Follow-on Assessment of LightSquared Ancillary Terrestrial Component Effects on GPS Receivers

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6 January 2012

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EXECUTIVE SUMMARY

The National Executive Committee (EXCOM) for Space-Based Positioning, Navigation, and Timing (PNT) tasked the National Space-Based PNT Systems Engineering Forum (NPEF) to conduct an assessment of the effects of LightSquared's planned deployment of terrestrial broadband systems on GPS receivers.[1] In accordance with the stated task, the NPEF focused on receivers supporting applications categorized as "General Location/Navigation" and on the first phase of LightSquared's deployment, which uses a single 10 MHz portion of spectrum (1526 – 1536 MHz designated as '10L') for Ancillary Terrestrial Component (ATC) transmissions. "Cellular" devices were tested by the National Telecommunications and Information Administration (NTIA) and "Certified Aviation Receivers " were analyzed by the Federal Aviation Administration (FAA). These results will be published in a separate report. Other categories of receivers were tested, and LightSquared handset transmissions in the band above GPS L1 from 1627.5 – 1656.7 MHz were simulated as permitted by the tasking. No further testing of the 10 MHz signal in the upper band (1545.2 – 1555.2 MHz designated as '10H') was conducted. Results documented in NPEF Report[2], Technical Working Group (TWG) Report[3] and the Radio Technical Commission for Aeronautics (RTCA) report[4] demonstrate that operations in the '10H' band will significantly degrade or deny GPS for all categories of devices. No proposed mitigation filters or devices were available for this test activity.

Laboratory testing was conducted at the Space and Naval Warfare Systems Command Pacific in San Diego, CA from 4 October 2011 through 14 October 2011 as a test risk reduction activity. Laboratory testing verified the hardware configuration, software compatibility and testing procedures prior to anechoic chamber testing. Anechoic chamber testing was conducted at U.S. Army Research Laboratory (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF) at White Sands Missile Range, NM from 31 Oct 2011 thru 3 November 2011, under tightly calibrated and defined RF conditions. LightSquared provided their planned antenna, filters, and signal definitions to ensure an accurate simulation of the proposed LightSquared Long Term Evolution (LTE) ATC and handset signals.

Data analysis used NTIA provided criteria for harmful interference, a maximum-power irregular terrain propagation model, and 62 dBm effective isotropically-radiated power (EIRP) as directed in the EXCOM task. Testing showed that most General Navigation devices were affected by the LightSquared '10L' signal. A significant percentage of general navigation devices (75%) experienced degradation in receiver carrier to noise density ratio (C/N_o) of 1 dB (i.e. 25% reduction of C/N_o) or greater at an equivalent distance of greater than 100 meters from the LightSquared simulated tower. Although not part of the NPEF task, lab and chamber test results

[1] EXCOM Tasking letter to the NPEF, 12 October 2011
[2] *Assessment of LightSquared Terrestrial Broadband System Effects on GPS Receivers and GPS-dependent Applications*, NPEF, 1 Jun 2011
[3] *The Technical Working Group Final Report into LightSquared Interference with GPS*, 29 Jun 2011
[4] DO-327 *Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations*, RTCA, 3 Jun 2011

continued to show significant degradation to high precision and timing user equipment. A significant percentage of these devices (83%) experienced degradation in receiver C/N_o of 1 dB or greater at an equivalent distance of greater than 100 meters from the LightSquared simulated tower. Worst-case effects at maximum interference signal power of -15 dBm varied for each device, ranging from no significant effect to complete loss of GPS tracking. The Office of the Secretary of Defense, Chief Information Officer tasked the Massachusetts Institute of Technology (MIT) Lincoln Laboratory to perform an independent peer-review and engineering assessment of the NPEF testing methods and findings. Their independent assessment concluded, "Findings support conclusion that Lower 10 MHz LightSquared signal results in harmful interference to majority of GPS devices tested.[5]"

Conclusion 1: *Based on test results, LightSquared's lower 10 MHz signal configuration causes harmful interference to the majority of general navigation GPS receivers tested.*

Test results demonstrated 69 of 92 General Navigation devices experienced harmful interference, defined as a 1 dB increase in the GPS receiver noise, with the lower 10 MHz (1526-1536 MHz) signal. No additional testing is required to determine that terrestrial high-power transmission in the MSS band impacts general navigation receivers.

