remain in the observed pseudorange, the likely error source in the conducted test configuration would be the UWB transmitter. Although ARL:UT took care in calibration of all test equipment, it is possible that a hardware timing variance could contribute to any observed pseudorange error. However, the collection of baseline test cases (with common hardware and no active UWB source) will allow for quantification of any observed pseudorange errors in the UWB active case.

In the radiated test configuration, all GPS constellation error sources and hardware timing variances are present. However, due to the relatively short data collection period, only higher order terms are expected to be present in the observed data. Thus, equation 2-12 remains unchanged for the radiated test case. With so many error sources present in the data, the radiated test configuration does not lend itself to a quantitative analysis of the compatibility of UWB and GPS technologies. However, as the radiated test configuration makes use of the identical GPS receiver hardware as was used in the conducted test case, it does provide for a 'reasonableness' check to ensure the quantitative results generated from the conducted test configuration are valid. In addition, given the use of baseline test cases and multiple satellite tracking scenarios, it is possible to utilize the radiated test data to explore, in some depth, the unique response of a particular GPS receiver device in the presence of 'real world' tracking environment and a known UWB transmitter.

2.4 Reacquisition Performance

The final potential impact of UWB signals on GPS receivers is that UWB signals may cause GPS receivers to be unable to acquire GPS satellites or to delay the acquisition of GPS satellites. The effective range of this impact may be larger than the range determined for a loss of GPS signal. This is due to the increased signal-to-noise ratio necessary for the GPS receiver to lock onto a given satellite. As described in section 1.8.4.2, the data collected for the acquisition performance test criteria should allow a pass / fail determination (in a manner similar to that utilized in [2]) of a receiver's ability to reacquire a GPS signal when subjected to varying levels of UWB.

An additional figure of merit can be a comparison of each receiver's acquisition performance in baseline tests to their performance in tests in which an external signal source in inserted into the test setup.

3.0 Test Methodology

3.1 General Overview

As described in the Section 1, two general types of testing were performed, laboratory conducted and outdoor radiated, each preceded by careful equipment calibration and in the case of the outdoor radiated tests, spectral characterization of the RF environment.

The conducted tests were performed in a controlled laboratory environment in which the test parameters were controlled by the testing team. These tests took the conducted output of the UWB test device, mixed it with the output of a GPS simulator, and applied it to the input of the GPS receiver under test. The effects of the antenna and preamplifier for each GPS receiver , in these tests, were bypassed as the UWB signal was applied directly to the input of each receiver at its antenna port. The GPS signals that the receivers tracked were simulated by the GPS simulator which was controlled by the test team.

In contrast, the outdoor radiated tests (including single UWB device, aggregate UWB devices, ground penetrating radars, and part 15 certified devices) were completed with the GPS receivers acquiring and tracking "real-world" signals from the active GPS constellation. Each GPS receiver was utilizing the antenna and the pre-amplifier that were designed for the receiver. The receivers were also subjected to the effects of the local RF environment at ARL:UT in which ambient noise, multipath effects, and constellation variances were all present. Prior to each test case, ambient RF characteristics were measured to determine the background RF environment.

3.2 Equipment Description and Calibration Information

The principal equipment used in the data collection phase were the GPS receivers, the UWB devices, and the GPS simulators used in the conducted tests. This section describes these instruments and discusses the calibration procedures used to ensure proper performance during this effort.

3.2.1. GPS Test Receivers

Six GPS receivers were used for both the conducted and radiated testing described in this report. Note that a seventh receiver (Allen Osborne Turborogue SNR-8000) was acquired for this testing, but was removed from the test program due to the interference it caused with other GPS receivers used in the conducted test setup. Table 1-4 described the make and model of each of these receivers.

Testing was conducted for both the C/A (Course Acquisition, 2 MHz bandwidth) Code and the P (Precision, 20 MHz bandwidth) Code operation (for those receivers capable of tracking the P-code). Testing included course acquisition and precision performance measurements of the test GPS receivers when subjected to potentially interfering UWB signals. Section 8 provides references for manufacturer supplied specifications on the receivers used in this test effort.

Section 1.7.2. listed the GPS parameters that had originally been intended to be collected from each receiver under test. Not all of these parameters were available from each receiver, however. Table 3-1 lists all of the parameters from section 1.7.2 that were actually collected from each receiver. These same parameters were collected from each receiver for every test conducted throughout the entirety of the test effort. Appendix C provides more information about the format of these and other data parameters as they were collected from the GPS receivers.

Table 3-1 Data Parameters Collected from each GPS Receiver

Receiver Name	GPS Parameters Collected
Novatel 3151 (L1 only receiver)	L1 pseudorange
	L1 carrier phase
	L1 pseudorange standard deviation
	L1 carrier-to-noise ratios
	L1 Tracking State (cycle slip information)
Novatel Millennium (L1 and L2 receiver)	L1 and L2 pseudorange
	L1 and L2 carrier phase
	L1 and L2 pseudorange standard deviation
	L1 and L2 carrier-to-noise ratios
	L1 and L2 tracking state (cycle slip information)
Ashtech Z12 (L1 only receiver)	L1 carrier phase
	L1 code transmit time (to determine

	pseudorange)
	L1 carrier-to-noise ratios
	estimated receiver position
Ashtech ZSensor (L1 and L2 receiver)	L1 and L2 carrier phase
	L1 and L2 carrier-to-noise ratios
	estimated receiver position
	L1 and L2 code transmit time (to determine pseudorange)
Garmin 150XL (L1 only receiver)	L1 and L2 carrier-to-noise ratios
	estimated receiver position
Trimble 4700 (L1 and L2 receiver)	No documentation provided on format of proprietary data output[2]

As can be seen, the two Novatel and two Ashtech receivers provided, at a minimum, the raw pseudorange, carrier phase, and carrier-to-noise ratio measurements. Since the Garmin is strictly an aviation receiver, it did not provide the raw pseudorange or carrier phase measurements.

3.2.2. UWB Sources

The following UWB sources were used in this test program:

(1) Time Domain PulsON Application Developer (PAD),
(2) Time Domain UWB signal generator,
(3) Sensors and Software Ground Penetrating Radar (GPR), and
(4) FCC Part 15 certified devices.

3.2.2.1. Time Domain PulsON Application Developer (PAD)

The Time Domain PAD used in the single UWB transmitter tests is capable of eighteen different operating modes, as described in Table 3-2. These modes include three unique pulse repetition frequencies (PRF) of 1, 5, and 10 MHz, four representative duty cycles, 25%, 50%, 60%, and 100%, and up to three different burst on / off times for a given duty cycle. The PAD was operated throughout this test effort in such a way that only its pseudo-random code was modulating the carrier signal; no information was modulated onto the carrier. For all eighteen operating modes, the pseudo-random code consisted of 1024 bits. The spectral characteristics of the Time Domain PADs are described in Appendix B.

[2] Although the binary format of the Trimble data is proprietary, it is convertible to RINEX format, and as such should give both pseudorange and carrier phase information.

3.2.2.2. Time Domain UWB Signal Generator

The UWB signal generators used in the aggregation tests were designed and developed by Time Domain. The signal generators were capable of two operational modes, both utilizing a 5 MHz pulse repetition frequency (PRF). The first mode represented a "worst-case" transmission scenario, with the UWB device using a 100% duty cycle (continuous mode). The second mode utilized a 50% duty cycle (burst mode), at 4 milliseconds "on" and 4 millisecond "off". These correspond to modes 7 and 9, respectively, in Table 3-2. Both modes utilized a pseudorandom noise code structure of approximately 10^8 bits in length. For these devices, only the pseudo-random code was modulated onto the carrier. The spectral characteristics of the Time Domain signal generators are described in Appendix B.

Table 3-2 Time Domain PAD Operational Modes

UWB Mode #	Nominal PRF	On Time	Off Time	Duty Cycle
	(MHz)	(ms)	(ms)	%
1	1	na	0	100
2	1	1	1	50
3	1	4	4	50
4	1	10	10	50
5	1	2	6	25
6	1	8	4	66
7	5	na	0	100
8	5	1	1	50
9	5	4	4	50
10	5	10	10	50
11	5	2	6	25
12	5	8	4	66
13	10	na	0	100
14	10	1	1	50

15	10	4	4	50
16	10	10	10	50
17	10	2	6	25
18	10	8	4	66

3.2.2.3. Sensors and Software Ground Penetrating Radar

Sensors and Software Inc. provided two Ground Penetrating Radar (GPR) devices for the radiated test. The emissions from the both the Sensor and Software Noggin 1000 and Noggin 250 GPR devices were oriented in such a way that accurately reflects the nominal operating condition of the devices, with their emissions directly coupled into the ground. It is important to note that the amount of radiated energy from such a device that is reflected off the ground is largely due to the physical makeup of the soil next to which it is operated (principally clay in the case of this testing), and therefore does not reach the GPS antenna in a uniform or symmetric manner. Manufacturer supplied information on these devices is included in Appendix B.

3.2.2.4. Part 15 Certified Devices

Two Part 15 Certified electronic devices were used to support this testing effort. These devices included a Motorola Radius SP10 Walkie-Talkie, and a Gateway Model GP7-450, Mini-Tower, Personal Computer (PC). They represent readily available electronic devices that are both intentional and unintentional radiators, and are intended to provide a sampling of ‘typical’ RF emissions from such devices. The Walkie-Talkie was only tested in its “un-keyed” state, that is, in its receive mode.

3.2.3. GPS Simulators

Two simulators were utilized in this testing effort. The first device used to simulate GPS signals was a Joint Program Office (JPO) certified, Global Simulation Systems (GSS) STR4760 12 channel simulator, located at Holloman AFB, New Mexico. The output of the STR4760 was used to simulate a complete and realistic GPS constellation. The STR4760 simulator provides L2 band C/A code signals as well as the L1 band C/A and P code signals. Each satellite contribution, when set to nominal power, is approximately –130 dBm in a 2 MHz bandwidth.

The second device used to simulate the GPS signal was a JPO certified, GSS STR2760, also located at Holloman AFB, New Mexico. The STR2760 is a slightly older model simulator with only 10 GPS channels, however, with regards to its operation and measurement performance, it is identical to the STR 4760. It was used in this effort because the STR4760 which was used at the start of the conducted testing was no longer available when testing of the final two receivers started. Sample plots of the output of the STR4760 simulator, in the L1 band, are provided in Appendix C.

The same simulator settings were used throughout all conducted tests. The settings from each of the simulator configuration files which were accessible via the control Graphical User Interface (GUI) on the simulator workstation are listed in Appendix C. The critical simulator settings were as follows:

1. **All GPS satellites were enabled.** This implies that all of the satellites that would be available in a real, "Live Sky" constellation were modeled during testing.

2. **All simulated errors were turned off**. The settings in the *GPS Constellation File* on the simulator workstation are misleading on this point since they indicate "L1-L2 Delay modeled." In examining the truth data provided by the simulator log files, however, it is noted that "pseudorange error = 0", indicating that the simulated errors were not active during testing.

3. **The GPS to UTC time difference was modeled.** This indicates that a fixed 13 second delay between GPS and UTC time was introduced in the data output by the simulator.

4. **The simulated position used was**

Latitude:	**N 30° 23.045468817'**
Longitude:	**W 97° 43.636879832'**
Height:	**207.601948869 m .**

This corresponds to a surveyed site located at ARL:UT. This was the same site used for radiated testing.

5. **The simulated time and date used were July 26, 2000, 06:00:00 GPS time.**

In accordance with point **3.** above, this time would be 13 seconds ahead of Universal time (UTC).

6. **The week 49 GPS almanac was used.**

3.2.4. Calibration of Devices

The GPS receivers used in this study were calibrated per manufacturer standards and traceable to the conventional standards used by the manufacturer. Upon receipt, each receiver was operated in its nominal operating configuration, with collected position data compared to a known survey coordinate. Measured positions from each receiver were proven to meet the performance specifications provided by the manufacturer.

Note that this process was repeated following testing to ensure that the receivers were operating normally during the data collection campaign.

The UWB transmitters were calibrated to current FCC Part 15 rules at a certified FCC test laboratory and traceable to NIST. Data was collected for each type of UWB device under test in order to determine their conducted and radiated characteristics. These tests were completed at Professional Testing, located in Round Rock, Texas. The data gathered from this calibration effort is referenced in Appendix D.

The two GPS simulators used in this effort were maintained and operated by the 746th Test Squadron at Holloman AFB. This equipment is maintained to operating standards and undergoes routine calibration to ensure proper performance. Calibration of these instruments is traceable to NIST.

Finally, all of the laboratory test equipment used in this effort was calibrated and traceable to NIST. The conducted path loss of both laboratory test setups were measured at both GPS frequencies, L1 and L2, as well as over a wide-bandwidth sweep that encompasses the spectrum of the UWB signals under test. This data is referenced in Appendix A.

3.3 Conducted Testing

The conducted laboratory test was configured to accurately simulate potential UWB effects on GPS receivers by applying the UWB emissions along with a representative GPS signal provided by a GPS simulator to typical GPS receivers. In this way, the potential impact of an UWB signal on the receiver can be evaluated without the variations in receiver performance due to different GPS antenna implementations, multipath effects, ambient noise effects, noise figure sensitivity due to pre-amplifiers, antenna polarization mismatch effects, and inter-modulation effects from front-end amplifiers. Figure 3-1 illustrates the conducted interference test configuration for receivers 1, 2, 3, & 4 while Figure 3-2 illustrates the conducted interference test configuration for receivers 6 & 7. The same GPS simulator, spectrum analyzer, test setup, and computer were used for all tests for receivers 1, 2, 3, & 4. For receivers 6 & 7, a different simulator, the GSS STR2760, and a slightly different test setup were utilized. The same GPS simulator, spectrum analyzer, test setup, and computer were used for all tests involving receivers 6 & 7.

In all of the conducted tests, and within the limitations of each GPS simulator, the simulator produced signals that would be received from a normal 24 satellite GPS constellation at a given location. The configurable simulator settings used throughout testing are included in Appendix C. During a test, programmable attenuators inserted various levels of attenuation in order to provide different UWB interference levels, simulating the attenuation (or gain) of the UWB signal due to:

Transmit and receive antenna gains and efficiencies,
Cable losses,
Free-space attenuation, and
Other losses (e.g., propagation through foliage, rain/fog attenuation, etc.)

A list of the attenuation levels used for each phase of conducted testing is given in Section 5 of this document.

A resistive power divider / combiner provided the means to mix the simulated GPS signal and the potentially interfering UWB signal. The final test configuration had additional variable attenuators, power dividers, cables, etc. that were essential to a real-life test set-up.

The spectrum analyzer indicated in Figure 3-1 was used to measure the characteristics of the UWB signal as seen by the GPS receiver. During each test, the spectrum analyzer was set-up to perform frequency sweeps for each UWB attenuation level. This spectral data was collected in preliminary tests in order to verify the proper operation of the interfering source under test. After this verification, it was no longer necessary to collect the spectral data. This explains why a number of conducted data sets do not include this data. The spectrum analyzer, however, remained in the test setup in order to verify visually that the interfering source functioned properly.

The computer shown in Figure 3-1 was used to control the test equipment and record all of the data from the GPS receivers. By using a computer based data collection process, the test sequences could be run automatically – thereby mitigating the opportunity for human error.

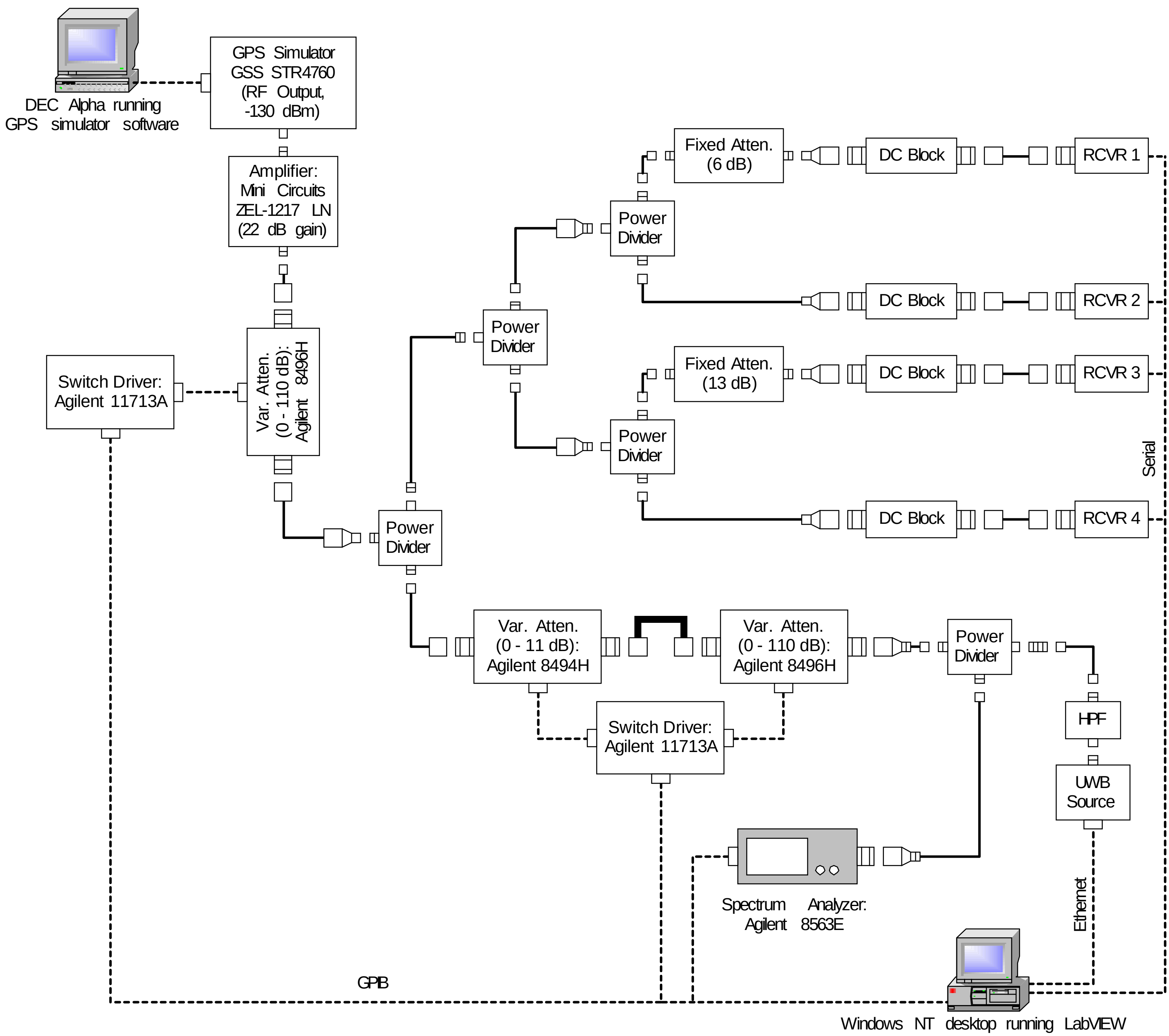


Figure 3-1 Conducted Test Laboratory Setup for Receivers 1, 2, 3, and 4.