Conclusion 2: *Immediate use of the Mobile Satellite Spectrum (MSS) for terrestrial service is not viable due to significant systems engineering and integration challenges.*

Current and previous tests have shown all categories of GPS receivers were impacted by high-power transmissions in the MSS band (1525-1559 MHz). The NPEF recommends denying the proposed LightSquared LTE signal plan deployment due to its corresponding GPS user impacts.

At this time, no proposed mitigations address interference from the '10H'signal. Although '10L' mitigations have been proposed, they have not been tested and verified to have no impact on GPS receiver performance and the Position, Velocity, and Timing (PVT) applications for which they are used. If and when mitigations are available, a long term transition and implementation plan would be necessary to protect existing GPS services and users. In addition, both the NPEF Report and TWG Report noted that retrofits or upgrades to military and Federal Aviation Administration (FAA) applications would take a minimum of 10-15 years to implement. This minimum timeframe takes into account the necessary steps to design, test, manufacture, install, calibrate, and certify all affected GPS applications requiring upgrade, retrofit, or replacement. The unbudgeted costs associated with this process will be commensurate with its duration and the total number of end-user applications affected.

Conclusion 3: *Handset transmissions have the potential to impact General Navigation GPS receivers.*

[5] *MIT Lincoln Labs Independent Review of LightSquared Ancillary Terrestrial Components Effects on GPS Signals,* 6 January 2012 (Note: This document is For Official Use Only (FOUO))

Test data show some GPS receivers were susceptible to receiving interference from LightSquared handset transmissions in the 1627.5 – 1656.7 MHz band. Handset test data collected are sufficient, but additional analysis is required. This analysis would include the characterization of actual LightSquared handsets and aggregate radio frequency interference (RFI) modeling of multiple handset users in a given region.

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1. OVERVIEW

1.1 INTRODUCTION

The LightSquared Ancillary Terrestrial Component (ATC) Follow-on Test was designed to assess the impacts to military and commercial Global Positioning System (GPS) User Equipment (UE), in the presence of LightSquared ATC deployment of a 10 MHz Long Term Evolution (LTE) Signal at 1526-1536 MHz and 62 dBm effective isotropically-radiated power (EIRP). This test also assessed the impact due to LightSquared handset transmissions at 1627.5-1656.7 MHz. These test conditions were selected pursuant to the Space-Based Positioning, Navigation and Timing (PNT) Executive Steering Group Tasking Statement to the National PNT Engineering Forum (NPEF),[6] dated 12 October 2011.

As the U.S. government lead for the Global Positioning System, the National Executive Committee for Space-Based Positioning, Navigation, and Timing (EXCOM) tasked the NPEF to conduct a follow-on assessment of the effects on GPS UE based upon LightSquared's planned deployment of ATC transmitters. The NPEF, co-chaired by DoD and DOT, assumed overall test planning, conduct, and reporting responsibilities. The Anechoic Chamber test plan[7] was coordinated with National Telecommunications and Information Administration (NTIA) and LightSquared prior to test execution in compliance with the tasker.

Originally LightSquared proposed to deploy capability in three phases (Phase 0, Phase 1, and Phase 2). Phase 0 was one 5 MHz bandwidth signal from 1550.2 – 1555.2 MHz (designated '5H'), Phase 1 was two 5 MHz bandwidth signals from 1526.3 – 1531.3 MHz and 1550.2-1555.2 MHz (designated 'Dual 5'), and Phase 2 was two 10 MHz bandwidth signals from 1526-1536 MHz and 1545.2 – 1555.2 MHz (designated 'Dual 10'). After results were released from both the NPEF and Technical Working Group (TWG) reports, LightSquared proposed a new initial deployment approach with only one 10 MHz signal from 1526-1536 MHz (designated '10L'). LightSquared has proposed deploying the upper band at a later date.