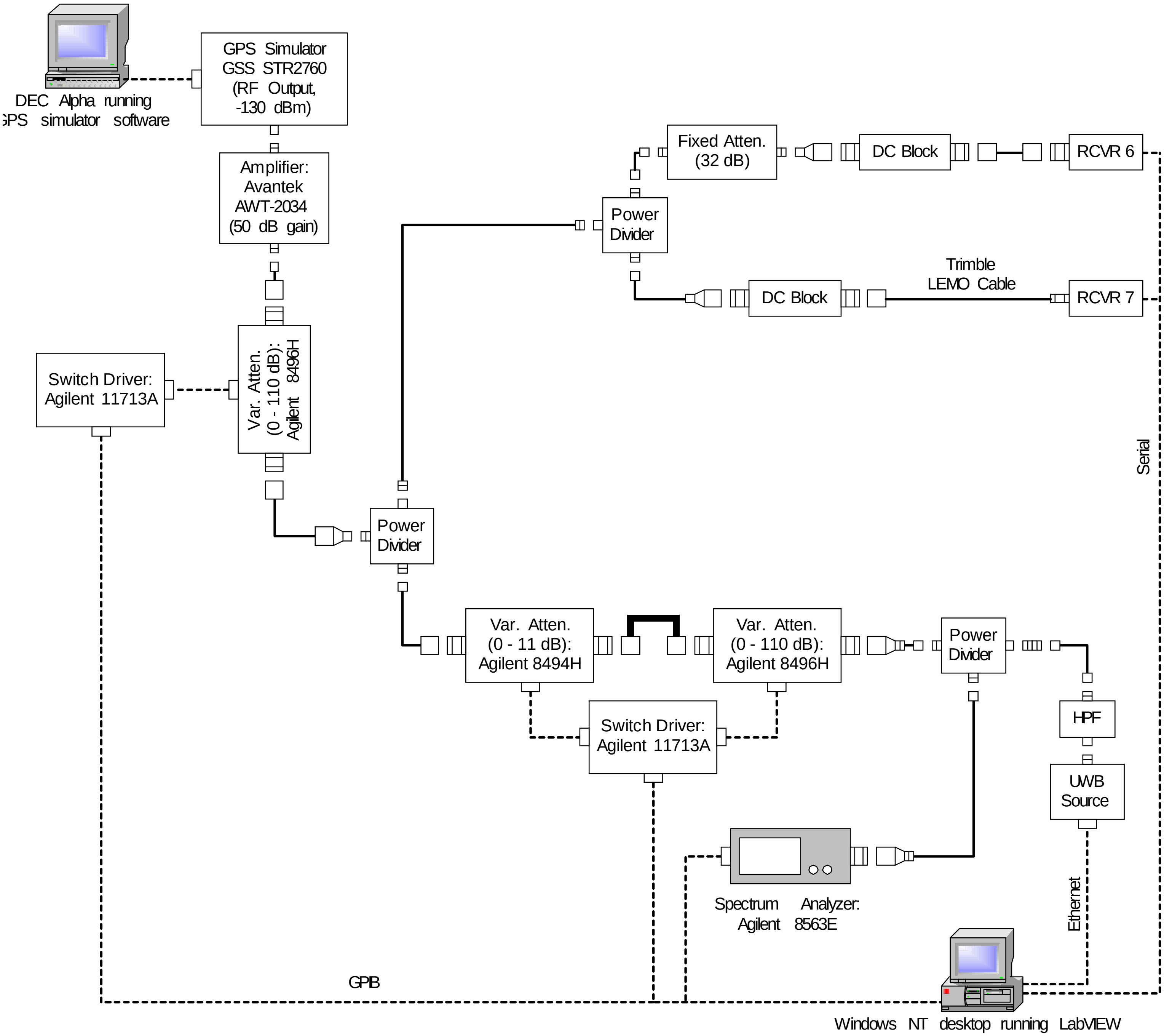


Figure 3-2 Conducted Test Laboratory Setup for Receivers 6 and 7

3.3.1. Spectrum Analyzer Settings

Table 3-3 lists the spectrum analyzer measurements made for each of the Time Domain PAD and Time Domain Signal Generator UWB sources. Each of the UWB operational modes listed in Table 3-2 were tested. These measurements were based upon current knowledge of the practical limitations of the spectrum analyzer used as well as common techniques used in the EMC community. The losses or gains (e.g. due to cables, directional antennas or amplifiers) have not been included in this data; therefore the path loss information provided in Section 5 and Appendix A must be used in conjunction with spectral measurements to determine the actual power level of the UWB signal under test. The listed measurements are best applicable to non-burst (continuous) modes. When used for burst modes, there is potential problem of aliasing between the spectrum analyzer sweep rate and the burst duty cycle. This would prevent the accurate determination of the energy contained in the bursted UWB signal. Spectral measurements recorded during testing, which are now part of the main data set, were done with the trace in normal mode in order to view the complete energy content of the signals. The sixteen sweeps listed in Table 3-3 were performed for the initial ranging accuracy tests. These measurements were repeated for each operating mode on both the PAD and Signal Generator UWB devices after all of the conducted testing had been completed. These measurements were made using the max hold trace mode, as well as other spectrum analyzer settings that would enhance the clarity of the captured waveforms. This data is referenced in Appendix B.

Table 3-3 Spectrum Analyzer Settings

Sweep Number	RBW (kHz)	VBW (kHz)	Start Freq. (MHz)	Stop Freq. (MHz)
1	1000	3000	50	6000
2	1000	3000	1226.6	1228.6
3	1000	3000	1217.6	1237.6
4	1000	3000	1574.42	1576.42
5	1000	3000	1565.42	1585.42
6	1000	1	50	6000
7	1000	1	1226.6	1228.6
8	1000	1	1217.6	1237.6
9	1000	1	1574.42	1576.42
10	1000	1	1565.42	1585.42
11	1	.3	1227.5951	1227.6049
12	1	.3	1575.4151	1575.4249
13	1	.3	1227.5512	1227.6488
14	1	.3	1575.3712	1575.4688
15	1	.3	1227.5023	1227.6977
16	1	.3	1575.3223	1575.5177

3.3.2. Power Meter Measurements

As a separate validation of the UWB devices provided by Time Domain, a power meter and power sensor were used to measure the total average output power of each device. Total average power was measured using a thermistor power sensor, since diode sensors often do not respond accurately to UWB signals. Care was taken in selecting the power sensor head in order to prevent overload. The power meter and sensor used in this test effort were the Agilent 4418B, and the Agilent 8482A, respectively.

Although the power meter / sensor were used to verify the output power levels of each UWB device tested, no formal power meter data was taken. Therefore, no power meter data has been included in this test report.

3.3.3. Conducted Test Setup Issues

In order to accomplish the maximum number of tests possible, the first four receivers were tested simultaneously (which was the most that could be run at one time), followed by the second two receivers. Each receiver collected the simulated GPS satellite signal and the UWB or white noise emissions (combined through a resistive power divider). Due to the different GPS signal strength requirements for each receiver (due to differing architectures), different values of fixed attenuation were utilized in each receiver signal path. It should be noted that a slightly different test setup was used for the later two receivers, resulting in different power level settings for that setup. The actual GPS power levels presented to each receiver in both test setups is given in Section 5 of this report.

In order to accommodate the analysis of receiver impact for different operational scenarios, conducted tests were performed at two separate GPS simulator power levels. The first simulator power level corresponded to the level that a receiver would be subjected to in a typical, “live – sky”, radiated environment. The second power level corresponded to the minimum guaranteed power level for GPS reception.

One additional note must be made regarding the conducted test setup. The Time Domain PAD device used in the conducted testing, is designed to use a diamond dipole antenna (shown in Appendix B). It was not possible to engineer an appropriate and accurate antenna emulator in time to support this test. A high pass filter, provided by Time Domain, was used instead to approximate the spectrum that the diamond dipole would radiate.

3.4 Radiated Testing

The second class of tests conducted were outdoor radiated tests. In these tests, the GPS receivers were tracking the live GPS constellation while simultaneously being subjected to the radiated RF emissions of a single UWB device, the aggregation of UWB devices, a GPR device, or the output of a part 15 certified device. Thus, in these tests the UWB signal was transmitted through the UWB antenna and was combined in free space with the incoming GPS signal. Since the GPS receivers were subjected to "real-world" operating conditions, they were also subjected to the errors typically associated with outdoor GPS tracking (such as signal multipath, atmospheric errors, and ambient RF noise). The GPS receivers involved in this testing were operated in the conventional manner, with pre-amplifiers and antennas installed and operational as directed by the manufacturer. Testing was conducted at a known and surveyed position on the ARL:UT facility. ARL:UT utilized data from the nearby NIMA GPS monitoring station to provide a differential GPS survey reference coordinate for this fixed site. The same types of data were collected for the radiated test as were collected for the conducted test.

Note that this testing utilized a central computer to provide controlled data collection from the GPS receiver, and to control the spectrum analyzer sweeps. This process was automated as much as practical to mitigate human operator error during the data collection process

3.4.1. Single UWB Transmitter and Part 15 Certified Device Tests

The UWB transmitters and Part 15 Devices used in these tests included those listed in section 3.2.2. In the case of the GPR devices, the transmitters were operated normally, with their antennas coupled directly to the ground. All other devices were operated in their normal operational mode, however, the antennas for these devices were positioned in such as way as to maximize the impact on the GPS receiver. For instance, for all ranges tested the Time Domain PAD antenna was maintained at least five degrees above the GPS receiver antenna when viewed on a horizontal plane. The intent of this UWB antenna placement was to maximize the antenna effects in such a manner that the linearly polarized UWB antenna pattern was maximized for impact on the GPS receiver. The ARL:UT test team attempted to also limit the separation angle between the plane of the GPS antenna and the UWB antenna to less than ten degrees in order to minimize potential satellite blockage. This was achieved for most of the ranges in the radiated tests within 2.5°. The final two ranges, 1.0 meter and 0.5 meter, however, exhibited antenna separation angles of 15.66° and 31.63°, respectively; this was unavoidable due to the way that the radiated test setup was configured. The heights at which the UWB source / antenna were placed above the ground in order to achieve these antenna separation angles at each UWB source range is given in Table 3-4. These heights were achieved for test ranges between eight meters and one meters by placing the Time Domain PAD on top a single plastic crate, or two to three stacked plastic crates, each 11.25" in height. The proper height for the 0.5 meter test range was achieved by placing the PAD directly on the concrete monument which was nominally 6.4” above the ground (an average number due to ground unevenness around the monument.) The receiver antenna was placed on a platform so that its phase center was nominally 1.47’ above the ground. A side view of this setup is shown in Figure 3-3.

Table 3-4 UWB Source Heights for Each Test Range

UWB Source Range (m)	UWB Antenna Height (ft)
8.0, 5.0	4.23
4.0, 3.5, 3.0, 2.5	3.29
2.0, 1.5, 1.0	2.35
0.5	1.95

As shown in Figure 3-4, the UWB transmitters and unintentional radiators were initially placed at a distance 8 meters from the GPS receiver under test. First a 20 minute baseline data set was taken where GPS data was collected, but the UWB device was not operating. The UWB source was then activated, and 20 minute GPS data sets were collected for each the following distances: 8, 5, 4, 3.5, 3, 2.5, 2, 1.5, 1, 0.5 meters. After each 20 minute test, spectral data was captured using a Antenna Research Associates CLS / 110A wideband conical antenna, in conjunction with a Miteq AFS3-00100600-20-ULN pre-amp and a Agilent 8595E spectrum analyzer. These measurements included all of the sweeps listed in Table 3-3. This data was intended only to characterize the ambient RF conditions surrounding the test site. This same methodology was employed for the GPR devices and the part 15 devices. In the case of the aggregate tests, an additional factor was introduced: the number and placement of the active UWB signal generators.

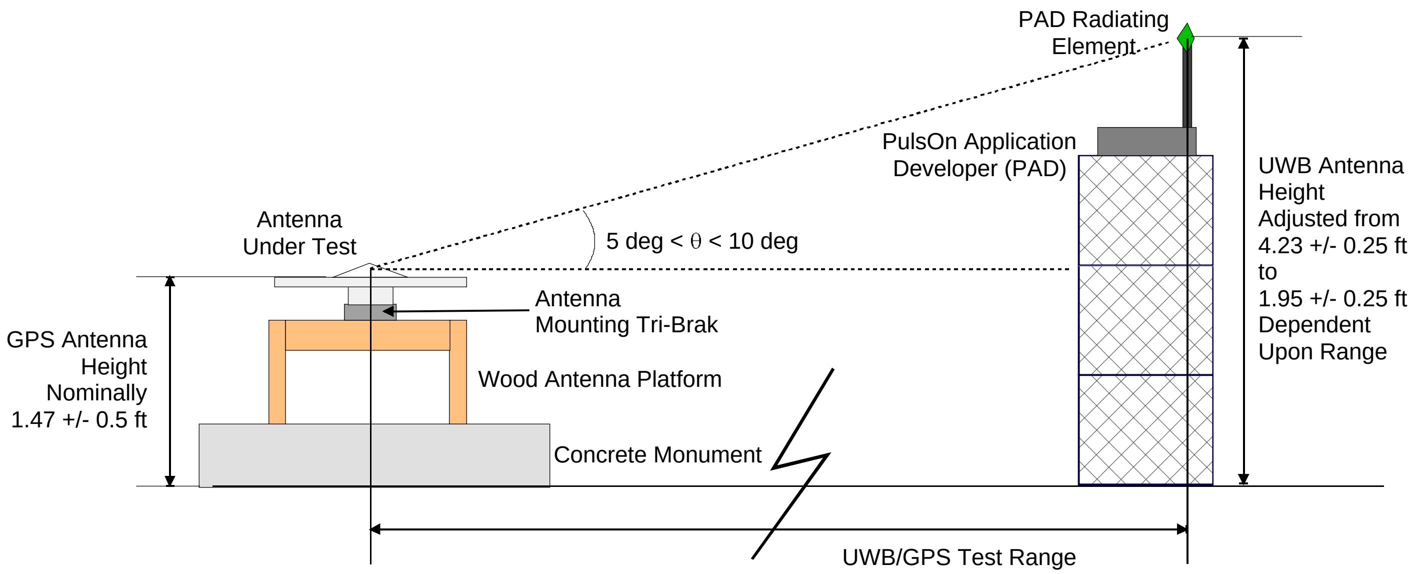


Figure 3-3 Side View of Radiated Setup

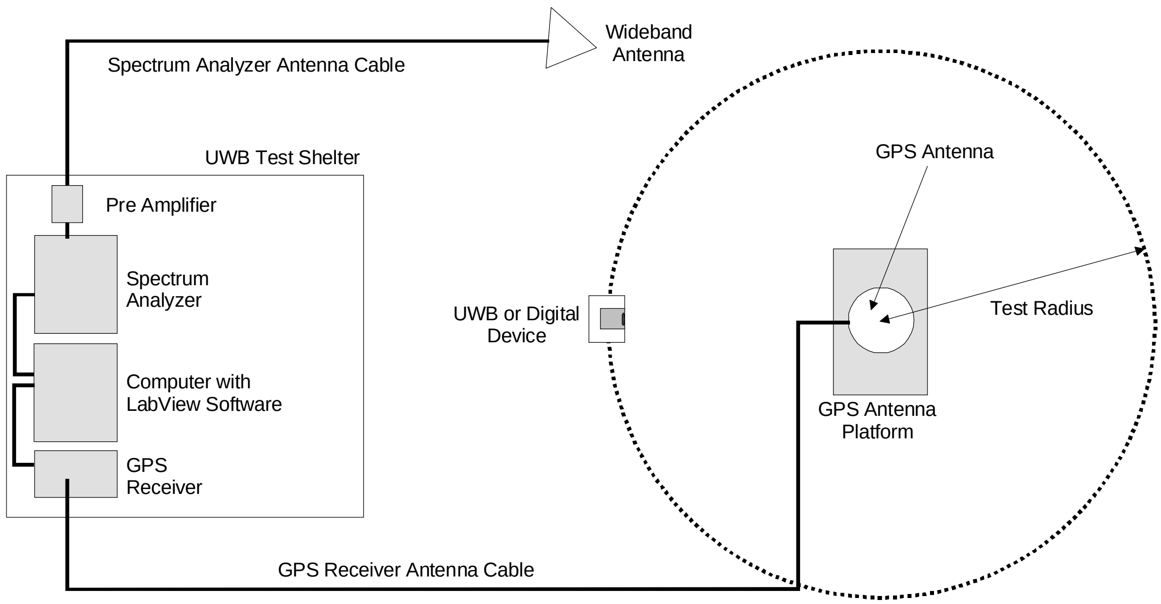


Figure 3-4 Field Layout UWB, GPR, Digital Devices Radiated Interference Test

3.4.2. Aggregate UWB Transmitter Test

The UWB transmitters used in the aggregation testing were arrayed about the GPS receiver at a given distance for each test case. Initially, the signal generators were turned off and a 20 minute baseline data set was collected. They were then turned on sequentially and data taken for a 20 minute sampling period. After each period of data collection, an additional set of signal generators were turned on. The sequence, as shown in Figure 3-5, was as follows: 1, 2, 4, 8, and 16 active devices transmitting symmetrically about the GPS antenna.

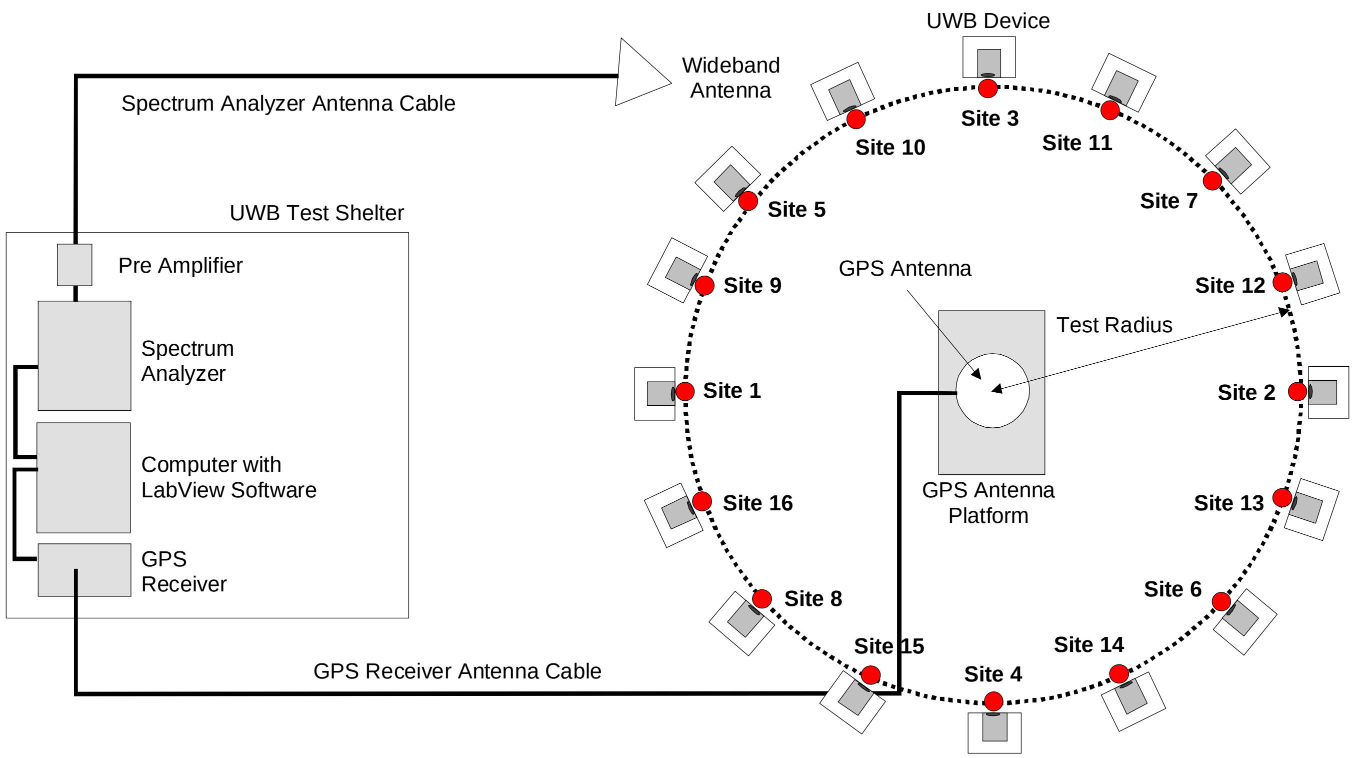
When the last data set was collected for the given range, an RF spectrum sweep was made to measure the characteristics of the combined real-world signals present during the test. The same test setup as in the single device radiated tests was used to perform the frequency sweeps shown in Table 3-3.

Following the spectrum analyzer measurements, all UWB devices were deactivated, the distance between the transmitter array and the GPS antenna was decreased to the next level and the process was repeated.

Due to time constraints, the UWB distances tested in aggregate tests were only a subset of those tested in single device tests. These distances included 8, 5, 4, 3, 2, and 1 meters. Adjustable test stands were built for each signal generator in order to provide the same UWB source heights for each distance as in single device tests, as given by Table 3-4.

The test setup was adjusted for aggregate tests in order to prepare it for possible inclimate weather. There was concern that such weather could interrupt the testing, which would compromise the integrity of the data set, and possibly damage the UWB signal generators. As such, protective hard plastic covers were placed over the signal generators and securely fastened to the test stands upon which the signal generators were mounted. Measurements were taken to verify that the plastic covers did not distort the UWB signal.

Figure 3-5 Field Positioning Layout UWB/GPS Aggregate Radiated Interference Test



4.0 Detailed Test Procedures

4.1 Conducted Interference Test

4.1.1. Overview

The conducted tests were intended to provide data collected from a controlled laboratory environment in which the majority of parameters were known and controlled. These tests were intended to capture the two types of data sets needed to estimate the impact of UWB transmissions on GPS receivers. The first data set is useful in analyzing the impact of UWB transmissions on the ranging accuracy of the GPS receivers. The second set is useful in analyzing the impact of UWB transmissions on GPS receivers' acquisition performance in both "cold start" and "warm start" modes. "Cold start" mode refers to when a GPS receiver is first powered up and initialized with no data present in its position location algorithms, while "warm start" refers to the case when a GPS receiver is already powered up, has lost "lock", and as such does not have an accurate position location estimation, but is in the process of reacquiring GPS satellites with the data it has within its position location algorithms. From comments received to the Test Plan, it was determined that the "warm start" acquisition tests were of greater interest to the community as a whole. Therefore, "cold start" tests were not performed due to time constraints.

4.1.2. Real-World Baseline Data

Prior to the execution of the conducted tests, an Ashtech Z-12 GPS receiver was taken to a surveyed point at the Applied Research Laboratories, the University of Texas at Austin (ARL:UT) and data was collected for a period of eight hours. The coordinates calculated from the collected data were used as the positional input to the GPS simulator for all conducted tests. The operational parameters of the simulator throughout testing were configured to match the scenario documented by the baseline test data. This included not only the surveyed position, but the GPS satellite constellation, as well as the time and length of the baseline test period. These settings are documented in Appendix C. It is important to note that the data collected during the baseline test represents a "real-world" environment in which a variety of variables affecting the GPS receiver were present. These variables include signal fading due to ionospheric propagation and/or multi-path components, local environmental noise in the GPS bands, antenna variations, front-end amplifier variations, and satellite elevation angles which all impacted the GPS receivers perception of satellite signal-to-noise ratios.

4.1.3. Receiver Normalization Procedure

A realistic testing scenario was desired for the conducted test effort. Towards this end, data was collected for each GPS receiver and its corresponding antenna individually in a live-sky environment for a twenty minute period. From this data, an "average" live-sky carrier to noise ratio for the satellites in view for each receiver was established. This carrier to noise level was used to determine the appropriate GPS simulator power to be injected into each receiver. Using the test configuration described in Figure 3.1, a single receiver was connected to the setup while 50 Ω matched loads were connected to the other receiver outputs, and the simulator output power was adjusted until the average carrier to noise reading of the receiver was equal to the average live-sky level. In this step, the GPS simulator was adjusted to provide the same satellite data for the timeframe of the live sky data collection, i.e. the same satellite geometry, antenna patterns, and signal strength levels, for the same date and time during which the outdoor data collection was made. With the simulator depicting the same satellite constellation, position data, and signal amplitude as presented to the test setup, a precise duplication of the live sky received data was presented to each receiver processor, without any real-world interference issues, antenna pattern gain variations, or variances in active antenna preamplifier gain. The power that was delivered to each receiver's antenna port then approximated the power level that was supplied to it when the receiver was gathering live sky data with its antenna and pre-amplifier. This procedure was repeated for each receiver under test, and the corresponding simulator power levels in each case were noted.

All of the receivers under test were then connected to the test setup as they would be in a actual test. Due to differing architectures of the receivers tested, each required a different simulator output power. To achieve this, it was necessary to first adjust the simulator to match the carrier to noise levels of the receiver(s) that required the strongest GPS signal power. In the case of the test described in Figure 3.1, this was receivers 2 and 4, which required nearly identical signal strengths. Fixed attenuators of various values were then placed in-line of the signal paths of the remaining receivers (1 and 3) so that those receivers would "see" live-sky signal levels as well. Additional measurements were made to verify that there was no cross-interference between any of the receivers. It was determined that the power dividers and the fixed attenuators used in the test setup were sufficient to isolate the receivers from one another.

The preceding procedure referred to the first conducted test involving Receivers 1 – 4. The same procedure was used to establish the simulator power levels and fixed attenuator values for Receivers 6 and 7 in the second conducted test, depicted in Figure 3.2.

It must be noted that due the complexity of testing multiple receivers simultaneously, it was impossible to set all of them exactly at their average live-sky power levels. The final test configurations chosen for the conducted test effort were deemed to be the best compromise for all of the receivers involved so that each receiver was tested as close to its measured live-sky level as possible. The GPS simulator power provided to each receiver during conducted "Live Sky" tests, as documented in Tables 5-8 and 5-11, were all within 2.5% of the simulator powers that were necessary to achieve the actual measured "Live Sky" power level for each receiver. It should be noted that the

Trimble receiver (RCVR 7) tested in the second set of conducted tests, required a very high GPS simulator power to function properly. This was due to the to the large gain (50 dB) of the pre-amplifier used in conjunction with its antenna during normal operation. This in turn required that a unusually large amount of fixed attenuation be placed in the signal path of the Novatel Millennium receiver (RCVR 6) so as not to over-drive the receiver front end, and so that it operated near its average live-sky value. This large attenuation was also in-line between the receiver and the UWB source so that injected UWB signal for some test conditions could be quite low. It is possible, therefore, that the data collected for RCVR 6 does not indicate the full range of UWB impact on that receiver.

4.1.4. Additional Test Preparation

While the behavior of the receivers at typical live-sky levels is an important test condition, it was felt that it was more important to characterize the receivers' performance when operated at the minimum guaranteed power level of –130 dBm. In order to run tests representative of this condition, the power level of the receivers was dropped by a fixed amount from their live-sky power levels to the minimum guaranteed power level. Using path loss measurements from the test setup, and knowing the nominal output power of the simulator, the GPS power level presented to each receiver could be calculated. The power output of the simulator was then lowered by the difference between the live-sky power level and the minimum guaranteed power level. These calculations are demonstrated in Section 5. Again, since the setup included multiple receivers, it was impossible to set all of the receivers at exactly the minimum guaranteed power level. It was found that the receivers could not reliably re-acquire the GPS signal at the minimum guaranteed power level once the receiver had lost satellite lock. Therefore, it was necessary to raise the minimum power level provided to the receivers when conducting acquisition performance tests so that the receivers could re-acquire lock with no interfering signal injected into the test setup. Since this level is still significantly less than the live-sky signal level, it was felt that it would provide a sufficient indication of the worst – case impact that UWB emissions have on the re-acquisition performance of GPS receivers.

The last step before beginning tests was to determine the appropriate attenuation levels for use in both the ranging accuracy and acquisition performance tests. First, a test was run with each receiver to determine the full range of UWB power levels that would impact the performance of the receivers. This was done with the GPS simulator presenting the average live-sky power level to the receivers. The UWB operational mode with the highest energy content in the GPS bands, mode 13, was used in this evaluation in order to gauge the worst-case impact. Starting at the maximum UWB attenuation level, the receiver's response was monitored in real-time, using the receiver control GUI on a PC or the receiver front panel display, as the attenuation in-line with the UWB source was incrementally lowered by means of the programmable attenuator. The attenuation was lowered until the C/N readings of the satellites in view to the receiver began to drop. This attenuation level defined the outer limit of UWB impact. The attenuation was further decreased to determine the UWB signal levels where the impact would become more severe, and where more measurement points would be required. From this information, and considering the time limitations of the testing schedule, an attenuation level set was selected for both ranging accuracy and acquisition performance tests. These attenuation level sets are described in Section 5. Due to the additional time required to conduct thirty trials in the acquisition performance tests, only nine attenuation levels were selected for those tests, compared with twenty attenuation levels for the ranging accuracy tests. In both cases, the attenuation levels spanned the entire range of UWB impact for all of the receivers tested assuming that an average live-sky GPS power level was presented to the receivers. This attenuation level set could then also be used to determine the full range of UWB impact when the minimum guaranteed GPS power level was used.

Tests were conducted with the simulator output power set at the average live-sky level, and the minimum-guaranteed level. This was done in order to measure the impact of UWB emissions on GPS reception in both a realistic scenario, and a worst – case scenario. As mentioned previously however, the principal intent of this test effort was to measure the worst – case impact. Therefore, while all eighteen UWB operational modes were tested at the minimum – guaranteed GPS power level, only three were tested at the average live-sky level.

4.1.5. Conducted Baseline Data Collection

The first test performed, which did not involve the UWB source, served as a baseline of the GPS receivers' performance when used with the simulator. The receivers were connected through the conducted test setup as described in Figures 3-1 and 3-2 to the simulator in such a way that their external active or passive antennas were by-passed. The simulator was configured to exactly represent the day, time, constellation configuration, and satellite signal levels that were present at the original "real world" baseline data acquisition done at ARL:UT. Data was then collected from each receiver for the same eight hour period that the initial baseline was performed. This data is valuable in establishing a baseline for the GPS receivers performance without the variables that were encountered in the live-sky baseline data acquisition. These variables include signal fading due to ionospheric propagation and/or multi-path components, local environmental noise in the GPS bands, antenna variations, front-end amplifier variations, and satellite elevation angles which all impacted the GPS receivers perception of satellite signal-to-noise ratios. These baseline tests were performed for both the Ranging Accuracy and the Acquisition Performance test criteria.

4.1.6. Receiver Response to Broad-Band Noise

As a part of the conducted tests, the GPS receivers were normalized against a broadband white noise source in the manner similar to that described in the

Department of Transportation (DOT)/Stanford test plan. This test used the same test setup and procedure as the conducted UWB tests, except that a broadband white noise signal was injected in place of the UWB signal. The output power level of the white noise source used during testing was chosen through comparison with average output power levels of the UWB source. The average power of the operational mode with highest the energy content in the GPS bands, mode 13, was measured using a spectrum analyzer. The output power of the white noise source was then adjusted until the same average power was achieved at L1. This was done in order to facilitate the direct comparison of the effects of UWB and White Noise signals on GPS receivers. Data was then collected on each receiver's response to varying levels of the broadband white noise as described in the procedures below. White noise tests were run for both the Ranging Accuracy and the Acquisition Performance test criteria.

4.1.7. Ranging Accuracy

For all of the tests performed, the data listed in Table 3-1 was collected for each receiver. For all tests, one epoch equals one second. Reference Figures 3-1 and 3-2 for details pertaining to the test setup.

The following represents a rough outline of the steps that were completed during each ranging test.

1. The GPS simulator, GPS receivers, UWB source, and test instrumentation are initialized.
2. The UWB attenuator is set to its maximum attenuation (to prevent any initial injection of the UWB signal.)
3. Start the GPS simulator. Receivers are now tracking the simulated satellites.
4. Turn UWB device on and set to desired operational mode.
5. Wait until all receivers have obtained receiver lock (> 4 satellites).
6. For each UWB attenuation level, do:
   A. Set UWB attenuator to current attenuation level.
   B. Collect data from receivers for 1200 epochs.
   C. Perform spectrum analyzer sweeps

4.1.8. Acquisition Performance

For all of the tests performed, the data listed in Table 3-1 was collected for each receiver. For all tests, one epoch equals one second. Reference Figures 3-1 and 3-2 for details pertaining to the test setup.

The following represents a rough outline of the steps that were conducted during each acquisition performance test:

1. The GPS simulator, GPS receivers, UWB source, and test instrumentation are initialized.

2. The UWB attenuator is set to its maximum attenuation (to prevent any initial injection of the UWB signal.)
3. Start the GPS simulator. Receivers are now tracking the simulated satellites.
4. Turn UWB device on and set to desired operational mode.
5. Wait until all receivers have obtained receiver lock (> 4 satellites).
6. For each UWB attenuation level, do:
   A. Set UWB attenuator to current attenuation level.
   B. For each of 30 trials do:
      i. Collect data from receivers for 10 epochs.
      ii. Set GPS attenuator to the maximum attenuation (to block the GPS signal so that the receivers lose lock on all satellites).
      iii. Collect data from the receivers for 30 epochs.
      iv. Set GPS attenuator to zero attenuation (to allow the receivers to reacquire lock)
      v. Collect data from receivers for 180 epochs
   C. Perform Spectrum analyzer sweeps.

The first 10 epochs of GPS data collection (step i.) will provide data for comparison of the receiver performance before and after it loses the GPS signal. The next 30 epochs of GPS data collection (step iii.) will verify that the receiver has lost lock with the satellite signals once they have been blocked. The final 180 epochs of data collection (step v.) will allow a determination of whether the receiver can reacquire the satellite signals once they have been re-introduced.

4.2 Single Source Radiated Interference Test

4.2.1. Overview

The radiated tests were intended to provide data collected from a “real-world” environment in which GPS receivers received signals from the live-sky GPS constellation. Three separate kinds of single source radiated tests were conducted, each using ranging accuracy as the test criteria. These included tests involving single UWB sources, Part 15 certified devices, or ground penetrating radars (GPR). These tests were not repeated using acquisition performance as the test criteria due to the complexity required to perform such a test and the limited testing schedule. During these tests each receiver was tested individually using the preamp and antenna designed for its use. See Figure 3-3 for a visual description of the test setup used during this testing.

4.2.2. Test Preparation

In a similar manner as was done in the conducted testing, a test was performed to assess the range of UWB impact on a receiver in a live-sky environment. An UWB source was initially placed at large distance from the receiver antenna, while the output of the receiver was monitored in real time for variations. The distance between the UWB source and the receiver antenna was reduced to the point where initial impact was noted in the C/N levels of the receiver. The distance was further reduced to determine the distances at which the impacts on the receiver due to the UWB source were enhanced. Equal range increments between the receiver antenna and the initial point of impact were selected as test locations for the radiated tests and were marked with stakes on the test site.

4.2.3. Baseline Data Collection

Baseline tests were run prior to each radiated test so that a comparison could be made between the performance of a receiver with and without the effects of UWB emission. These baselines were accomplished by placing the receiver's antenna on the test site as shown in Figure 3-3 with no UWB source present. Then GPS information was collected from the receiver for a predetermined period. Initially, a baseline test for a given receiver was intended to run over a 16 hour period on a single day just prior to when an UWB test was to be conducted with that receiver. It was felt that this would give the best comparison between the performance of the receiver when operating under normal conditions and when being subjected to UWB signals regardless of the time of day that a test was run. The baseline tests for the first three single UWB source tests (for Receivers 1, 2, and 3) were run in this manner. Poor weather conditions during the test effort, however, reduced the available testing schedule such that it was required to modify the baseline test procedure. For the remaining radiated tests, a twenty minute baseline with no UWB source present was run just prior to each test for a given receiver. This is opposed to running one long baseline in a single day, as was done previously, that would be the reference for all of the tests conducted with a given receiver. The procedure below assumes that the second type of baseline is used.

4.2.4. Single Interfering Source Test

For all of the tests performed, the data listed in Table 3-1 was collected for each receiver. For all tests, one epoch equals one second. Reference Figure 3-4 for details pertaining to the test setup.

The following is a rough outline of the steps involved in conducting the tests that involved a single in-band signal source. This applies to tests conducted with a single PAD device, or any of the part 15 certified devices or GPR devices tested. Exceptions have been noted.

1. The GPS receiver, and test instrumentation are initialized. The receiver is now tracking the live-sky constellation.
2. Place in-band signal source at maximum $\mathbf{R_{UWB}}$**.** At this point the source is off.

3. Collect 1200 epochs of baseline data from receiver.
4. Turn on interfering source. If UWB test, set UWB source to desired operational mode.
5. For each $\mathbf{R_{UWB}}$, do:
   A. Move UWB device to current range and height. If GPR test, device height is not changed.
   B. Collect data from receiver for 1200 epochs.
   C. Perform spectrum analyzer sweeps.

4.3 Aggregate Radiated Interference Test

4.3.1. Overview

The radiated aggregation tests overall were very similar to the single interference source radiated tests. Like the previous radiated tests, the aggregate tests were intended to provide data collected from a "real-world" environment in which the GPS receivers received signals from the live-sky GPS constellation. As noted previously, the same test site, and a similar test configuration were used to determine the aggregate effects of multiple UWB devices as shown in Figure 3-4. During these tests each receiver was tested individually using the preamp / antenna designed for its use. Once again, only the ranging accuracy test criteria was used. For each UWB range in a given aggregate test, however, five separate UWB device configurations were tested as described in section 3.4.2.

4.3.2. Baseline Data Collection

Baseline data was collected in manner similar to that employed in the radiated testing. Immediately prior to an aggregation test for a given receiver, twenty minutes of data was collected with the receiver antenna on the test site, with no UWB signals present.

4.3.3. Aggregate Test

For all of the tests performed, the data listed in Table 3-1 was collected for each receiver. For all tests, one epoch equals one second. Reference Figure 3-5 for details pertaining to the test setup.

The following is a rough outline of the steps involved in conducting the tests that involved an aggregate of UWB sources.

1. GPS receiver and test instrumentation are initialized. The receiver is now tracking the live-sky constellation.
2. Place all 16 UWB devices at maximum $\mathbf{R_{UWB}}$. At this point, they are all off.
3. Collect 1200 epochs of baseline data from receiver.

4. For each $\mathbf{R_{UWB}}$, do:
   A. Move UWB devices to current range and height.
   B. For n = 1 to 5 do:
      i. Turn on 2^{n-1} UWB devices in the order shown in Figure 3-4, and set all to desired operational mode (all devices are operating in same mode).
      ii. Collect 1200 epochs of GPS data.
   C. Perform spectrum analyzer sweeps.

4.4 Quality Assurance of Data

All of the raw test data collected in this test effort was acquired by automated data collection software. While the tests were running, the raw data collected by this software was saved to the hard drive of the control computer. At appropriate breaks in the testing sequence, the raw test data files located on the hard drive were preserved on Compact Disks (CDs). Operator actions and observations were recorded in test notebooks, scanned versions of which have been included in Appendix E.

The automated data collection software was tested extensively to insure that it collected data free of corruption. Part of this software validation consisted of a data verification process performed on the data obtained from preliminary conducted interference tests. In this process, a procedure was followed to first, determine that the collected data was continuous, that is, that data had been collected for every epoch in the test period, and second, that the data was reasonable in terms of start and stop times, number of satellites in view, and carrier to noise levels. The results of these verifications were recorded in the test log books. The procedures used to perform these verifications has been included in Appendix E.

5.0 Key Information for Conducted Tests

This section provides data that characterizes the test setups used in the conducted testing. This data includes path loss measurements and calculated GPS simulator power levels in each test setup. This data will be useful in determining the equivalent range of UWB impact on a GPS system as discussed in Section 2-2. Data in this section is only given for the GPS frequencies, L1 and L2. The test setup was characterized more thoroughly by collecting path loss measurements across 20 MHz bandwidths centered at L1 and L2, and a wide bandwidth, .05 GHz to 10 GHz. This data is referenced in Appendix A.

5.1 Path Loss Measurements for Test Setup – Receivers 1, 2, 3, 4

The path loss for each signal path in the test setup depicted in Figure 3-1, the UWB path, the GPS simulator path, and the spectrum analyzer path were measured with a vector network analyzer. Table 5-1 lists the path loss between the UWB source and each receiver. Table 5-2 lists the path loss between the output of the amplifier connected to the GPS simulator and each receiver. Table 5-3 lists the path loss between the UWB source and the spectrum analyzer. Table 5-4 combines the fixed path loss measurements with the additional attenuation provided by the programmable attenuators for each programmable attenuator level used in the first phase of conducted testing.

Table 5-1 Fixed UWB Path Losses for Receivers 1,2, 3, & 4

Receiver	UWB Path Loss at GPS L1 (dB)	UWB Path Loss at GPS L2 (dB)
RCV1	32.33	31.97
RCV2	27.00	26.47
RCV3	39.19	38.73
RCV4	26.73	26.21

Table 5-2 Fixed GPS Path Losses for Receivers 1, 2, 3, & 4

Receiver	Path Loss at GPS L1 (dB)	Path Loss at GPS L2 (dB)
RCV1	26.28	25.43
RCV2	20.60	19.80
RCV3	33.08	32.10
RCV4	20.60	19.66

Table 5-3 Fixed UWB to Spectrum Analyzer Path Losses for Receivers 1-4

Path Loss at GPS L1 (dB)	Path Loss at GPS L2 (dB)
7.17	7.09

Table 5-4 Variable UWB Path Losses with Programmable Attenuators, Receivers 1-4

Programmable Attenuator Setting (Db)	Path Loss for Each Receiver	L1 Loss	L2 Loss	Programmable Attenuator Setting (Db)	Path Loss for Each Receiver	L1 Loss	L2 Loss
60	RCV1	92.33	91.97	18	RCV1	50.33	49.97
	RCV2	87.00	86.47		RCV2	45.00	44.47
	RCV3	99.19	98.73		RCV3	57.19	56.73
	RCV4	86.73	86.21		RCV4	44.73	44.21
43	RCV1	75.33	74.97	16	RCV1	48.33	47.97
	RCV2	70.00	69.47		RCV2	43.00	42.47
	RCV3	82.19	81.73		RCV3	55.19	54.73
	RCV4	69.73	69.21		RCV4	42.73	42.21
40	RCV1	72.33	71.97	14	RCV1	46.33	45.97
	RCV2	67.00	66.47		RCV2	41.00	40.47
	RCV3	79.19	78.73		RCV3	53.19	52.73
	RCV4	66.73	66.21		RCV4	40.73	40.21
37	RCV1	69.33	68.97	12	RCV1	44.33	43.97
	RCV2	64.00	63.47		RCV2	39.00	38.47
	RCV3	76.19	75.73		RCV3	51.19	50.73
	RCV4	63.73	63.21		RCV4	38.73	38.21
34	RCV1	66.33	65.97	10	RCV1	42.33	41.97
	RCV2	61.00	60.47		RCV2	37.00	36.47
	RCV3	73.19	72.73		RCV3	49.19	48.73
	RCV4	60.73	60.21		RCV4	36.73	36.21
31	RCV1	63.33	62.97	8	RCV1	40.33	39.97
	RCV2	58.00	57.47		RCV2	35.00	34.47
	RCV3	70.19	69.73		RCV3	47.19	46.73
	RCV4	57.73	57.21		RCV4	34.73	34.21
28	RCV1	60.33	59.97	6	RCV1	38.33	37.97
	RCV2	55.00	54.47		RCV2	33.00	32.47
	RCV3	67.19	66.73		RCV3	45.19	44.73
	RCV4	54.73	54.21		RCV4	32.73	32.21
25	RCV1	57.33	56.97	4	RCV1	36.33	35.97
	RCV2	52.00	51.47		RCV2	31.00	30.47
	RCV3	64.19	63.73		RCV3	43.19	42.73
	RCV4	51.73	51.21		RCV4	30.73	30.21
22	RCV1	54.33	53.97	2	RCV1	34.33	33.97
	RCV2	49.00	48.47		RCV2	29.00	28.47
	RCV3	61.19	60.73		RCV3	41.19	40.73
	RCV4	48.73	48.21		RCV4	28.73	28.21
20	RCV1	52.33	51.97	0	RCV1	32.33	31.97
	RCV2	47.00	46.47		RCV2	27.00	26.47
	RCV3	59.19	58.73		RCV3	39.19	38.73
	RCV4	46.73	46.21		RCV4	26.73	26.21

5.2 Path Loss Measurements for Test Setup – Receivers 6 & 7

The path loss for each signal path in the test setup depicted in Figure 3-2, the UWB path, the GPS simulator path, and the spectrum analyzer path were measured with a vector network analyzer. Table 5-5 lists the path loss between the UWB source and each receiver. Table 5-6 lists the path loss between the output of the amplifier connected to the GPS simulator and each receiver. The path loss between the UWB source and the spectrum analyzer is the same in this test setup as in the test setup for Receivers 1 through 4, given in Table 5-3. Table 5-7 combines the fixed path loss measurements with the additional attenuation provided by the programmable attenuators for each programmable attenuator level used in the second phase of conducted testing.