The LightSquared proposal to confine operations to the '10L' signal (1526-1536 MHz) of the Mobile-Satellite Services (MSS) frequency band was the focus of this testing. The LightSquared ATC Follow-on Test characterized the effects of the '10L' LightSquared signal on a variety of representative GPS receivers used by federal and commercial GPS-dependent users, systems, and networks. Additionally, prior testing did not fully address the potential impact on GPS receivers due to LightSquared handset transmissions at 1627.5-1656.7 MHz. LightSquared provided information that handset transmission will occur in two 10 MHz blocks with center frequencies of 1651.7 MHz and 1632.5 MHz. These signals were also simulated to test the impact on GPS receivers.

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[6] EXCOM Tasking letter to the NPEF, 12 October 2011

[7] *Test Plan for the LightSquared Ancillary Terrestrial Component Effects on GPS Receivers: Follow-on Test (Anechoic Chamber)*, NPEF, 23 Oct 2011

As a test risk reduction effort, laboratory testing was conducted at the Central Engineering Agency (CEA) laboratory at Space and Naval Warfare Systems Command, Pacific (SPAWAR-Pacific) in San Diego, CA from 4 Oct 2011 through 14 October 2011. The subsequent Anechoic Chamber testing was conducted at Army Research Laboratory Electromagnetic Vulnerability. Assessment Facility (EMVAF) at White Sands Missile Range (WSMR), NM from 31 Oct 2011 through 3 Nov 2011.

1.2 FOLLOW-ON TEST SCOPE

The test scope, as defined in the NPEF Tasking Statement,[8] was focused on receivers supporting applications that fit into the "General Location/Navigation" category as defined by the TWG report.[9] Further, the scope was also focused on only the first phase of LightSquared deployment (10L) with a maximum base station EIRP of 32 dBW (62 dBm) per sector. The follow-on test effort included participants from across the U.S. Federal government and commercial entities including LightSquared. Test participants are listed below:

- Department of Commerce
    - National Weather Service
    - National Oceanic Atmospheric Agency (NOAA) Coast Survey
    - NOAA National Center for Atmospheric Research (NCAR)
- Department of Interior - Bureau of Land Management (BLM)
- Department of Transportation
    - Federal Aviation Administration (FAA)
    - Federal Highway Administration (FHWA)
    - Federal Railroad Administration (FRA)
- Department of Defense
    - United States Navy – SPAWAR-Pacific
    - United States Navy – Naval Research Lab
    - United States Naval Observatory
    - United States Air Force – 746th Test Squadron
    - United States Army – Army Research Lab
    - National Geospatial-Intelligence Agency
- Department of Homeland Security - United States Coast Guard
- United States Department of Agriculture
- Department of State
- Commercial Participants
    - Broadcom
    - Garmin
    - Hemisphere GPS
    - John Deere
    - LightSquared
    - OnStar
    - Trimble

[8] EXCOM Tasking letter to the NPEF, 12 October 2011
[9] *The Technical Working Group Final Report into LightSquared Interference with GPS*, 29 Jun 2011

Due to the time constraints for test completion, the NPEF did not limit federal or commercial participants requested receivers from participating in the testing. In addition, as allowed by the tasking statement, other receivers were tested (at each participating organization's discretion) as well as the effect of simulated LightSquared handsets. The follow-on cell phone testing was conducted by NTIA and LightSquared in a separate event.

1.3 INDEPENDENT TEST ASSESSMENT

Idaho National Labs (INL) was identified and tasked to provide an independent assessment of the test plan, setup and execution. Specific taskings included:

- Review the testing requirements established in the NPEF Tasking Statement and compare them to the test plan.
- Review the test set-up and observe the test execution and data collection. Additionally INL should ensure that the test plan and test execution accomplish the objectives and meet the requirements established by the tasking letters.

Overall the INL team had no major discrepancies to report.[10] Testing was conducted as planned.

The Office of the Secretary of Defense, Chief Information Officer tasked the Massachusetts Institute of Technology (MIT) Lincoln Laboratory to perform an independent peer-review and engineering assessment of the NPEF testing methods and findings. Their independent assessment concluded, "Findings support conclusion that Lower 10 MHz LightSquared signal results in harmful interference to majority of GPS devices tested.[11]"

2. SPAWAR LABORATORY TEST

Laboratory testing was an essential step in designing and executing the Anechoic Chamber test plan. Laboratory testing provided the opportunity to plan and execute:

- Test events
- Timing of test events
- Optimization of test sequences
- Synchronization of test equipment

The test team made adjustments to the lab test configuration to ensure optimum test sequences during the chamber testing. Lessons learned ensured all GPS scenario times moved forward in time (instead of resetting the GPS time each day). These laboratory activities greatly improved the efficiency, value and execution of Anechoic Chamber testing.