Table 5-5 Fixed UWB Path Losses for Receivers 6 & 7

Receiver Output	Path Loss at GPS L1 (dB)	Path Loss at GPS L2 (dB)
RCV6	55.5	52.9
RCV7	21.47	21.3

Table 5-6 Fixed GPS Path Losses for Receivers 6 & 7

Receiver	Path Loss at GPS L1 (dB)	Path Loss at GPS L2 (dB)
RCV6	46.7	45.2
RCV7	14.8	13.9

Table 5-7 Variable UWB Path Losses with Programmable Attenuators, Receivers 6 & 7

Programmable Attenuator Setting	Path Loss for Each Receiver			Programmable Attenuator Setting	Path Loss for Each Receiver		
(Db)		L1 Loss	L2 Loss	(Db)		L1 Loss	L2 Loss
60	RCV6	115.50	112.90	18	RCV6	73.50	70.90
	RCV7	81.47	81.30		RCV7	39.47	39.30
43	RCV6	98.50	95.90	16	RCV6	71.50	68.90
	RCV7	64.47	64.30		RCV7	37.47	37.30
40	RCV6	95.50	92.90	14	RCV6	69.50	66.90
	RCV7	61.47	61.30		RCV7	35.47	35.30
37	RCV6	92.50	89.90	12	RCV6	67.50	64.90
	RCV7	58.47	58.30		RCV7	33.47	33.30
34	RCV6	89.50	86.90	10	RCV6	65.50	62.90
	RCV7	55.47	55.30		RCV7	31.47	31.30
31	RCV6	86.50	83.90	8	RCV6	63.50	60.90
	RCV7	52.47	52.30		RCV7	29.47	29.30
28	RCV6	83.50	80.90	6	RCV6	61.50	58.90
	RCV7	49.47	49.30		RCV7	27.47	27.30
25	RCV6	80.50	77.90	4	RCV6	59.50	56.90
	RCV7	46.47	46.30		RCV7	25.47	25.30
22	RCV6	77.50	74.90	2	RCV6	57.50	54.90
	RCV7	43.47	43.30		RCV7	23.47	23.30
20	RCV6	75.50	72.90	0	RCV6	55.50	52.90
	RCV7	41.47	41.30		RCV7	21.47	21.30

5.3 GPS Signal Levels – Ranging Tests on Receivers 1, 2, 3, & 4

For each class of tests, two different GPS signal levels, the Minimum Guaranteed, or “Min” level, and the average “Live Sky” level, were tested. For a “Live Sky” test, the power output of the simulator was adjusted to provide the same GPS power level at each receiver’s antenna port as was seen during the receiver normalization procedure discussed in Section 4.1.3. The “Live Sky” power level was achieved for this test setup by adjusting the nominal simulator output power of –130 dBm by +17.5 dB. The GPS power delivered to each receiver in the test setup can be calculated by subtracting the path loss measurement between the output of the amplifier connected to the simulator and each receiver, given in Table 5-2, from the power output of the simulator, and then adding the gain of the 22 dB amplifier. These calculations are given in Table 5-8.

For a “Min” level test, the power output of the simulator was adjusted to provide the minimum guaranteed GPS power level of –130 dBm at the antenna port of each receiver as determined by RTCA/DO 229B. Due to architectural differences between the receivers, this level could only be approximately achieved at the input of each receiver. This configuration was achieved by adjusting the nominal simulator output power of –130 dBm by +4.5 dB. The GPS power delivered to each receiver in the test setup can be calculated by subtracting the path loss measurement between the amplifier and each receiver, given in Table 5-2, from the power output of the simulator, and then adding the gain of the 22 dB amplifier used on the output of the simulator. These calculations are given in Table 5-9.

Table 5-8 "Live Sky" GPS Signal Strengths for Ranging Accuracy Tests with Receivers 1-4

Receiver	GPS L1 Power Delivered to Receiver (dBm)	GPS L2 Power Delivered to Receiver (dBm)
RCV1	-116.78	-115.93
RCV2	-111.1	-110.3
RCV3	-123.58	-122.6
RCV4	-111.1	-110.16

Table 5-9 "Min" GPS Signal Strengths for Ranging Accuracy Tests with Receivers 1-4

Receiver	GPS L1 Power Delivered to Receiver (dBm)	GPS L2 Power Delivered to Receiver (dBm)
RCV1	-129.78	-128.93
RCV2	-124.1	-123.3
RCV3	-136.58	-135.6
RCV4	-124.1	-123.16

5.4 GPS Signal Levels – Acquisition Tests on Receivers 1, 2, 3, 4

For the "Min" Level tests on receivers 1, 2, 3, and 4, it was found that no receiver could reliably reacquire the GPS signal at the minimum signal level. Therefore, for the "Min" Level Acquisition testing done with these receivers, the power output of the simulator was increased until the receivers were able to reacquire the GPS simulator signal after the receivers had lost lock with it for 30 seconds. For these tests, the output of the simulator was adjusted by +11.5 dB above the nominal –130 dBm; this results in a GPS power 7 dB higher than was used for the "Min" level ranging accuracy tests. The resulting power levels at the receiver inputs are shown in Table 5-10.

Table 5-10 Acquisition "Min" GPS Signal Strengths for Receivers 1-4

Receiver	GPS L1 Power Delivered to Receiver (dBm)	GPS L2 Power Delivered to Receiver (dBm)
RCV1	-122.78	-121.93
RCV2	-117.1	-116.3
RCV3	-129.58	-128.6

RCV4	-117.1	-116.16

5.5 GPS Signal Levels – Ranging and Acquisition Tests on Receivers 6 & 7

The "Live Sky" power level was achieved for this test setup by adjusting the nominal simulator output power of –130 dBm by +12dB. The "Min" power level was achieved by adjusting the nominal simulator output power level by +0dB. Again, a compromise was made so that both receivers could be operated near their average "Live-Sky" power level during "Live-Sky" tests. A compromise was also made so that for "Min" level testing, the GPS signal strength provided to each receiver would not over-drive the receiver nor be too far from the minimum guaranteed level. It was found that both receivers 6 and 7 could reliably reacquire at these power levels, so these same power levels were used for Acquisition Performance testing as well.

The GPS power delivered to each receiver in this test setup can be calculated by subtracting the path loss measurement between the output of the amplifier connected to the simulator and each receiver, given in Table 5-6, from the power output of the simulator, and then adding the gain of the 50 dB amplifier. The GPS power levels delivered to the receiver antenna ports of receivers 6 & 7 during ranging tests are given in Table 5-11 and Table 5-12 for "Live Sky" and "Min" level testing, respectively.

Table 5-11 "Live Sky" GPS Signal Strengths for Receivers 6 & 7

Receiver	GPS L1 Power Delivered to Receiver (dBm)	GPS L2 Power Delivered to Receiver (dBm)
RCV6	-114.7	-113.2
RCV7	-93.3	-91.9

Table 5-12 "Min" GPS Signal Strengths for Receivers 6 & 7

Receiver	GPS L1 Power Delivered to Receiver (dBm)	GPS L2 Power Delivered to Receiver (dBm)
RCV6	-126.7	-125.2
RCV7	-105.3	-103.9

6.0 Total Data Collected, Location, and Structure

Data collected during this test effort has been stored on the Applied Research Laboratories web servers. Approximately twelve gigabytes of data exists and has been made available to the public. The data can be accessed at the web page, sgl.arlut.utexas.edu / asd / Cure / index.html. To access the data, first click on the button labeled, "Test Plan for UWB / GPS Compatibility Effects", and then click the "Test Data" button that appears. Completing the required registration form will bring up the root directory labeled UWB_Test_Data. The following documentation describes the organization of the file directories that contain data files for each phase of testing.

It must be noted that there may be some variation in the naming of individual files contained in the data set compared to what is described here. All of the provided data files, however, have been organized in the appropriate directories corresponding to the tests from which they were taken.

6.1 Directory Structure

The directory structure used for the data storage is as follows:

UWB Test Data folder

|

Conducted Test Data folder **Documents folder** **Radiated Test Data folder** **Aggregate Test Data folder**

The **Conducted Test Data** Folder contains all of the data collected during both phases of the conducted testing and has the following structure:

Conducted Test Data folder

|

Ranging Test Data folder	**Acquisition Test Data folder**	**Simulator Truth Data folder**	**LiveSky Reference Data folder**
|	**|**	**|**	**|**
………	**…….**	**…….**	**……..**

The **Simulator Truth Data** folder contains two example log files collected from each of the two GPS simulators used during conducted testing. The *STR4760_Live_Sky_Test.txt* file is an example of a file generated by the GSS STR4760 simulator during the first phase of conducted testing for a "Live Sky" test. The *STR2760_Min_Level_Test.txt* file was generated by the GSS STR2760 simulator for a "Min" level conducted test during the second phase of conducted testing.

The **LiveSky Reference Data** folder contains the data collected with each receiver just prior to conducted testing to determine the appropriate "Live Sky" simulator power level as described in section 4.1.3. Each file in this folder contains twenty minutes of GPS data in either ASCII or binary format. No data is provided for the Trimble receiver

(RCVR 7) since at the time when these measurements were taken, the test team was unable to analyze Trimble's proprietary binary output. Therefore the measurements for this receiver were taken by hand in real – time over a twenty minute period using the PC GUI provided by Trimble. In all, the files provided in this directory are:

livesky_garmin.asc	ASCII "Live Sky" reference data for Garmin 150XL
Livesky_z12.asc	ASCII "Live Sky" reference data for Ashtech Z12
novatel_millenium_livesky.bin	Binary "Live Sky" reference data for Novatel Millennium
novatel3151_livesky.asc	Binary "Live Sky" reference data for Novatel 3151
novatel3151_livesky.bin	ASCII "Live Sky" reference data for Novatel 3151
Z-Sensor SN Levels.xls	ASCII "Live Sky" reference data for Z-Sensor saved in Excel worksheet

6.1.1 CONDUCTED RANGING ACCURACY TEST DATA

The directory structure for both the **Ranging Test Data** folder and the **Acquisition Test Data** folder are similar, but there are differences between them due to the differences in the way that the tests were conducted. The **Ranging Test Data** folder structure appears as follows:

Ranging Test Data folder

Receiver_Baselines folder | **White_Noise folder** | **Ultra Wideband folder**

Min_Level folder **Live_Sky folder** | **Min_Level folder** **Live_Sky folder** | **Min_Level folder** **Live_Sky folder**

All **Min_Level** folders contain data collected using the minimum guaranteed simulator power while **Live_Sky** folders contain data collected using the measured "Live Sky" simulator power level.

In both the **Min Level** and **Live Sky** folders in the **Receiver Baselines** folder, there will be files of the form *RCVX_01_01_00_CON_RA.GRC*, where X is the receiver number corresponding to the data contained in the file. There is one file for each receiver, and each file contains an eight hour GPS data set that was collected from a receiver without any in-band source connected to the test setup as described in section 4.1.5.

The **Ultra Wideband** folder contains all data sets collected during conducted ranging tests involving the TDC PAD UWB source. The **White Noise** folder contains data collected during conducted ranging tests with the broadband white noise source connected to the test setup as described in section 4.1.6.

The directory structure within the **Ultra Wideband** folder appears as follows:

Ultra Wideband folder
|
Min_Level folder **Live_Sky folder**
| **|**
UWBMode1 UWBMode2 … UWBMode18 (folders) **UWBMode1 UWBMode7 UWBMode13 (folders)**

Each **UWBMode** folder contains data for tests conducted with the UWB source connected to the test setup and operating in one out of the possible eighteen modes described in Table 3-2.

In each operational mode folder in both the **Min Level** and the **Live Sky** folders, are folders for each receiver tested:

UWBModeX folder
|
RCV1 folder
RCV2 folder
RCV3 folder
RCV4 folder
RCV6 folder
RCV7 folder

Each **RCVX** folder has the following contents:

RCVX folder
|
0dB Folder
2dB Folder
4dB Folder
6dB Folder
8dB Folder
10dB Folder
12dB Folder
14dB Folder
16dB Folder
18dB Folder
20dB Folder
22dB Folder
25dB Folder
28dB Folder
31dB Folder
34dB Folder
37dB Folder
40dB Folder

43dB Folder
60dB Folder

RCVX_01_*XX*_concat_live_CON_RA.grc

The directory structure within the **White Noise** folder appears as follows:

White Noise folder

Min_Level folder	**Live_Sky folder**
RCV1 folder	**RCV1 folder**
RCV2 folder	**RCV2 folder**
RCV3 folder	**RCV3 folder**
RCV4 folder	**RCV4 folder**
RCV6 folder	**RCV6 folder**
RCV7 folder	**RCV7 folder**

Each **RCVX** folder has the following contents:

RCVX folder

0dB Folder
2dB Folder
4dB Folder
6dB Folder
8dB Folder
10dB Folder
12dB Folder
14dB Folder
16dB Folder
18dB Folder
20dB Folder
22dB Folder
25dB Folder
28dB Folder
31dB Folder
34dB Folder
37dB Folder
40dB Folder
43dB Folder
60dB Folder
RCVX_01_XX_concat_live_CON_RA.grc

In both the **White Noise** and **Ultra Wideband** folders, each X**dB Folder** contains a file, **.grc* (which denotes: of type, GPS data), containing 20 minutes of GPS data from the given receiver at the UWB programmable attenuator setting corresponding to X dB, and a file, **.spa* (which denotes: of type, spectrum analyzer data), containing the spectrum analyzer sweeps listed in Table 3-3.

The **.grc* file that resides in the in each of the **RCVR**X folders represents a DOS concatenation of all of the GPS data collectively contained in each of the **XdB** folders. This file contains approximately eight hours of GPS data encompassing one complete UWB operating mode test for the given receiver.

6.1.2 CONDUCTED ACQUISITION PERFORMANCE TEST DATA

The **Acquisition Test Data** folder structure appears as follows:

Acquisition Test Data folder
|
Receiver_Baselines folder — **White_Noise folder** — **Ultra Wideband folder**

- **Receiver_Baselines folder**
  - **Min_Level folder**
  - **Live_Sky folder**
- **White_Noise folder**
  - **Min_Level folder**
  - **Live_Sky folder**
- **Ultra Wideband folder**
  - **Min_Level folder**
  - **Live_Sky folder**

In both the **Min Level** and **Live Sky** folders in the **Receiver Baselines** folder, there are folders, **RCVX**, for each receiver. In each **RCVX** folder there are three folders, **35dB_rcvX**, **40dB_rcvX**, and **45dB_rcvX** (or like named folders) which each contain 30 folders corresponding to individual trials. Each trial folder contains a **.grc* file which consists of GPS data collected from receiver X. All of the data in the three **XdB_rcvX** folders cumulatively represents roughly eight hours of GPS data from a single baseline test for receiver X where no in-band signal was injected into the test setup as described in section 4.1.5. The structure of the test automation software used to collect this data required that the data set be broken up into three folders.

The directory structure within the **Ultra Wideband** folder appears as follows:

Ultra Wideband folder

- **Min_Level folder**
  - **UWBMode1 UWBMode2 … UWBMode18 (folders)**
- **Live_Sky folder**
  - **UWBMode1 UWBMode7 UWBMode13 (folders)**

In each operational mode folder in both the **Min Level** and the **Live Sky** folders, are folders for each receiver tested:

UWBModeX folder
|
RCV1 folder
RCV2 folder
RCV3 folder
RCV4 folder

RCV6 folder
RCV7 folder

Each **RCVX** folder has the following contents:

RCVX folder
|
5dB Folder
10dB Folder
15dB Folder
20dB Folder
25dB Folder
30dB Folder
35dB Folder
40dB Folder
45dB Folder

Each XdB folder has the following contents:

XdB folder
|
Trial1 folder
Trial2 folder
....
Trial30 folder

RCVX_01_XX_XX_concat_CON_AQ.GRC

where each **TrialX** folder contains a **.grc* file containing GPS data collected during that trial, and the *RCVX_01 .... *.grc* file in the XdB folder is a DOS concatenation of all the **.grc* files contatined in each of trial folder for that attenuation level. This constitutes roughly 2.5 hours of GPS data.

The directory structure within the **White Noise** folder appears as follows:

White Noise folder
|

Min_Level folder	Live_Sky folder
|	|
RCV1 folder	RCV1 folder
RCV2 folder	RCV2 folder
RCV3 folder	RCV3 folder
RCV4 folder	RCV4 folder
RCV6 folder	RCV6 folder
RCV7 folder	RCV7 folder

Each **RCVX** folder has the following contents:

RCVX folder
|
5dB Folder
10dB Folder
15dB Folder
20dB Folder
25dB Folder
30dB Folder
35dB Folder
40dB Folder
45dB Folder

Each XdB folder has the following contents:

XdB folder
|
Trial1 folder
Trial2 folder
....
Trial30 folder
RCVX_01_XX_XX_concat_CON_AQ.GRC

Where each **TrialX** folder contains a *.grc file containing GPS data for that trial, and the RCVX_01 .... *.grc file in the XdB folder is a DOS concatenation of all the *.grc files in each trial folder for that attenuation level. This constitutes roughly 2.5 hours of GPS data.

6.1.3 RADIATED TEST DATA

The **Radiated Test Data Folder** contains all data collected from radiated testing involving individual in-band signal sources and has the following structure:

Radiated Test Data Folder
|

Digital Devices Folder	Ultra Wideband Folder	Ground_Penetrating_Radar
|	**|**	**|**
………	………	…….

The **Digital Devices Folder** contains all data for tests conducted with the two selected part 15 certified electronic devices. This directory has the following structure:

Digital Devices Folder
|
Digital_Device_1 Folder **Digital_Device_2 Folder**

where the **Digital_Device_1** folder contains data for the Motorola Radius SP10 Walkie-Talkie tests and the **Digital_Device_2** folder contains data for the Gateway Model GP7-450, Mini-Tower, Personal Computer (PC) tests as described in section 3.2.2.4.

The **Digital_Device_1 Folder** has the following structure:

Digital Devices 1 Folder
|
RCV1 **RCV2** **RCV3** **RCV4** **RCV6** **RCV7**
| **|** **|** **|** **|**
|
…… **……** **……** **……** **.......** **.......**

Each **RCVX** has the following structure:

RCVX
|
05m
10m
15m
20m
25m
30m
35m
40m
50m
80m
Baseline_20_Minutes

where the following folder definitions apply:

05m Folder – holds data for 0.5 meter range
10m Folder – holds data for 1.0 meter range
15m Folder – holds data for 1.5 meter range
20m Folder – holds data for 2.0 meter range
25m Folder – holds data for 2.5 meter range
30m Folder – holds data for 3.0 meter range
35m Folder – holds data for 3.5 meter range
40m Folder – holds data for 4.0 meter range
50m Folder – holds data for 5.0 meter range
80m Folder – holds data for 8.0 meter range

Baseline_20_Minutes – Holds data for the 20 Minute baseline completed prior to the start of the test.

Each **XXm** folder contains a **.grc* file and a **.spa* file which contain the GPS data and spectrum analyzer sweep data used to characterize the ambient spectral environment around the test site (includes sweeps given in Table 3-3), respectively for the given source range.

The **Digital Device 2** folder has the following structure:

```
                Digital Devices 2 Folder
                           |
                         RCV 6
                           |
     PC_wCover_rcv6             PC_w-oCover_rcv6
          |                            |
         05m                          05m
         10m                          10m
         20m                          20m
         40m                          40m
       baseline                     baseline
```

The **PC_wCover_rcv6** folder contains data collected while operating the PC in its nominal configuration, with an exterior cover. The **PC_w-oCover_rcv6** folder contains data collected while operating the PC *without* an external cover. Each **XXm** folder and the **baseline** folders contain both a **.grc* file containing GPS data and a **.spa* file containing ambient spectral data. As can be seen, only a limited number of distances were tested with only a single receiver due to limited time.

The **Ultra Wideband Folder** has the following directory structure:

```
                          Ultra Wideband Folder
                                    |
      rcv1 Folder             rcv2 Folder       .....       rcv7 Folder
       |                          |                              |
   UWBMode1_Files         UWBMode1_files            UWBMode1_files
   UWBMode10_Files        UWBMode10_files           UWBMode10_files
   UWBMode12_Files        UWBMode12_files           UWBMode12_files
   UWBMode13_Files        UWBMode13_files           UWBMode13_files
   UWBMode15_Files        UWBMode15_files           UWBMode15_files
   UWBMode16_Files        UWBMode16_files           UWBMode16_files
   UWBMode18_Files        UWBMode18_files           UWBMode18_files
   UWBMode4_Files         UWBMode4_files            UWBMode4_files
   UWBMode7_Files         UWBMode7_files            UWBMode7_files

           RCVX_01_BL_RAD_RA.GRC (only for RCV1, RCV2, RCV3)
```

Each **UWBMODE#_Files** Folder has the following directory structure:

UWBMode# Folder
|
05m Folder
10m Folder
15m Folder
20m Folder
25m Folder
30m Folder
35m Folder
40m Folder
50m Folder
80m Folder
Baseline_20_Min (only for RCV4, RCV6, RCV7)

As can be seen, there were two different formats used to collect the baseline data, as mentioned in section 4.2.3. For the first three receivers tested, a single baseline test was conducted over a sixteen hour period in one day just prior to the UWB tests. For the last three receivers, a twenty minute baseline was run just prior to the test for each UWB operational mode.

Each XXm folder contains a **.grc* file and a **.spa* file which contain the GPS data and spectrum analyzer sweep data, respectively for the given source range.

The **Ground Penetrating Radar** folder contains data collected from tests involving the two ground penetrating devices and has the following directory structure:

Ground Penetrating Folder
|
Device1 Folder **Device2 Folder**

The **Device1** folder contains data for tests run with the Sensors and Software Noggin 1000 device, while the **Device2** folder contains data for tests run with the Sensors and Software Noggin 250 device.

Each **DeviceX** folder has the following structure:

```
                    DeviceX
                       |
rcv4 Folder                      rcv6 Folder
     |                                |
   05m Folder                       05m Folder
   10m Folder                       10m Folder
   15m Folder                       15m Folder
   20m  Folder                      20m  Folder
   25m Folder                       25m Folder
   30m Folder                       30m Folder
   35m Folder                       35m Folder
   40m  Folder                      40m  Folder
   50m  Folder                      50m  Folder
   80m  Folder                      80m  Folder
   Baseline_20_Min                  Baseline_20_Min
```

Each **XXm** folder contains a **.grc* file and a **.spa* file which contain the GPS data and spectrum analyzer sweep data, respectively for the given source range.

Due to the limited availability of these devices, they were tested with only two receivers.

6.1.4 AGGREGATE TEST DATA

The **Aggregate Test Data** folder has the following structure:

```
              Aggregate Test Data folder
                          |
              Ranging_Test_Data folder
                          |
RCV4 folder                         RCV6 folder
     |                                   |
   .....                                ....
```

Each **RCVX** folder has the following structure:

RCVX folder

|

UWBMode1 folder **UWBMode2 folder**

Where UWBMode1 and 2 are the two available modes on the signal generators used for aggregate testing and correspond to operational modes 7 and 9, respectively in Table 3-2.

Each **UWBX** folder has the following structure:

UWBX folder
|
10m folder
20m folder
30m folder
40m folder
50m folder
80m folder
Baseline_20_Min

Each **XXm** folder contains five **.grc* files which are GPS data files for each of the five UWB source configurations (1, 2, 4, 8, or 16 devices transmitting), and a **.spa* file which contains that spectrum analyzer sweeps.

Again, limited time only allowed aggregate testing on two receivers.

7.0 Automated Data Collection Software

7.1 Overview of LabVIEW

LabVIEW is a program development environment in which a graphical programming language is used to create programs in block diagram form. It is a general-purpose programming system with an extensive library of functions to suit a wide variety of programming tasks. LabVIEW, however, is especially suited for applications involving instrument control and data processing (acquisition, storage, analysis, and presentation). It includes conventional program development tools, which coupled with the graphical interface, allow for simplified software development and troubleshooting.

A LabVIEW program is known as a Virtual Instrument (VI) since its appearance and operation can be much like that of a physical instrument. VIs, however, are similar to functions or subroutines of conventional text-based programming languages. There are three essential components to any VI: the interactive user interface, the data flow diagram which serves as the source code, and the icon which allows the program to be used in other LabVIEW programs. The interactive user interface, known as the front panel, simulates the front panel of a physical instrument. It can contain controls such as knobs and push buttons, and indicators such as digital read-outs and graphs, which allow the user to interact with the VI in real-time, as it executes. In the block diagram, the user can construct the functionality of the VI using standard programming structures such as “for” or “while” loops implemented as graphical blocks. The entire functionality of a VI can be accessed by means of its graphical icon. A VI can be executed, and data can be passed to or from another VI by means of its icon in the same way that a subroutine is accessed by a program in a conventional programming language. This supports a hierarchical and modular programming approach.

7.2 Degree of Automation

This section is meant to describe how the test procedures outlined in section 4.0 were implemented in the Test Automation Software (TAS) using LabVIEW. This description will also demonstrate the level of automation that that was implemented in the TAS. Great detail has been included in this section to show clearly which operations were performed by the test operator, and which were performed by the TAS. A slightly different LabVIEW program was created for each test type, conducted, single source radiated, and aggregate radiated. For the conducted tests, the same program was used to run both the ranging accuracy and acquisition performance conducted tests. The basic limitation to the level of automation implemented in the TAS was the lack of ability to completely control the UWB source, the GPS receivers under test, and the GPS simulator from within the TAS. In general, these devices were initialized and configured by the operator by means each device’s control software / front panel. Although the devices under test were configured by the operator, all data collection and file archival to hard disk were completely automated by means of the TAS. A general assumption in the development of the TAS software was that all data processing would be deferred until after data collection had been completed. Therefore this document only makes reference to items directly related to data collection and archival.

The descriptions below represent a rough functional outline of how a test operator would interact with the algorithms implemented in LabVIEW. They assume that all devices involved have been powered up and are essentially ready for testing. For all tests one epoch = one second. The GPS data to be collected for each test condition are listed in Table 3-1. The actual procedures followed during each phase of the testing are referenced in Appendix E.

7.3 Conducted Interference Test

7.3.1. Ranging Accuracy

1. Operator initializes the GPS receivers by cycling their power. This is done externally of the TAS.
2. Operator commands GPS simulator to generate normal GPS constellation signals for the duration of the test period. This is done externally of the TAS via the simulator control computer.
3. Before starting measurements, the operator launches the control software for the UWB source and GPS receiver (s), where applicable. This is done externally of the TAS.
   A. In the GPS receiver control software / receiver front panel, the operator will configure the GPS receiver(s) as desired for testing and will verify that the receiver(s) have achieved receiver lock.
   B. Using a test program, the test operator samples data from the serial port for each receiver, to ensure that each COM port interface is functioning properly, and that data is streaming from each serial port properly.
   C. In the UWB source control software, the operator initializes the UWB source.
   D. In the UWB source control software, the operator sets the UWB source's operational mode and commands it to transmit signals.
      - By default, the UWB attenuator is set to the maximum attenuation so that no UWB is injected into the test setup at this point.
4. In the TAS, the operator selects the receiver(s), to be tested and selects the proper COM port for each receiver.
5. The operator starts the TAS.
6. The TAS initializes the spectrum analyzer.
7. While the operator does not press the VI stop button in the TAS:
   A. In the TAS, the operator sets the UWB OPERATIONAL MODE control to correspond to the current setting on the UWB device.
   B. The TAS will wait until:
      i. In the TAS, the operator presses the START MEASUREMENTS button.
   C. For each attenuation level to be tested:

i. The TAS commands the UWB programmable attenuator to achieve the current UWB attenuation level.
ii. For 1200 epochs, the TAS will do:
    a. Read GPS data from the computer serial port for each receiver. This data will include data items listed in Table 3-1.
    b. Write the GPS data for each receiver to separate files.
iii. TAS will perform all sweeps listed in Table 3-3 on the spectrum analyzer.
iv. TAS will write spectrum analyzer data to file with time stamp.

7.3.1.1. Comments

This program structure implies that up to eight receivers can be fully tested simultaneously by a single run of the TAS. For the two conducted test phases in this test effort, four and two receivers, respectively, were tested simultaneously. In both cases, the TAS was configured to run all twenty attenuation levels for a selected UWB mode in a single eight hour session. After the operator selects the receivers and the UWB operational mode to be tested, and starts the TAS, the TAS selects the proper file paths for data archival. Two data files are recorded for each attenuation level. These consist of a GPS data file (*.GPR) and a spectrum analyzer file (*.SPA) which are recorded in the folder corresponding to the attenuation level currently under test for the given UWB operational mode. After all of the UWB attenuation levels have been tested for a particular configuration, another UWB operational mode can be tested by making the appropriate adjustments to the UWB source, selecting the new mode in the TAS, and pressing the START MEASUREMENTS button once again.

7.3.2. Acquisition Performance

1. Operator initializes the GPS receivers by cycling their power. This is done externally of the TAS.
2. Operator commands the GPS simulator to generate normal GPS constellation signals for the duration of the test period. This is done externally of the TAS via the simulator control computer.
3. Before starting measurements, the operator launches the control software for the UWB source and GPS receiver(s). This is done externally of the TAS.
    A. In the GPS receiver control software / receiver front panel, the operator configures the GPS receiver(s) as desired for testing and will verify that the receiver(s) have achieved receiver lock.
    B. Using a test program, the operator samples data from the serial port for each receiver, to ensure that each COM port interface is functioning properly, and that data is streaming from each serial port properly.
    C. In the UWB source control software, the operator initializes the UWB source.

D. In the UWB source control software, the operator will set the UWB source's operational mode and command it to transmit signals.
    - By default, the UWB attenuator is set to the maximum attenuation so that no UWB is injected into the test setup at this point.
    - By default, the GPS attenuator is set to zero attenuation so that the receiver can track the simulator signal.
4. In the TAS, the operator selects the receiver(s) to be tested and selects the proper COM port for each receiver.
5. In the TAS, the operator selects the UWB operational mode to be tested.
6. In the TAS, the operator selects the UWB attenuation levels to be tested.
7. The operator starts the TAS.
8. The TAS initializes the spectrum analyzer.
9. While the operator does not press the VI stop button in the TAS:
    A. For each attenuation level to be tested:
        i. The TAS commands the programmable attenuators to achieve the current UWB attenuation level.
        ii. The TAS will wait until:
            a. In the TAS, the operator presses *START MEASUREMENTS*.
        iii. For 30 trials:
            a. For 10 epochs, the TAS will do:
                1. Read GPS data from each computer serial port. This data will include data items listed in Table 3-1.
                2. Write the GPS data for each receiver to a separate file.
            b. The TAS sets the GPS programmable attenuator to maximum level, thus cutting off the GPS signal from the receivers.
            c. For 30 epochs, the TAS will do:
                1. Read GPS data from each computer serial port. This data will include data items listed in Table 3-1.
                2. Write the GPS data for each receiver to a separate file.
            d. The TAS sets the GPS programmable attenuator to zero thus allowing the full-strength GPS signal to be injected into the receivers.
            e. For 180 epochs, the TAS will do:
                1. Read GPS data from each computer serial port. This data will include data items listed in Table 3-1.
                2. Write the GPS data for each receiver to a separate file.
        iv. TAS will perform all sweeps listed in Table 3-3 on the spectrum analyzer.
        v. TAS will write spectrum analyzer data to file with time stamp

7.3.2.1. Comments

This program collects data only pertinent to the analysis of UWB effects on GPS receiver warm-start reacquisition. It is important to note that GPS data is being collected continuously from the beginning of a trial; this implies that no data epochs are missed when the GPS attenuation levels are changed. Although the structure of this program is similar to that of the Ranging Accuracy test, it has been adapted specifically to accommodate the nuances of the Acquisition Performance testing. To permit automation of the testing, the GPS simulator was run continuously through all thirty trials for an attenuation level. This implies that each trial represents a scenario shifted slightly in time compared to another trial. To reduce the amount of operator interaction required for this testing, three attenuation levels for a given UWB operational mode were tested in the same test session which ran for approximately eight hours.

An entire operational mode was then evaluated by conducting three such sessions to test all nine attenuation levels. For each trial, a single GPS data file is collected and stored in a corresponding folder for that trial. Although it was part of the basic functionality of the TAS, Spectrum analyzer data was not collected during acquisition testing to reduce testing time.

7.4 Radiating Interference Test

7.4.1. Ranging Accuracy

1. Before starting measurements, the operator launches the control software for the UWB transmitter and GPS receiver. This is done externally of the TAS.
   A. In the GPS receiver control software / receiver front panel, the operator configures the GPS receiver(s) as desired for testing and verifies that the receiver(s) have achieved receiver lock.
   B. Using a test program, the operator samples data from the serial port for each receiver to ensure that each COM port interface is functioning properly, and that data is streaming from each serial port properly.
   C. A 20 minute baseline data set is collected from the receiver prior to turning the UWB sources on. This data will include data items listed in Table 3-1.
   D. In the UWB source control software, the operator will initialize the UWB source.
   E. In the UWB source control software, the operator will set the UWB source's operational mode and command it to transmit signals.
2. In the TAS, the operator selects the receiver to be tested and selects the proper COM port for the receiver.
3. The operator starts the TAS.
4. The TAS initializes the spectrum analyzer.
5. While the operator does not press the stop button in the TAS:
   A. If starting a new test, the operator sets the UWB operational mode in the TAS.
   B. The operator must select, in the TAS, the UWB source range to be tested.

C. The operator should move the UWB source to the appropriate range from the GPS receiver.
D. The TAS will wait until:
   i. In the TAS, the operator presses START MEASUREMENTS.

E. For 1200 epochs, the TAS will do:
   i. Read GPS data from the computer serial port. This data will include data items listed in Table 3-1.
   ii. Write the GPS data to file.
F. TAS will perform all sweeps listed in Table 3-3 on spectrum analyzer.
G. TAS will write spectrum analyzer data to file with time stamp.

7.4.1.1. Comments

This program is similar to the one used for the conducted ranging accuracy test. The principle differences in this program are that a real GPS constellation was used, only one receiver was tested at a time, and the UWB attenuation was controlled by varying the distance between the UWB source and the GPS receiver. Therefore, after a data set was collected for a given test range, the operator was required to move the UWB source to a new range, and press START MEASUREMENTS before more data could be collected. This was repeated until all ten ranges for a given UWB operational mode were tested. This implies that significantly less automation could be employed in the radiated testing compared with the conducted testing. Both **.GPS* and **.SPA* data sets were collected for each distance. Also a baseline data set was conducted prior to every test, in order to characterize the ambient conditions.

7.5 Aggregate Radiated Interference Test

7.5.1. Ranging Accuracy

1. Before starting measurements, the operator launches the control software for the UWB transmitter and GPS receiver. This is done externally of the TAS.
   A. In the GPS receiver control software / receiver front panel, the operator configures the GPS receiver(s) as desired for testing and verifies that the receiver(s) have achieved receiver lock.
   B. Using a test program, the operator samples data from the serial port for each receiver to ensure that each COM port interface is functioning properly, and that data is streaming from each serial port properly.
   C. A 20 minute baseline will be run prior to turning the UWB sources on. This data will include data items listed in Table 3-1.
2. In the TAS, the operator selects the receiver to be tested and selects the proper COM port for the receiver.

3. The operator starts the TAS.
4. The TAS initializes the spectrum analyzer.
5. While the operator does not press the stop button in the TAS:
   A. If starting a test, in the TAS, the operator sets the UWB OPERATIONAL MODE.
   B. The operator must select, in the TAS, the UWB source range to be tested.
   C. The operator should move the UWB source to the appropriate range from the GPS receiver.
   D. For *x* UWB sources turned on (x $\in$ 1, 2, 4, 8, 16):
      i. Operator must turn on UWB sources for desired number of transmitters (i.e. 1, 2, 4, 8, 16) by means of external hardware switches on the devices themselves.
      ii. The TAS will wait until:
         a. In the TAS, the operator presses *START MEASUREMENTS*.
      iii. For 1200 1-second epochs, the TAS will do:
         a. Read GPS data from the computer serial port. This data will include data items listed in Table 3-1.
         b. Write the GPS data to file.
   E. TAS will perform all sweeps listed in Table 3-3 on spectrum analyzer.
   F. TAS will write spectrum analyzer data to file with time stamp.

7.5.1.1. Comments

This program is similar to that of the radiated ranging accuracy test. The principal difference between that test and this test was that multiple UWB sources were used. This required five different source configurations at each test range. Prior to an aggregate test, twenty minutes worth of baseline data was taken. Then a single source was turned on at the first distance of 8 meters, and a test was run. The tests were run with increasingly more sources turned on. After all the source configurations were tested, all devices were turned off, and moved inward to the next distance, and the sequence was repeated.

8.0 Reference Documents

[1] M. Luo, D. Akos, S. Pullen, P. Enge, “Potential Interference to GPS from UWB Transmitters: Test Plan – Version 4.5”, Stanford University,2000.

[2] *RTCA/DO-229B*, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, Section 2.5.7.1.2, p. 187; Section 2.5.6 pp 181 - 183,October 6, 1999.

[3] E.D. Kaplan, *Understanding GPS: Principles and Applications*, Norwood, MA: Artech House, pp. 219 - 225, 237 - 239 1996.

[4] *NovAtel Command Descriptions Manual*, Rev. Level 2.0, Novatel Communications Limited, March 1995.

[5] *Z Family Technical Reference*, Magellan Corporation, April 1999.

The following documents were also used during the testing effort and in the creation of this test report.

8.1 Industry

“UWB/GPS Interference Test Recommendations, Final Report”, Illgen Simulation Technologies, Incorporated, March 2000.

8.2 Standards

National Marine Electronics Association (NMEA) 0183 Standard for Interfacing Marine Electronic Devices, Version 2.3, March 1, 1998

Rinex Version 2, Werner Gurtner, Astronomical Institute, University of Berne, Switzerland

RTCA DO-253, Minimum Operational Performance Standards for Local Area Augmentation System Airborne Equipment.

8.3 Ultra Wideband Testing Consortium

ARL:UT Contract UTA 00-319, Time Domain Corporation

A. Characterization of Conducted Test Setup

The two test setups (see Figures 3-1 and 3-2) used for the conducted tests were fully characterized using a Hewlett Packard 8722ES Vector Network Analyzer. Due to the size of this characterization data, it has been stored in a number of files on the ARL:UT UWB data server in the Documents \ TS_CHAR_DATA folder where it can be readily accessed. Contained in these files are the full S – parameter measurements, given in amplitude and phase, for the various signal paths in both test setups. In general, these signal paths are:

- GPS simulator input to GPS receiver input
- UWB source input to GPS receiver input
- UWB source input to the spectrum analyzer input

This characterization data does not include the gain due to the amplifier used on the output of the GPS simulator or the loss due to the adapters used to connect the SMA cables at the output of the test setup to each receiver. Also, the path loss due the LEMO antenna cable placed in series with the Trimble receiver in the second test setup is not included. The path loss of this cable is quoted by the manufacturer to be 10 dB at L1.

Also included for the second setup is a characterization of the amplifier used on the output of the GPS simulator. Fixed attenuation of 32 dB was placed on the output of the amplifier so as not to over-drive the network analyzer. Only the S_{11} and S_{21} data is valid in this data set as the amplification is uni – directional. The amplifier used in the first setup (with a manufacturer quoted gain of 22 dB) was not available at the time of these characterizations (as it belonged to the 746 Test Squadron at Holloman AFB), so no data is provided for it.

Each signal path was characterized with three distinct sweeps, a 20 MHz sweep centered about the GPS L1 band (1.575 GHz), a 20 MHz sweep centered about the GPS L2 band (1.227 GHz), and sweep from 50 MHz to 10 GHz. There are 1600 data points for each sweep.

Given below is a list of the characterization data files located on the server, with a description of the signal path that each file corresponds to.

Table A-1 Characterization Data Files for Test Setup 1

File Name	Signal Path Description
Setup1_sim_rcv1_L1.s1	Simulator input to receiver 1 output at L1
Setup1_sim_rcv1_L2.s1	Simulator input to receiver 1 output at L2
Setup1_sim_rcv1_wb.s1	Simulator input to receiver 1 output with ultra-wide-band sweep
Setup1_sim_rcv2_L1.s1	Simulator input to receiver 2 output at L1
Setup1_sim_rcv2_L2.s1	Simulator input to receiver 2 output at L2
Setup1_sim_rcv2_wb.s1	Simulator input to receiver 2 output with ultra-wide-band sweep
Setup1_sim_rcv3_L1.s1	Simulator input to receiver 3 output at L1
Setup1_sim_rcv3_L2.s1	Simulator input to receiver 3 output at L2
Setup1_sim_rcv3_wb.s1	Simulator input to receiver 3 output with ultra-wide-band sweep
Setup1_sim_rcv4_L1.s1	Simulator input to receiver 4 output at L1
Setup1_sim_rcv4_L2.s1	Simulator input to receiver 4 output at L2
Setup1_sim_rcv4_wb.s1	Simulator input to receiver 4 output with ultra-wide-band sweep
Setup1_uwb_rcv1_L1.s1	UWB source input to receiver 1 output at L1
Setup1_uwb_rcv1_L2.s1	UWB source input to receiver 1 output at L2
Setup1_uwb_rcv1_wb.s1	UWB source input to receiver 1 output with ultra-wide-band sweep
Setup1_uwb_rcv2_L1.s1	UWB source input to receiver 2 output at L1
Setup1_uwb_rcv2_L2.s1	UWB source input to receiver 2 output at L2
Setup1_uwb_rcv2_wb.s1	UWB source input to receiver 2 output with ultra-wide-band sweep
Setup1_uwb_rcv3_L1.s1	UWB source input to receiver 3 output at L1
Setup1_uwb_rcv3_L2.s1	UWB source input to receiver 3 output at L2
Setup1_uwb_rcv3_wb.s1	UWB source input to receiver 3 output with ultra-wide-band sweep
Setup1_uwb_rcv4_L1.s1	UWB source input to receiver 4 output at L1
Setup1_uwb_rcv4_L2.s1	UWB source input to receiver 4 output at L2
Setup1_uwb_rcv4_wb.s1	UWB source input to receiver 4 output with ultra-wide-band sweep
Setup1_uwb_spa_L1.s1	UWB source input to spectrum analyzer output at L1
Setup1_uwb_spa_L2.s1	UWB source input to spectrum analyzer output at L2
Setup1_uwb_spa_wb.s1	UWB source input to spectrum analyzer output with ultra-wide-band sweep

Table A-2 Characterization Data Files for Test Setup 2

File Name	Signal Path Description
Setup2_sim_rcv1_L1.s1	Simulator input to receiver 6 output at L1
Setup2_sim_rcv1_L2.s1	Simulator input to receiver 6 output at L2
Setup2_sim_rcv1_wb.s1	Simulator input to receiver 6 output with ultra-wide-band sweep
Setup2_sim_rcv2_L1.s1	Simulator input to receiver 7 output at L1
Setup2_sim_rcv2_L2.s1	Simulator input to receiver 7 output at L2
Setup2_sim_rcv2_wb.s1	Simulator input to receiver 7 output with ultra-wide-band sweep
Setup2_uwb_rcv1_L1.s1	UWB source input to receiver 6 output at L1
Setup2_uwb_rcv1_L2.s1	UWB source input to receiver 6 output at L2
Setup2_uwb_rcv1_wb.s1	UWB source input to receiver 6 output with ultra-wide-band sweep
Setup2_uwb_rcv2_L1.s1	UWB source input to receiver 7 output at L1
Setup2_uwb_rcv2_L2.s1	UWB source input to receiver 7 output at L2
Setup2_uwb_rcv2_wb.s1	UWB source input to receiver 7 output with ultra-wide-band sweep
Setup2_uwb_spa_L1.s1	UWB source input to spectrum analyzer output at L1
Setup2_uwb_spa_L2.s1	UWB source input to spectrum analyzer output at L2
Setup2_uwb_spa_wb.s1	UWB source input to spectrum analyzer output with ultra-wide-band sweep
Setup2_amp_L1.s1	Avantek AWT-2034 amplifier at L1
Setup2_amp_L2.s1	Avantek AWT-2034 amplifier at L1
Setup2_amp_wb.s1	Avantek AWT-2034 amplifier at L1

B. Characteristics of the UWB Signal Sources

B.1 UWB TDC PAD Source

This UWB source is based on Time Domain Corporation's Pulson Applications Demonstrator (PAD). This particular PAD was configured to act as a transmitter only with a variety of different operational test modes. One PAD S/N 103 was used for the conducted testing, while the other S/N 123 was used for the radiated testing. The output spectrum of the PAD is consistent with many of the 2 GHz UWB systems currently being developed by Time Domain.