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[10] *Idaho National Laboratory Independent Assessment of the Follow-on Test of LightSquared Ancillary Terrestrial Component Effects on GPS Recievers*, 5 December 2011 (Note: This document is For Official Use Only (FOUO))
[11] *MIT Lincoln Labs Independent Review of LightSquared Ancillary Terrestrial Components Effects on GPS Signals*, 6 January 2012 (Note: This document is For Official Use Only (FOUO))

2.1 SPAWAR FACILITY

SPAWAR Central Engineering Activity (CEA) Laboratory provided capable and experienced testing of GPS Military and Civilian User Equipment. The CEA facility included:

- Portable anechoic chambers
- Inertial rate tables
- Complete inertial measurements unit (IMU) modeling
- Complete inertial navigation systems (INS) modeling
- Portable environmental chambers
- Multiple GPS simulators (Interstate Electronics Corporation (IEC), Advanced Global Navigation Simulator (AGNS), NAVLabs, CAST)
- Multiple Cesium and Rubidium clocks
- Multiple test stations
- Multiple jammer configurations
- Mobile engineering all-inclusive test (MEAT) rack

The CEA laboratory is located at the Space and Naval Warfare System Center, Pacific in San Diego, CA. In addition to special testing (such as LightSquared), the CEA routinely supports GPS receiver testing for the GPS Directorate and US Navy.

2.2 LABORATORY TEST LIMITATIONS

Laboratory testing provided a complete characterization of a GPS receiver excluding the antenna system. Portable anechoic chambers provided only for a qualitative analysis of the GPS receiver with its antenna system. The laboratory shares the same test limitations as the Chamber (see Section 3.3). Additional laboratory testing limitations include:

- Lack of complete characterization of the GPS receivers antenna system using the LightSquared transmit antennas or equivalent
- LightSquared handset generation did not use LightSquared handset filters due to non-availability

2.3 LABORATORY TEST SET-UP

A block diagram of the SPAWAR laboratory test set-up is shown in Figure 1. During the laboratory test, the LightSquared signal was generated using commercially available equipment with LightSquared-provided filters. Agilent signal generators (Model N5182A with LTE software version 10) were used to generate the LTE signals. The signals were amplified using a 40 dB gain mini-circuits amplifier, then filtered through the LightSquared-provided filter. Figure 3 is a block diagram of the ATC base station signal simulation setup.