The UWB PAD source has the capability to operate in numerous modes. The matrix shown in Table B-1 lists UWB test modes for the PAD UWB source to which the GPS receivers were subjected during testing. This matrix gives an arbitrary Test Designation Number and also provides the nominal Pulse Repetition Frequency (PRF) values that will be tested, as well as the On Time, Off Time, and Duty Cycle. These modes have a nominal PRF of 1 MHz, 5 MHz, or 10 MHz, with a 25 ns code span, and a code length of 1024 randomly spaced pulses (where all modes use time modulation). The burst modes listed below are realistic for product operations. Moreover, the non-burst (continuous) modes are unexpected for most product operations, however, it is the worst case operational mode. These modes can be accessed by means of the Time Domain PAD control software running on a PC.

B.1.1 PAD Output Spectrum

The output spectrums shown below in figures B-1 and B-2 represent the PAD non-burst mode E.I.R.P. and electric field strength. The PAD has the capability to have higher than Part 15 Class B emissions for PRFs greater than 1 MHz, but was externally attenuated to be within the FCC average field strength limit. The plots below are representative of the output spectrum (assuming appropriate external attenuation), however, the radiated spectrums were measured at an independent FCC certified testing laboratory and a report prepared by the laboratory is available in Appendix D. The measured radiated spectrum may appear different due to multi-path, free space loss frequency differences, site variations, etc.

Figure B-3 represents a conceptual block diagram of the generation of a PAD impulse. The output spectrum is created by firing an impulse generator, which is then filtered by a high pass filter, then shaped by the antenna (for radiated testing). The firing of the impulse generator is triggered by a very precise timing system, in which the timing signal is based upon the specific code, nominal PRF, and burst timing. The high pass filter and antenna are used to perform spectrum shaping, and are an integral part of the system in either the conducted or radiated tests. The peak radiated power pattern of the antenna used with the PAD is also given.

Table B-1 PAD Emission Modes

Test #	Nominal PRF	On Time	Off Time	Duty Cycle
	(MHz)	**(ms)**	**(ms)**	**%**
1	1	na	0	100
2	1	1	1	50
3	1	4	4	50
4	1	10	10	50
5	1	2	6	25
6	1	8	4	66
7	5	na	0	100
8	5	1	1	50
9	5	4	4	50
10	5	10	10	50
11	5	2	6	25
12	5	8	4	66
13	10	na	0	100
14	10	1	1	50
15	10	4	4	50
16	10	10	10	50
17	10	2	6	25
18	10	8	4	66

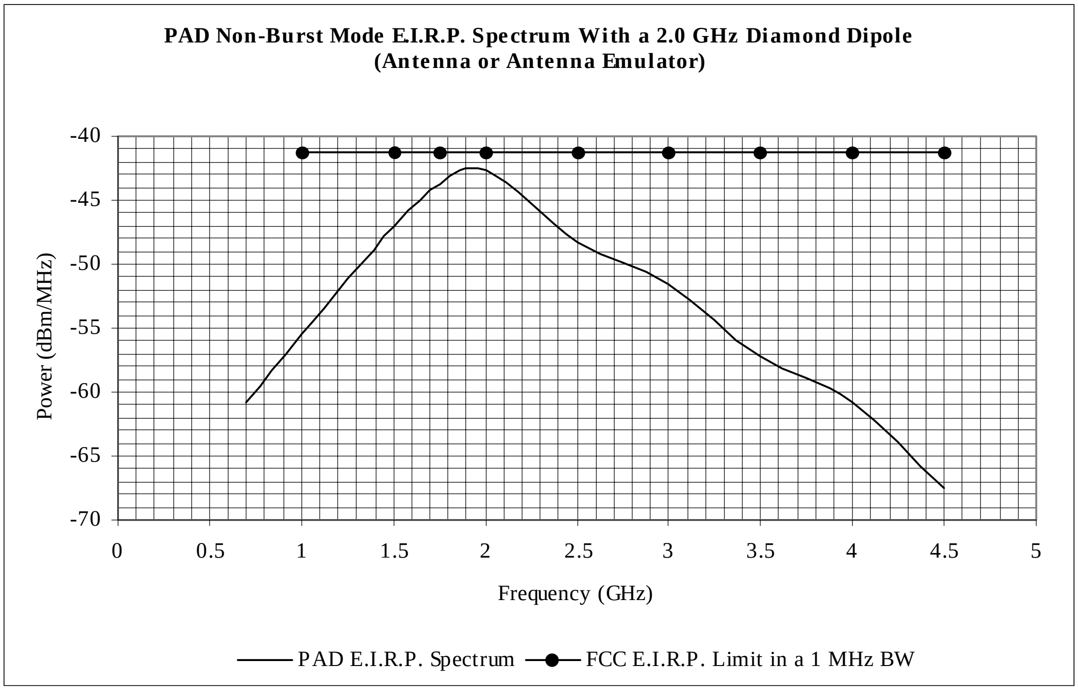


Figure B-1 PAD Non-Burst Mode E.I.R.P. Spectrum at 3 m

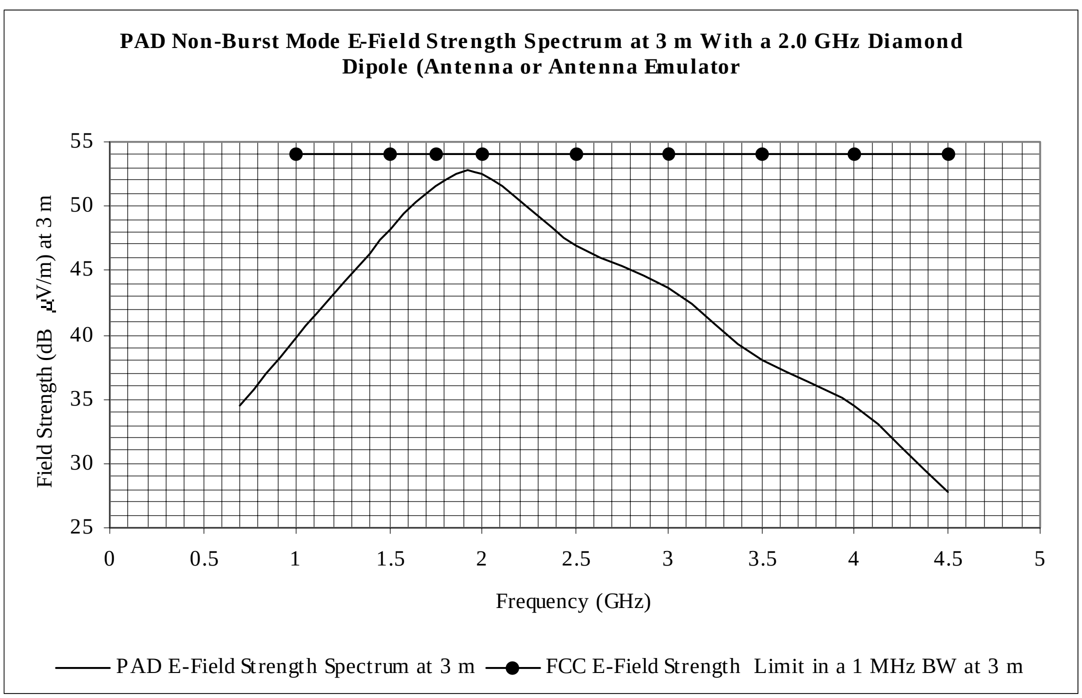


Figure B-2 PAD Non-Burst Mode E-Field Strength Spectrum at 3 m

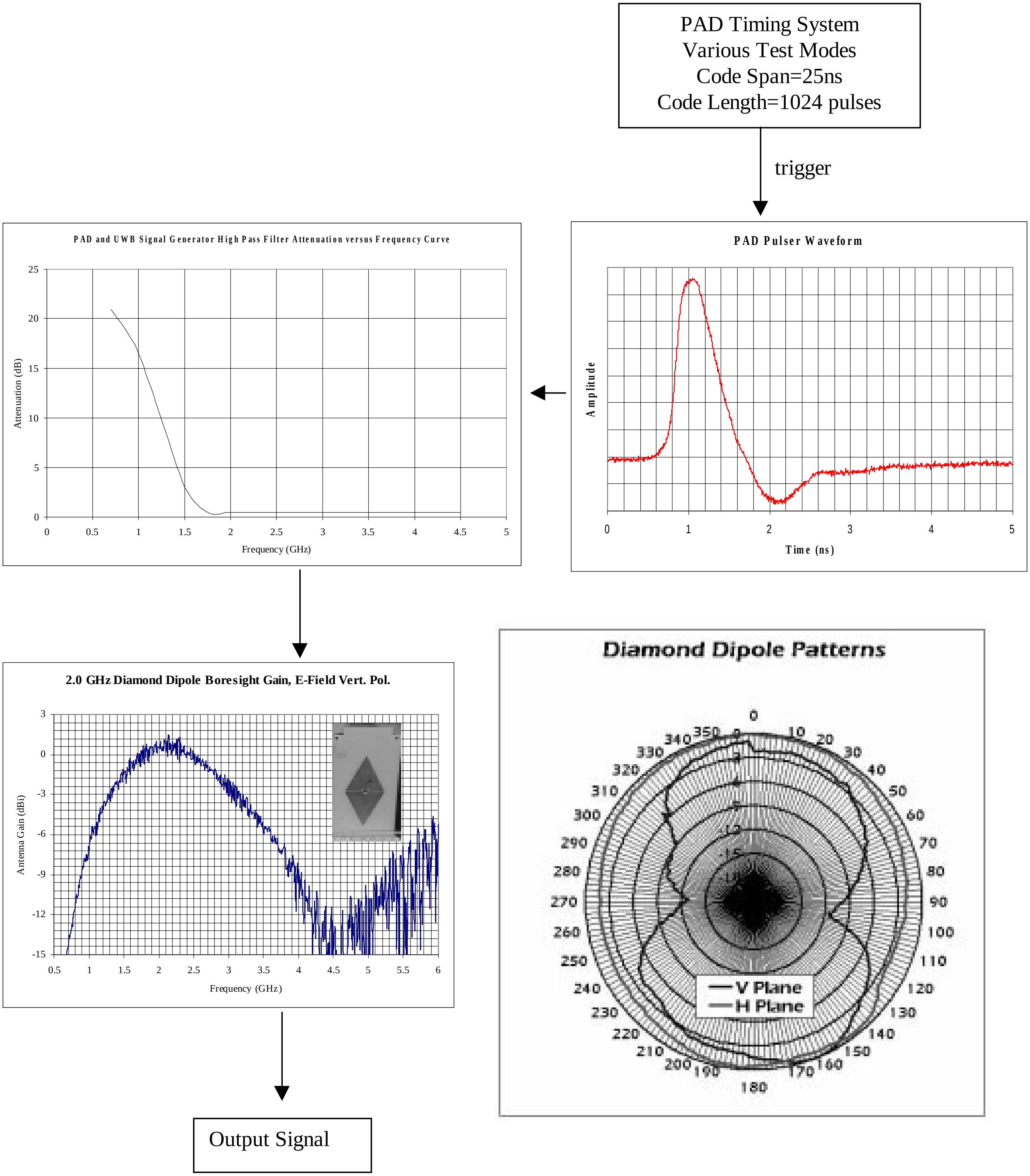


Figure B-3 PAD Transmitter Block Diagram

The conducted output spectrum of both a TDC PAD and a TDC Signal Generator were measured by the ARL:UT test team using a spectrum analyzer. These measurements have been placed on the web server in the directory UWB_Test_Data\ Documents \ Test Report Appendices \ Appendix_B \ Final_SPA_sweeps. The PAD_sweeps folder contains a characterization of all 18 operational modes that a PAD can generate, while the Noise_source_sweeps folder contains characterizations of the two operational modes available on that device. The spectrum analyzer sweeps used during conducted testing, given by Table 3-3, were used in the characterization of both devices. The Readme_first.doc file included with data explains the instrumentation setup used for these measurements.

B.2 TDC UWB Signal Generator Source

The UWB signal generators used for aggregate testing were developed by Time Domain Corporation. These devices were configured for only two operational modes in order to keep the device simple and cost effective. The output spectrum is consistent with many of the 2 GHz UWB systems developed by Time Domain.

The signal generator sources have the capability to operate in two modes. These modes are given in Table B-2 and correspond to modes 7 and 9 in Table B-1. These modes have a nominal PRF of 5 MHz, with a code span of 15 ns, and a code length of 8.4E6 pulses, and are time modulated. These modes were accessed by means of a physical toggle switch on the exterior of the devices.

Table B-2 Noise Generator Emission Modes

Test #	Nominal PRF	On Time	Off Time	Duty Cycle
	(MHz)	(ms)	(ms)	%
1	5	Na	0	100
2	5	4	4	50

B.2.1 TDC Signal Generator Output Spectrum

The output spectrums shown below in figures B-4 and B-5 represent the UWB signal generator non-burst mode E.I.R.P. and electric field strength. The UWB signal generator will have the capability to have higher than Part 15 Class B emissions, but can be externally attenuated to be within the FCC average field strength limit. The plots below are representative of the output spectrum (assuming appropriate external attenuation), however, the radiated spectrums were measured at an independent FCC certified testing laboratory and a report prepared by the laboratory is available in

Appendix D. The measured radiated spectrum may appear different due to multipath, free space loss frequency differences, site variations, etc.

Figure B-6 represents a conceptual block diagram of the generation of a Noise Generator impulse. The output spectrum is created by firing an impulse generator, which is then filtered by a high pass filter, then shaped by the antenna (for radiated testing). The firing of the impulse generator is triggered by a very precise timing system, in which the timing signal is based upon the specific code, nominal PRF, and burst timing. The high pass filter and antenna are used to perform spectrum shaping, and are an integral part of the system in either the conducted or radiated tests. The peak radiated power pattern of the antenna used with signal generator is also given.