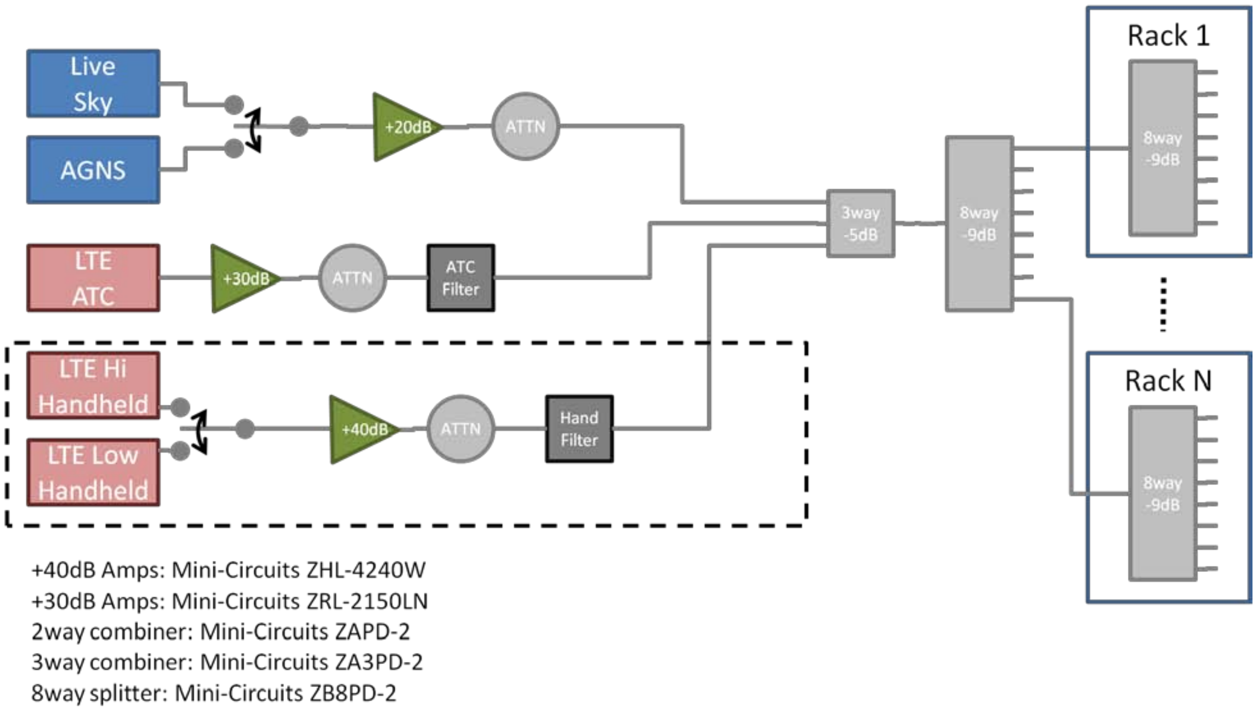

Figure 1 Laboratory Test Set-up

2.4 LABORATORY TEST EXECUTION

Thirty-four separate test events were executed in the laboratory. From these, the nine key anechoic chamber test events were developed. A summary of test events executed in the laboratory is found in Appendix B.1.

3. EMVAF ANECHOIC CHAMBER TEST

3.1 EMVAF FACILITY

The Army Research Laboratory (ARL) EMVAF, located at WSMR, houses an Anechoic Chamber measuring 110' x 70' x 40', allowing the testing of multiple GPS receivers and antennas simultaneously. This chamber housed all user equipment and antennas used during this test. External antennas and handheld UE were placed on a platform in the center of the chamber. The chamber also contained the LightSquared broadcast antennas (ATC and handset), placed far enough away from the UE antenna platform such that the UE antennas were in the far-field of the LightSquared antenna pattern. The GPS transmit antenna was built into the chamber, and was located near the ceiling in the center of the room. The LightSquared handset transmitter antenna was located near the ceiling and near the center of the room. The WSMR EMVAF Anechoic Chamber also included the AGNS and the LightSquared ATC Tower signal simulator and hardware (see Figure 2).