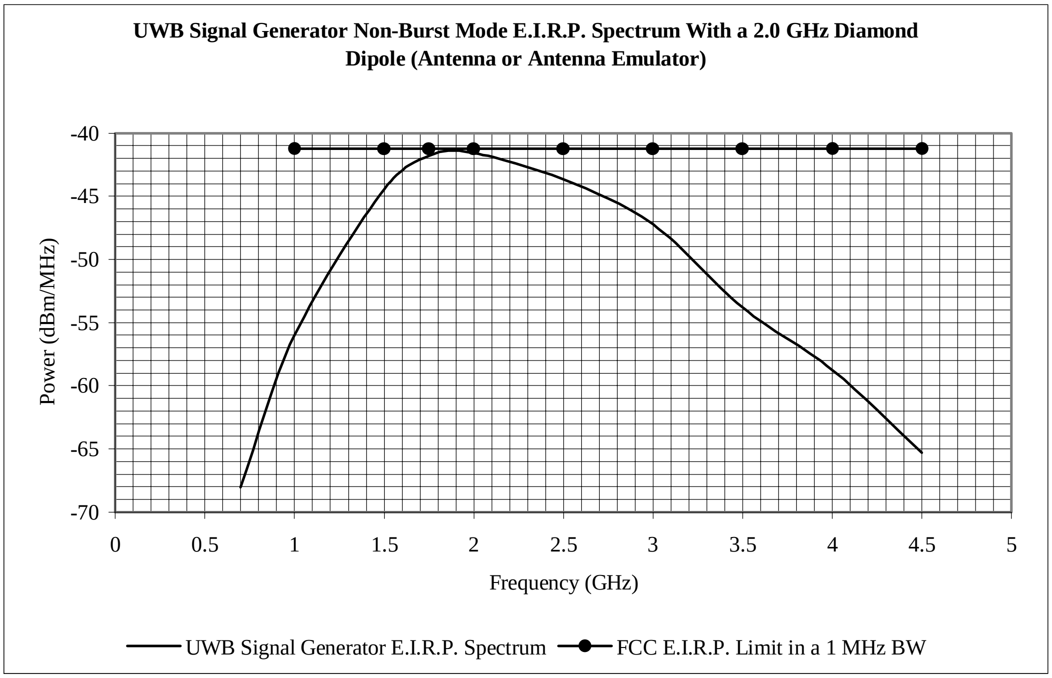


Figure B-4 UWB Signal Generator Non-Burst Mode E.I.R.P. Spectrum

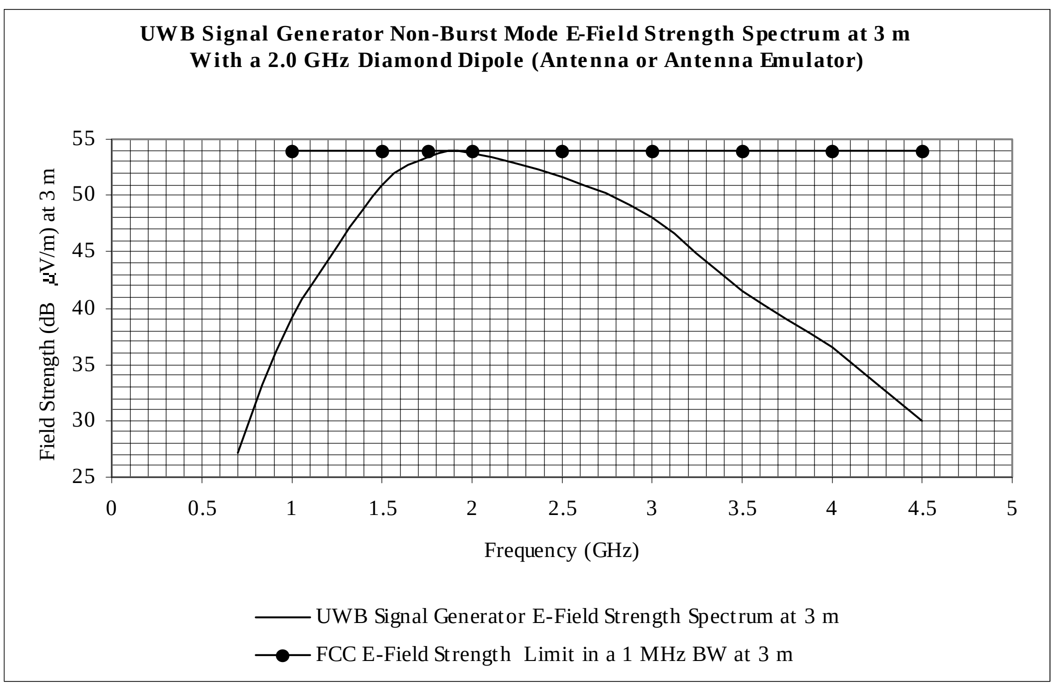


Figure B-5 UWB Signal Generator Non-Burst Mode E-Field Strength Spectrum

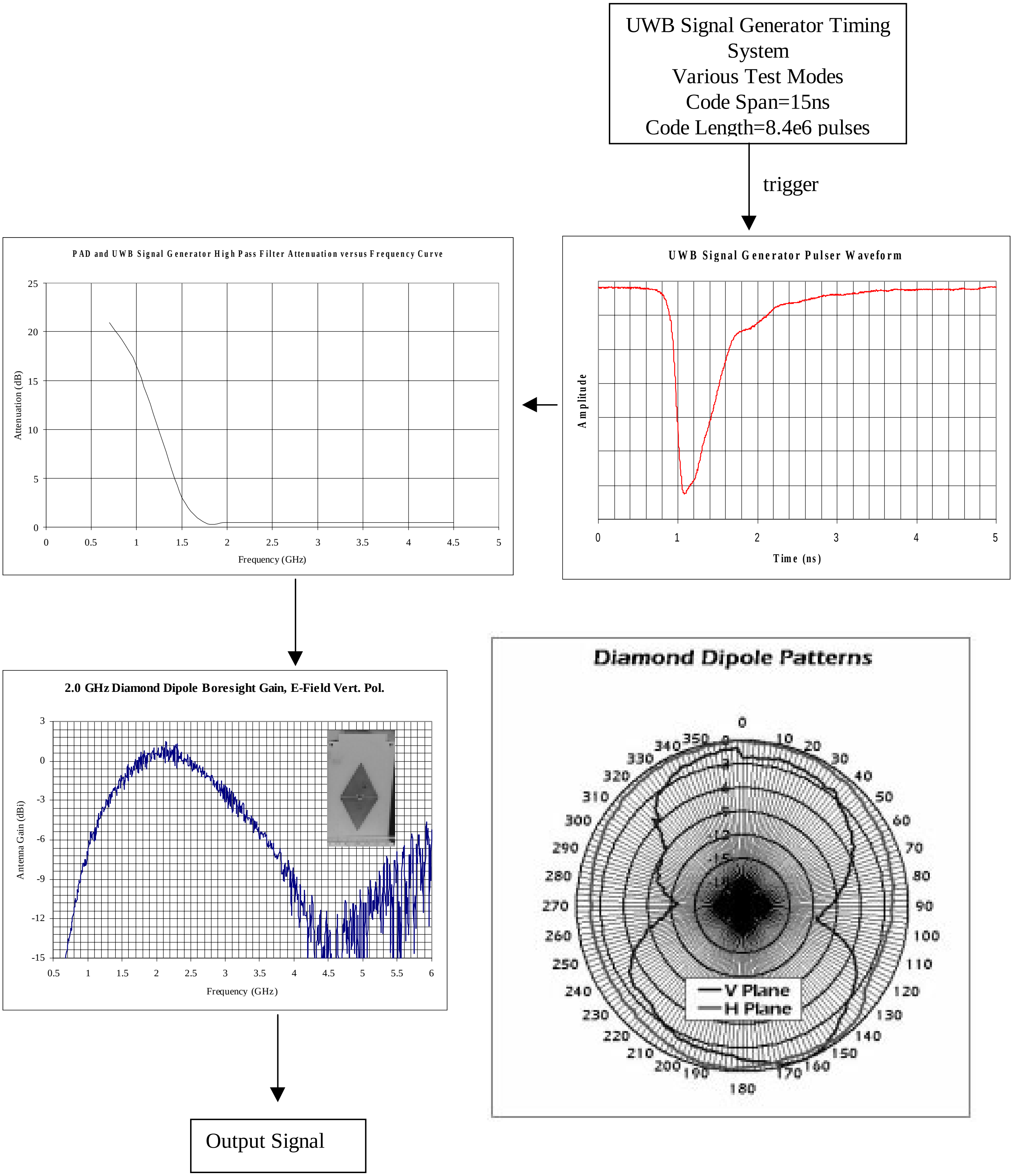


Figure B-6 Signal Generator Transmitter Block Diagram

B.3 Ground Penetrating Radar

Figures B-7 and B-8 give the measured output spectrum of the GPR devices evaluated in this test effort. This data was provided by the manufacturer; no spectral measurements on these devices were taken by the ARL:UT test team as part of this test effort.

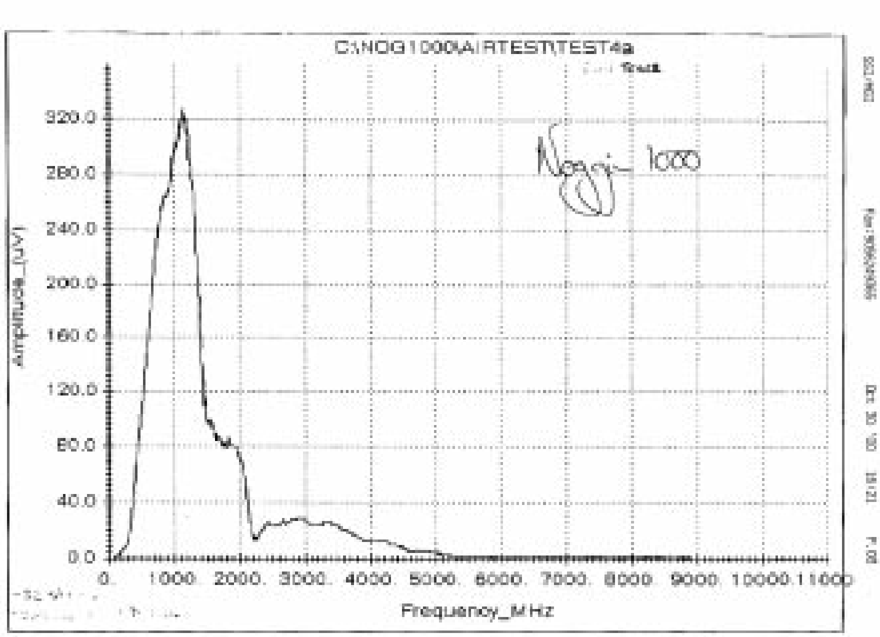


Figure B7: Output Spectrum of GPR Device 1, Sensors and Software Noggin 1000

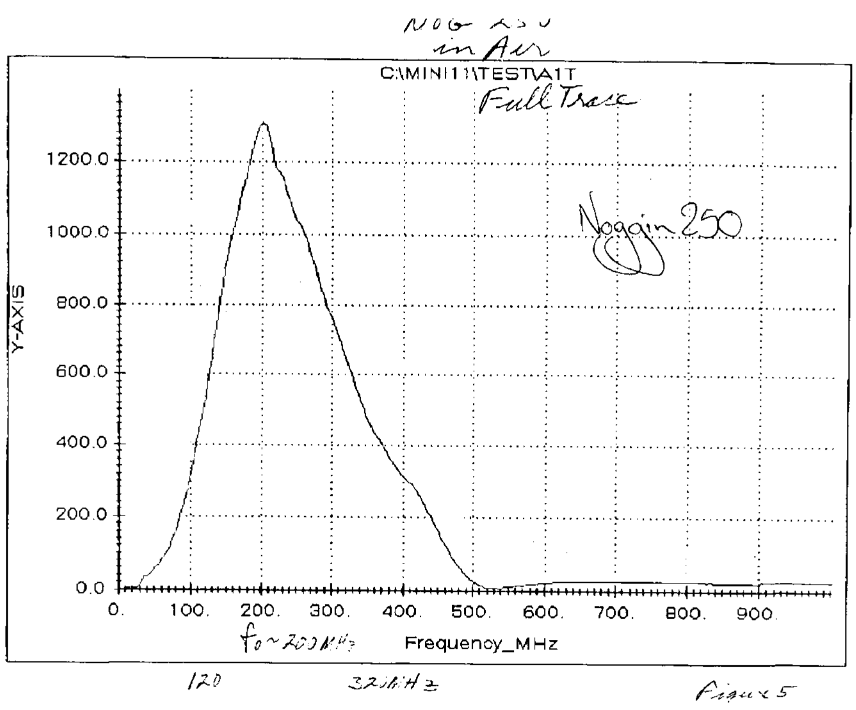


Figure B8: Output Spectrum of GPR Device 2, Sensors and Software Noggin 250

C. GPS Simulator and GPS Receiver Specifications

C.1 GPS Simulator Calibration Output Plots

Figures C – 1 through C – 4 present samples of the output spectrum of the GSS STR 4760 simulator used during testing. This data was provided by Time Domain Corporation.

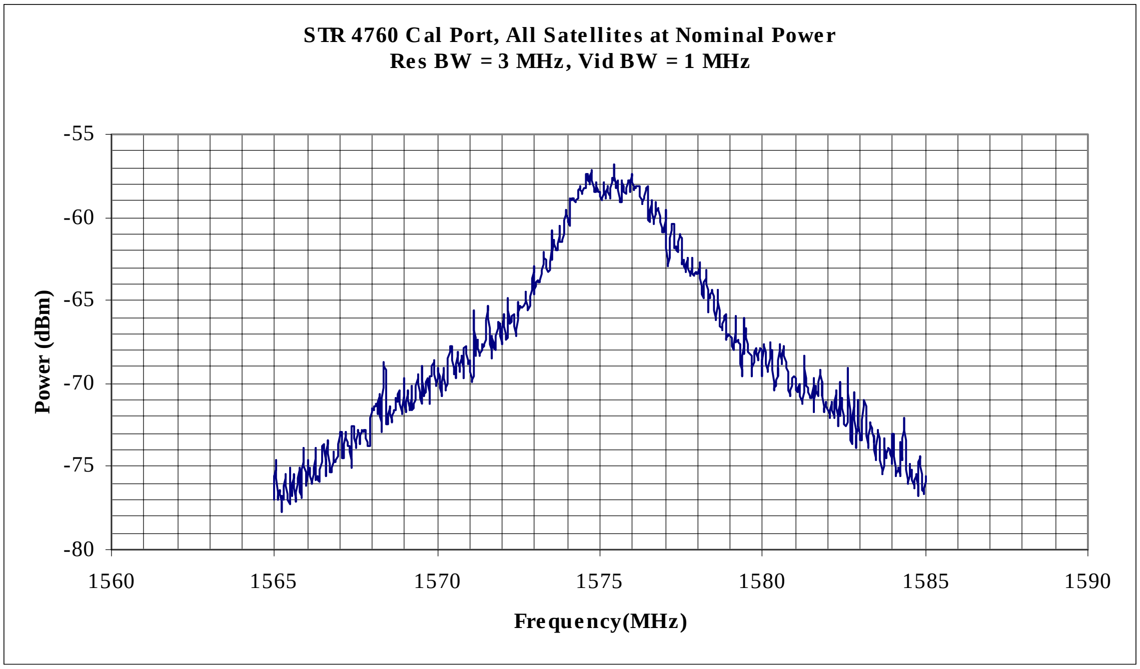


Figure C-1 GPS Simulator Calibration Output Example 1

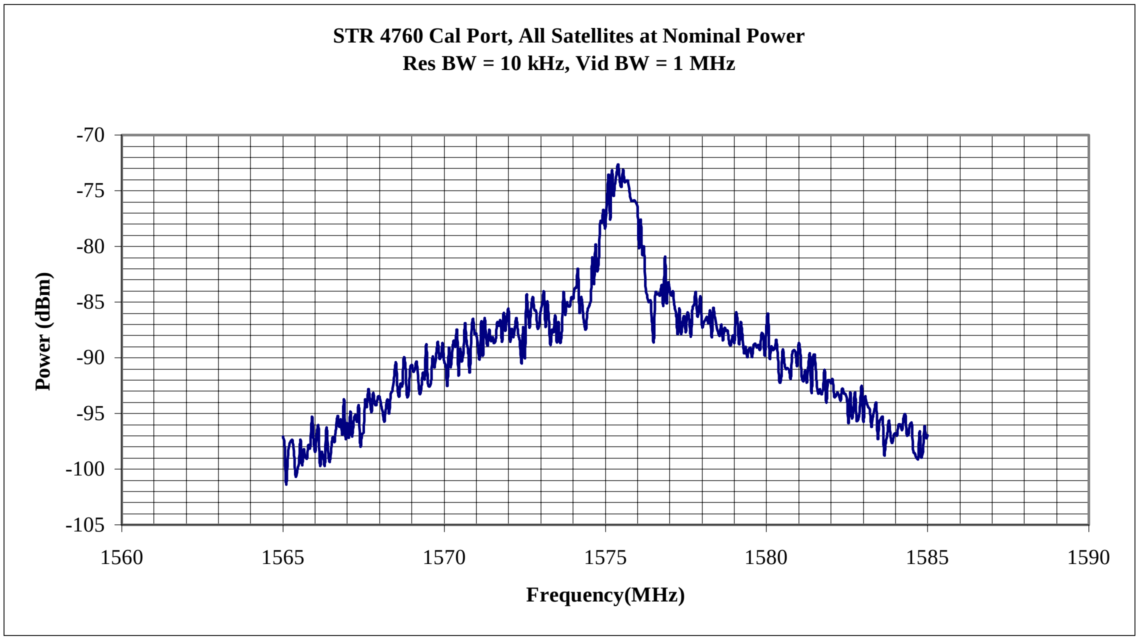


Figure C-2 GPS Simulator Calibration Output Example 2

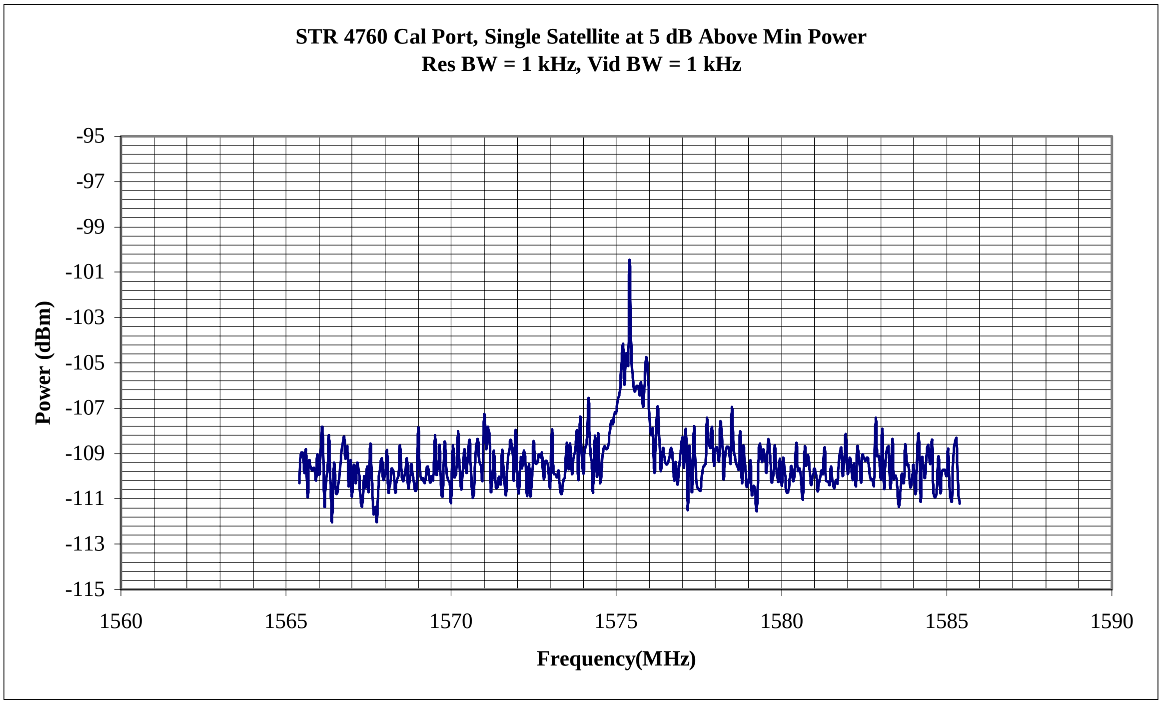


Figure C-3 GPS Simulator Calibration Output Example 3

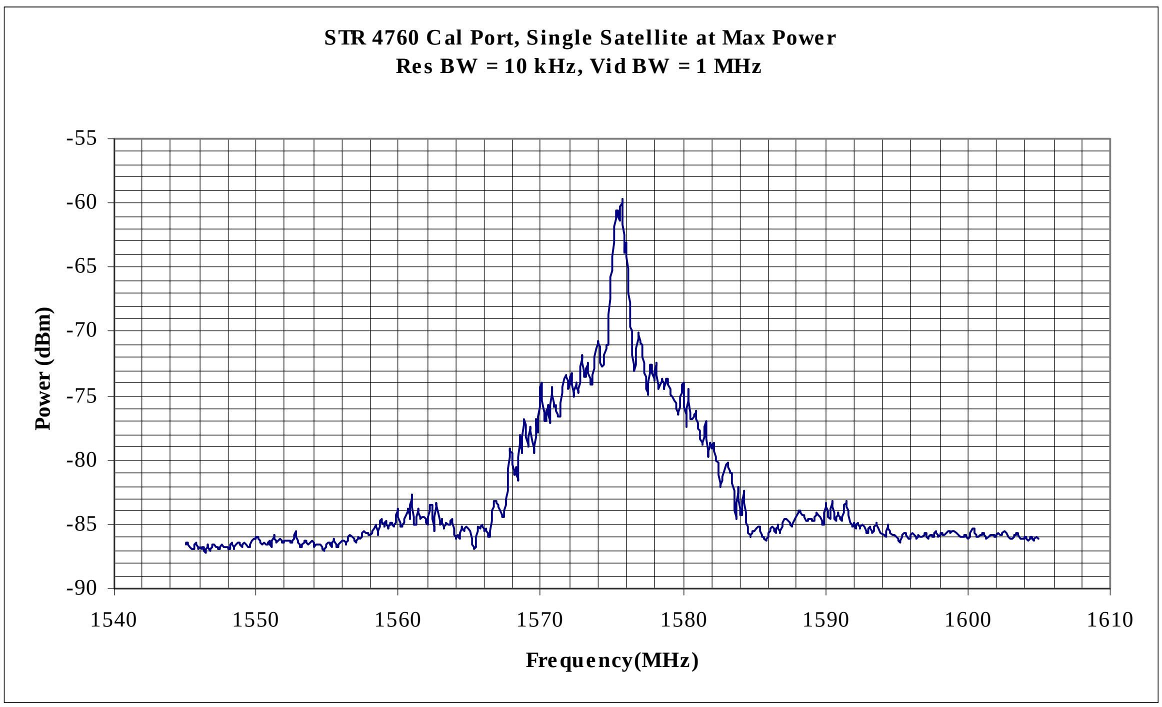


Figure C-4 GPS Simulator Calibration Output Example 4

C.2 Simulator Settings Used During Testing

Given below are the configurable GPS simulator settings used for all tests conducted with both the GSS STR4760 and the GSS STR2760. Most of these settings were accessible through the simulator control GUI on the simulator control DEC Alpha workstation. The individual menus are available through the Select / Edit Source Files button on the simulator control main window. There are five source file types to select.

File type: GPS_CONSTELLATION File Name: AUSTIN_WEEK_49.NAV_SAT;7

Contents:

Satellites Enable = 28

Obscuration Angle = 0 degrees

Obscuration Type = Earth Tangent

Satellite Selection Criterion = PDDP

Satellite Selection Combination Method = Seq. Replacements

Satellite Selection Sampling Interval = 6 s

Indicate Non-simulated Satellites Bad = Disabled

Diverge Ephemeris = Enabled

Diverge Clock = Enabled

Signal Strength = Modelled

L1 – L2 Delay = Modelled

GPS to UTC Time Difference – Delta tls = 13 sec.

Pseudorange Logging Rate = 1.0 s

Clock Noise = Disabled

Update Interval for Clock Noise = 60 (100 msec ticks)

Seed Value = 1

Surface Refractivity Index @ msl = ?

Tropospheric Delay = STANAG

TLM Parity Adjust = Current

Third Carrier Frequency Number = 0

G – Sensitivity coefficient (x-axis) = 0 s/s/g

G – Sensitivity coefficient (y-axis) = 0 s/s/g

G – Sensitivity coefficient (z-axis) = 0 s/s/g

File type: System Setup   File Name: DEF.SETUP;6

Contents:

Configuration = "GPS 4760#2069"

Antenna mappings	1	-----------------→	GPS 4760	**x** L1L2
	1:1		#2069	_ Pseudo-Y

NOTE: The significance of this description is not immediately apparent without viewing the menu window. This file was not modified for our use. ***x*** *denotes that the option was enabled, while* **_** *denotes that the option was not enabled.*

File type: Aircraft_personality   File Name: DEF.AIR_PER;2

Contents:

Linear velocity = 600 m/s

Linear accel'n = 50 m/s^2

Linear Jerk = 500 m/s^2

Max Stress Acc = 70 m/s^2

Max Stress Jerk = 500 m/s^2

Yaw Rate = 7 rad / s

Yaw Accel'n = 70 rad / s^2

Yaw Jerk = 700 rad / s^2

Elevation angle = 1.57 rad.

Pitch rate = 7 rad /s

Pitch accel'n = 70 rad/s^2

Pitch Jerk = 700 rad/s^2

Bank Angle = 3.14 rad

Roll Rate = 7 rad/s

Roll Accel'n = 70 rad/s^2

Roll Jerk = 700 rad/s^2

Aiding X offset = 0 m

Aiding Y offset = 0 m

Aiding Z offset = 0 m

Aiding Type = Strap down

File type: Static_Position   File Name: AUSTIN_REF_COM;2

Contents:

File Header = Holloman

Initial Latitude = North 30 degrees 23.045468817 minutes

Initial Longitude = West 97 degrees 43.6368709832 minutes

Height = 207.601948869 m

Heading = 0 degrees 0 minutes

File type: Antenna_Pattern   File Name: Defualt.Ant;1

Contents:

<No fields selected>

The scenario generated by the GPS simulator consists of the physical location, which is set through the Static_Position source file as shown above, and the time and date which is set through controls in the simulator control main window. The start date and time used for all tests was, July 26, 2000, 06:00:00 GPS time (in our case, 13 seconds ahead of UTC.)

C.3 GPS Receiver Messages Collected for each Receiver

This section lists the data messages collected from each receiver used in testing. The same set of messages were collected for every test run in this test effort. A short description of each message is given along with a description of the individual data fields that it provides.

C.3.1 NovAtel 3151 (RCVR1) & NovAtel Millennium (RCVR6):

The following messages were selected by the ARL:UT test team to be outputted by both of the Novatel receivers used in this test effort.

REPB (Raw Ephemeris)
PRN;
Subframe 1 of ephemeris data;
Subframe 2 of ephemeris data;
Subframe 3 of ephemeris data;

RGEC (Channel Range Measurements)
GPS week;
GPS second of week (SoW);
Satellites in View (SiV);
Receiver self-test status;
FOR (int i = 1; i <= SiV; i++){
PRN;
Pseudorange;
Pseudorange standard deviation;
Carrier phase;
Carrier Doppler frequency (instantaneous);
C/N_0;
Locktime;
Tracking state;}

SATB (Satellite Specific Data)
GPS week;
GPS SoW;
Solution status;
SiV;
FOR (int i = 1; i <= SiV; i++){
PRN;
Azimuth angle;
Elevation angle;

Residual;
Reject code;}

Reference: [4] *NovAtel Command Descriptions Manual,* p. 70 – 77

C.3.2 Ashtech Z-12 (RCVR2) & Z-Sensor (RCVR 4):

The following messages were selected by the ARL:UT test team to be outputted by both of the Ashtech receivers used in this test effort.

ALM (Almanac):
PRN;
Health;
Eccentricity;
Reference time for orbit;
Inclination angle at reference time;
Rate of right Asc.;
(Semi-major axis)^(0.5);
Lon of Asc. node;
Argument of perigee;
Mean anomaly at reference time;
af0;
af1;
Almanac week number;
GPS week;
GPS SoW;

MBN
PRN;
Elevation angle;
Azimuth angle;
Channel;
FOR (i = C/A Code Block Data, PL1 Code Data Block, PL2 Code Data Block){
S/N;
Full carrier phase;
Code xmit time;
Doppler measurement;
Range smoothing correction;
Range smoothing quality;}

PBN (Position Data):
GPS SoW;
Position X, Y, Z (ECEF);
Latitude;
Longitude;
Altitude;
Velocity X, Y, Z (ECEF);
Number of satellites used position calculation;
PDOP;
HDOP;
VDOP;
TDOP;

SNV (Ephemeris Data)

GPS week;
GPS SoW;
Tgd. group delay;
Iodc. clock data issue;
toc. second;
af2;
af1;
af0;
IODE Orbit data issue;
Mean anomaly correction;
Mean anomaly at reference time;
Eccentricity;
(Semi-major axis)^(0.5);
Reference time for orbit;
Cic. harmonic correction term;
Crc. harmonic correction term;
Cis. harmonic correction term;
Crs. harmonic correction term;
Cuc. harmonic correction term;
Cus. harmonic correction term;
Lon of Asc. node;
Argument of perigee;
Inclination angle at reference time;
Rate of inclination;
Accuracy;
Health;
Curve fit interval;
PRN;

Reference: [5] *Z Family Technical Reference*, p.138 –146

C.3.3 Garmin 150XL (RCVR3):

The output of the Garmin receiver was non-configurable, so the ARL:UT test team collected the entire message stream that the receiver outputted to its serial port by default. All data output from the Garmin was in ASCII format.

GPBOD (Bearing Origin to Destination):
Bearing (true);
Bearing (magnetic);

GPGGA (GPS Fix Data):
UTC time (HHMMSS);
Latitude;
Longitude;
GPS quality (no fix | GPS fix | DGPS fix);
Number of satellites in use;
HDOP;
Antenna altitude (MSL);
Geoidal separation differnce between WGS84 and MSL);

GPGSA (GPS DOP and Active Satellites):
Mode (no fix | 2D Fix | 3D fix);
SiV;
PDOP;
HDOP;
VDOP;

GPGSV (GPS Satellites in View):
SiV;
FOR (int i = 1; i <= SiV; i++){
PRN;
Elevation angle;
Azimuth angle;
S/N;}

GPRMC (GPS and Transit Specific):
UTC[1] time (HHMMSS);
Position valid (T | F);
Latitude;
Longitude;
Speed over ground;
Course over ground;
Date;
Magnetic variation;

GPWPL (Waypoint Location):
Nothing useful here;

PGRME (Proprietary Garmin Altitude):

Estimated horizontal position error (HPE);
HPE measure;
Estimated vertical position error (VPE);
VPE measure;
Estimated position error (EPE);
EPE measure;

Reference: correspondence with Garmin via fax

C.3.4 Trimble 4700

In numerous correspondences with Trimble, the ARL:UT test team was unable to receive any support in terms of configuring the receiver to output selected messages, nor what information was contained in the binary data streamed through the receiver serial port by default. It is known, at the very least, that this binary data can be converted to RINEX format.

D. Test Equipment Calibration Criteria and Data

All calibration data provided by the manufacturer with the test instrumentation used in this test effort is located on ARL:UT UWB data server in the directory, UWB_Test_Data\ Documents \ Test Report Appendices \ Appendix D \ Scanned Calibration Docs .

Documentation of FCC compliance tests performed on Time Domain Inc. Pulson Application Devices, and signal generators as well as the part 15 certified devices at Professional Testing in Round Rock, Texas are located on the ARL:UT UWB data server in the directory, UWB_Test_Data\ Documents \ Test Report Appendices \ Appendix D \ .

The devices that were tested and the corresponding files that contain the compliance test report are as follows:

Table D-1 FCC Compliance Test Report Data Files

Device Tested	Report Filename
Time Domain Corporation PAD S/N 103	*EMI_FCC_Comp_PAD_103.pdf*
Time Domain Corporation PAD S/N 123	*EMI_FCC_Comp_PAD_123.pdf*
Time Domain Corporation Signal Generator S/N 004	*EMI_FCC_Comp_UWBEmitter1_004.pdf*
Time Domain Corporation Signal Generator S/N 012	*EMI_FCC_Comp_UWBEmitter2_012.pdf*
Part 15 Certified device: Gateway GP7 – 450 desktop computer	*EMI_FCC_Comp_PC_GP7450.pdf*
Part 15 Certified device: Motorola Radius SP10 walkie – talkie	*EMI_FCC_Comp_MotorolaRadSP10.pdf*
Time Domain Corporation Signal Generator w/ plastic cover – as used in aggregate testing	*EMI_FCC_Comp_UWBNoiseGen.pdf*

E. Test Procedure Documentation and Log Data

Scanned copies of all log books used during testing are located on ARL:UT UWB data web server in the directory:

UWB_Test_Data\ Documents \ Test Report Appendices \ Appendix E \ Scanned Log Books

There were three log books used throughout testing. These log books, and the files that they are stored in are,

Conducted Testing, phase 1	*ConductedLogBk1_**
Conducted Testing, phase 2	*ConductedLogBk2_**
Radiated / Aggregate Testing	*RadiatedLogBk_**

where _* denotes that the log books have been broken up into a number of *.PDF files by page numbers.

All written test procedures used during this test effort have been place on ARL:UT UWB data web server in the directory:

UWB_Test_Data\ Documents \ Test Report Appendices \ Appendix E \ Test_Procedures

The description of each document is as follows:

Table E-1 Test Procedure Data Files

File Name	Description of File
Holloman_test_procedure3.doc	Test procedure for conducted, ranging accuracy tests
Holloman_test_procedure3_AP.doc	Test procedure for conducted, acquisition performance tests
Radiated_test_procedure.doc	Test procedure for radiated single device tests
Check_Continuity_procedure.doc	Test procedure for verification of ranging accuracy test data

F. Photos

Some digital photographs are provided in this section to show the test site at ARL:UT used for both radiated and aggregate testing, and to provide more detail about how the tests were conducted.

Figure F-1. Radiated / Aggregate Test Site.

All radiated and aggregate tests were performed in an open field behind ARL. The orange fencing denotes the outer limits of test site. The structure to the left housed all of all of the test equipment including the control computer, the GPS receiver, and the spectrum analyzer, and provided a covered enclosure from which the test operator could run tests.

Figure F-2: Time Domain Corporation PAD UWB device

This picture shows how the PAD was configured for radiated testing. The black box sitting on the plastic crate is the UWB generator, while the black pole in back is simply a support mast for the antenna (on the green PCB.) An SMA cable in back connects the UWB generator to the antenna.

Figure F-3: Single PAD UWB Device Radiated Test at 4 Meters

This picture shows how a normal single PAD device radiated test was conducted. The PAD was placed on varying numbers of plastic crates in order to achieve the proper angle between the PAD and GPS antennas (between 5 and 10 degrees).

Figure F-4: Single PAD UWB Device Radiated Test at 2 Meters

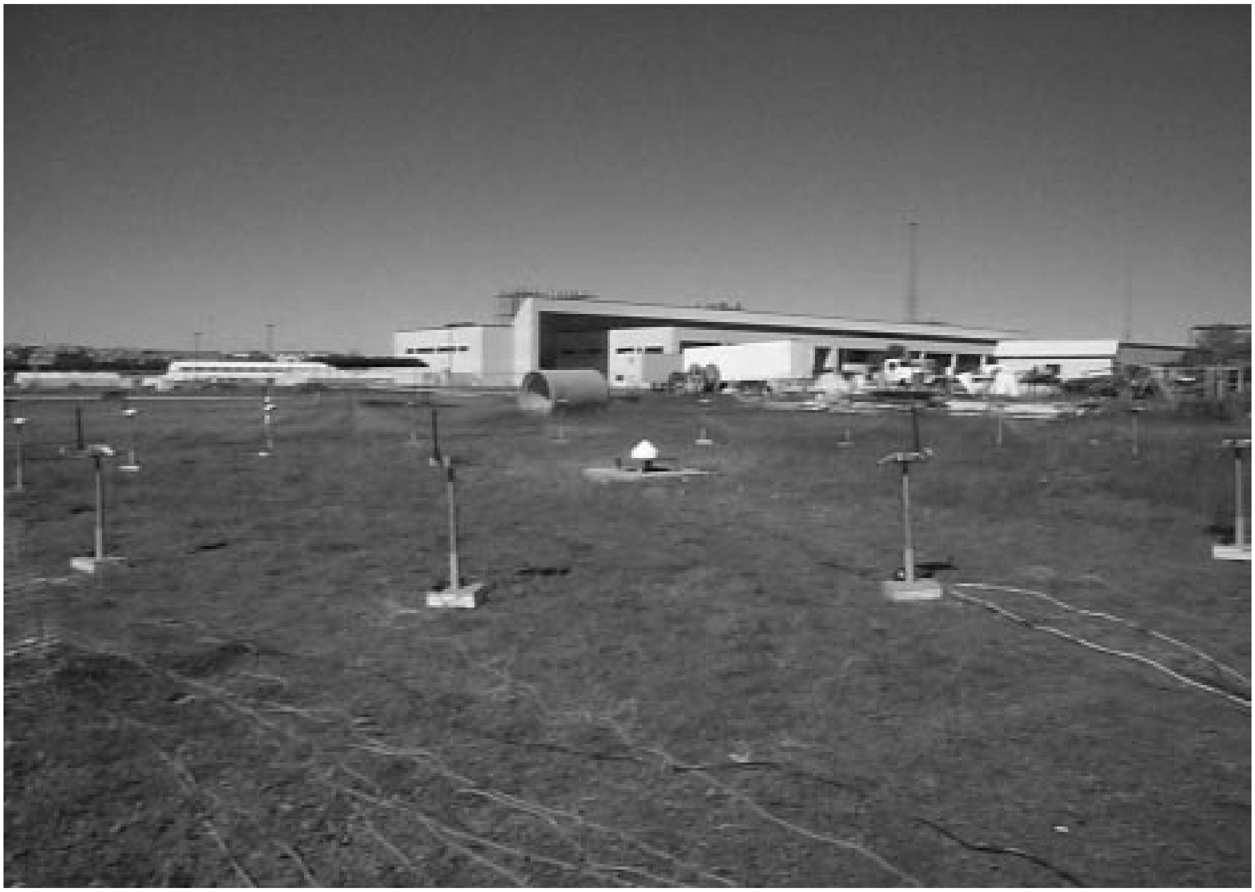


Figure F-5: Aggregation Test at 8 Meters

This picture shows how the Time Domain UWB signal generators were arrayed around the GPS antenna during an aggregation test. Each signal generator was connected to an antenna identical to that used in the single device radiated testing. The devices were then placed on height – adjustable stands to achieve the same height at each distance as was used in single device tests.

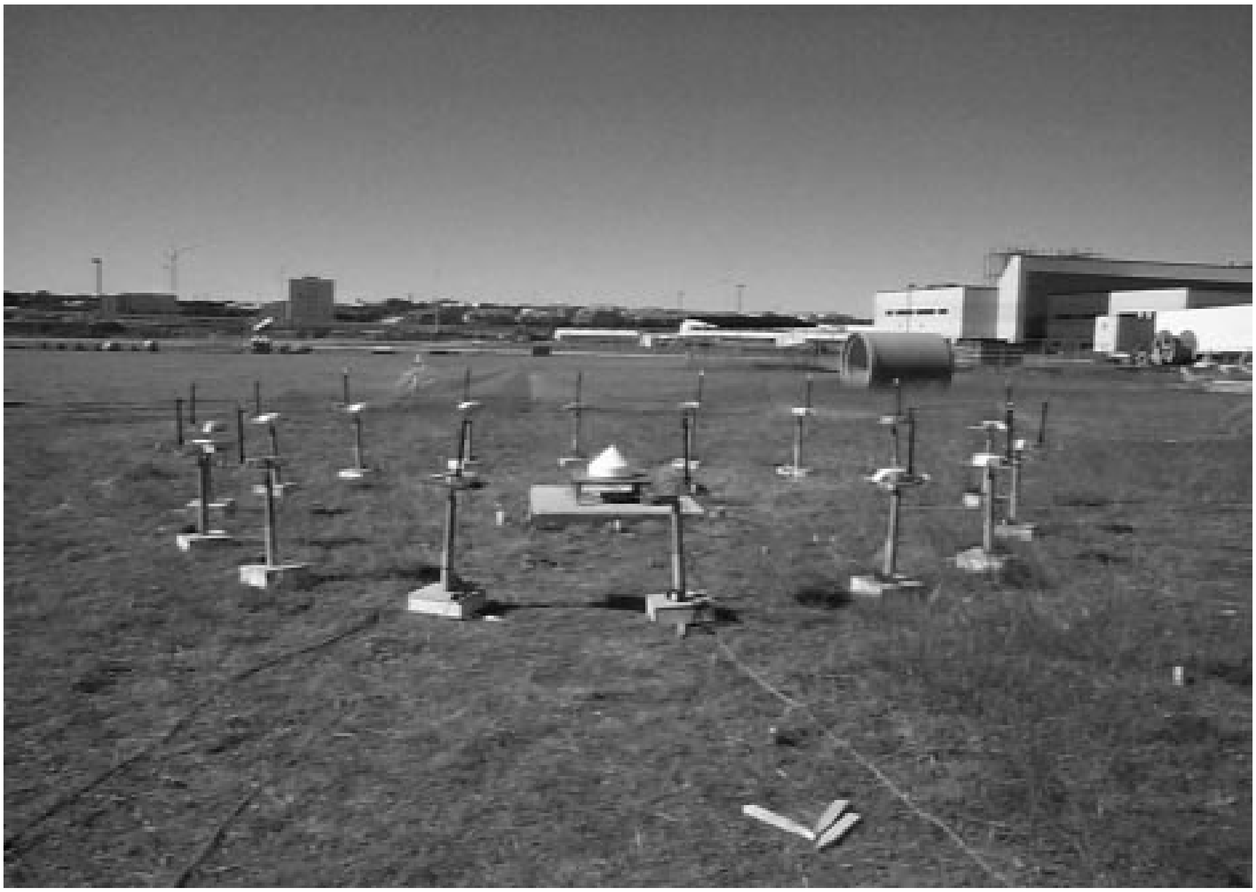


Figure F-6: Aggregation Test at 3 Meters

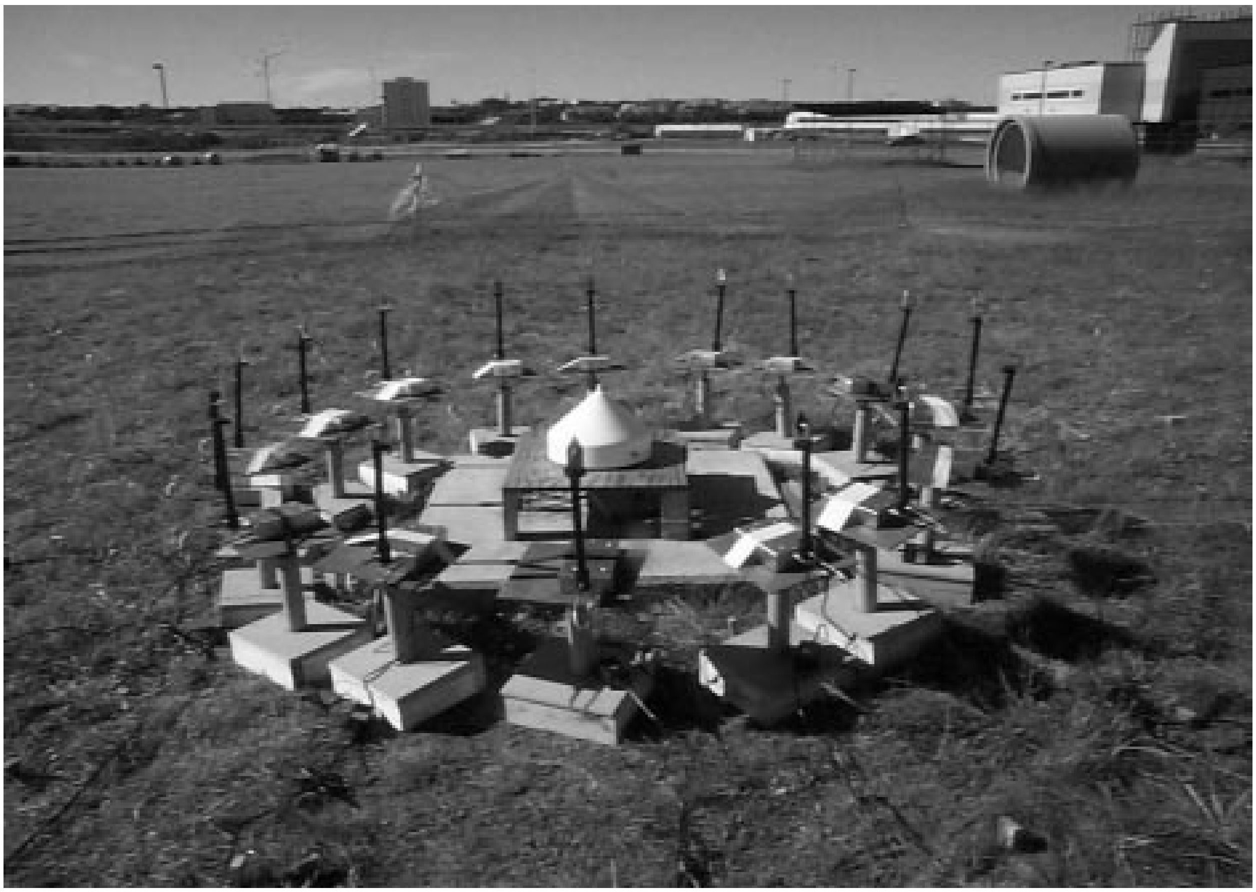


Figure F-7: Aggregation Test at 1 Meter

G. List of Parties providing comments on Test Plan

Name	Organization
William K. Kaneshiro, Lt Col, USAF, Chief, GPS Systems Integration and Engineering, NAVSTAR GPS Joint Program Office	The Joint Program Office
Steven Lazar, Clyde Edgar, Kristine Maine, Mark Simpson, Robert Wong, Srini Raghavan	The Aerospace Corporation
Dr. Per Enge, Ming Luo	Stanford University
Paul Withington, Rachel Reinhart, William Beeler	Time Domain Corporation
Thomas Stansell	Stansell Consulting
Alan Shertz, Alan Mcendoo	Geophysical Survey Systems Inc. (GSSI)
RTCA SC-159 WG-6 Discussion	Radio Technical Council for Aeronautics
Art Feinberg	Aviation Management Associates
John Reed, Gregory Czumak	Federal Communications Commission (FCC)
Kristen VanHoon	Simon Strategies
David Hilliard	Wiley, Rein and Fielding
Bill Petruzel	Federal Aviation Administration (FAA)
Dan Elwell	American Airlines
Paul Roosa	National Telecommunications and Information Administration (NTIA)
Gary Church	Aviation Managements Associates
Phil Inglis	TRP

Appendices

H. ARL Test Team Members

Name	Function
Mike Cardoza	Division Head, Advanced Systems Division Principal Investigator
Douglas Cummings	Project Manager/Engineer – RF Systems
Shane Shepherd	Project Manager/Engineer – GPS Systems
Leonard Shinn	Engineer – Electrical Systems
Aaron Kerkhoff	Engineer – RF Testing and Analysis
Mark Wolf	Engineer – RF Testing
Brian Gathright	Engineer – GPS Analysis
Mary Burke	Engineer – RF Testing
Jack Kayser	Engineer – RF Testing