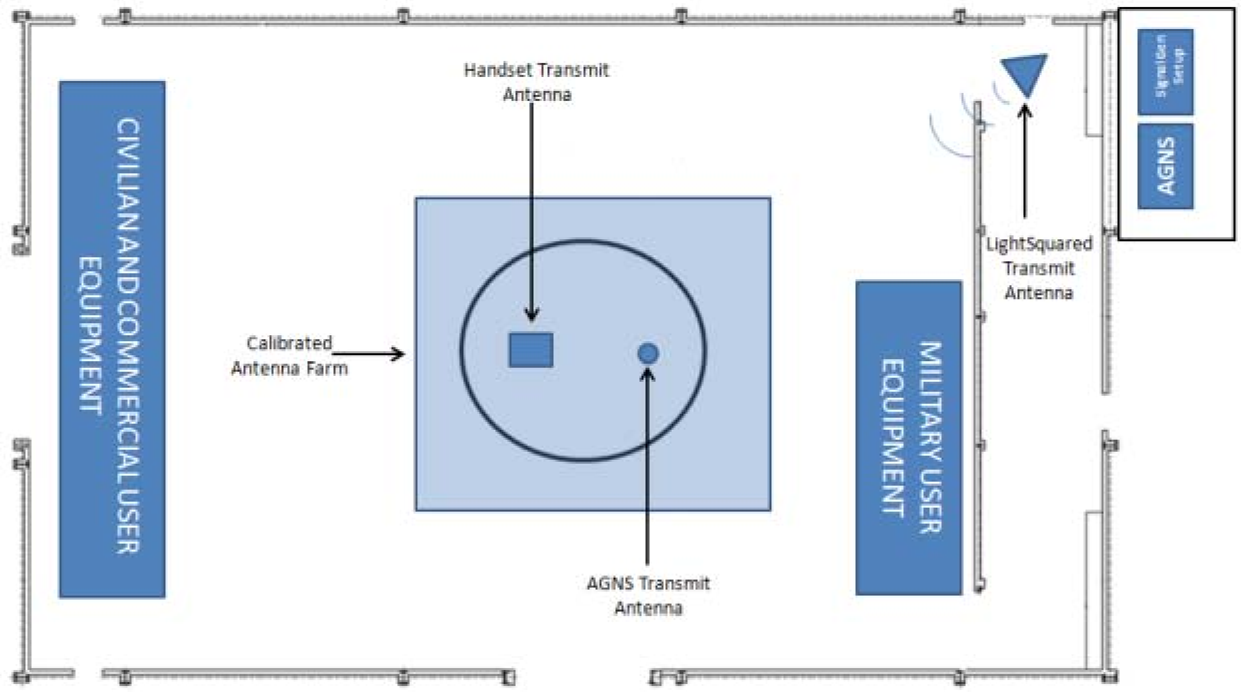

Figure 2 Basic Anechoic Chamber Layout

3.2 ANECHOIC CHAMBER TEST SETUP AND CALIBRATION

The test team meticulously setup and calibrated the simulators, antenna platform and test environment. Measurements were checked and rechecked several times. All signals were continuously monitored during testing to ensure accurate generated power levels. This section provides the simulation, setup and calibration details.

3.2.1 GPS Simulation

GPS Simulation was provided by the SPAWAR Advanced Global Navigation Simulator (AGNS). The AGNS is a research and development test tool that, as a subset of its capabilities, can be configured to simulate defined and future variations of the GPS satellite operations. The AGNS was configured to transmit in the chamber via a single antenna suspended from the ceiling. The AGNS simulator version used for the test was: SSC-SD – Advanced Global Navigation Simulator – AGNS Version 7.3.

In order to simulate a nominal 24-satellite constellation that meets the specification (IS-GPS-200) requirements, the team downloaded the latest 31 satellite almanac file covering the time period for the test week. The number of satellites was reduced to 24 by removing the satellites that did not occupy primary orbital slots. The resulting constellation is shown in Table 1 by Pseudorandom Noise (PRN) code and Space Vehicle (SV) type. Five AGNS simulations were generated, one for each day of the week. All simulations were 24 hours in length. All simulation start times were set to 0800 MST daily. The simulator was started each day within a few minutes of actual 0800 MST. The simulator transmitted continuously each day until all tests were completed. Table 2 shows the nominal signal power levels (as per IS-GPS-200 Rev E, Table 3-V) that were broadcast during the test for the weakest point on the calibrated grid.

Table 1 GPS Constellation Used in Chamber Test

SV Type	PRN
Block IIA	3, 4, 8, 9
Block IIR	2, 13, 14, 16, 18, 19, 20, 21, 22, 23, 28
Block IIRM	5, 7 ,12, 15, 17, 29, 31
Block IIF	1, 25

Table 2 Nominal GPS Signal Power Levels

	Block IIA/IIR Nominal Received Power		Block IIR-M/IIF Nominal Received Power	
Code	**L1 (dBW)**	**L2 (dBW)**	**L1 (dBW)**	**L2 (dBW)**
C/A	-158.5		-158.5	
L2C				-160
P(Y)	-161.5	-161.5	-161.5	-161.5
M			-158	-161

3.2.2 LTE Simulation

3.2.2.1 ATC Signal Simulation

During the chamber test, the LightSquared signal was generated using commercially available equipment with LightSquared-provided filters and antenna. Agilent signal generators (Model N5182A with LTE software version 10) were used to generate the LTE signals. In order to utilize both the +45 and -45 ports on the LightSquared transmit antenna, two strings of signal generation equipment were used. Agilent signal generators were configured to generate the 10 MHz Low (1526-1536 MHz) ATC signal. The signals were amplified using an Ophir 5063 HPA (200 W), then filtered through the LightSquared-provided filter. Figure 3 is a block diagram of the ATC base station signal simulation setup. A detailed description of the base station simulation is found in Appendix G, and detailed signal generator settings are found in Appendix H.

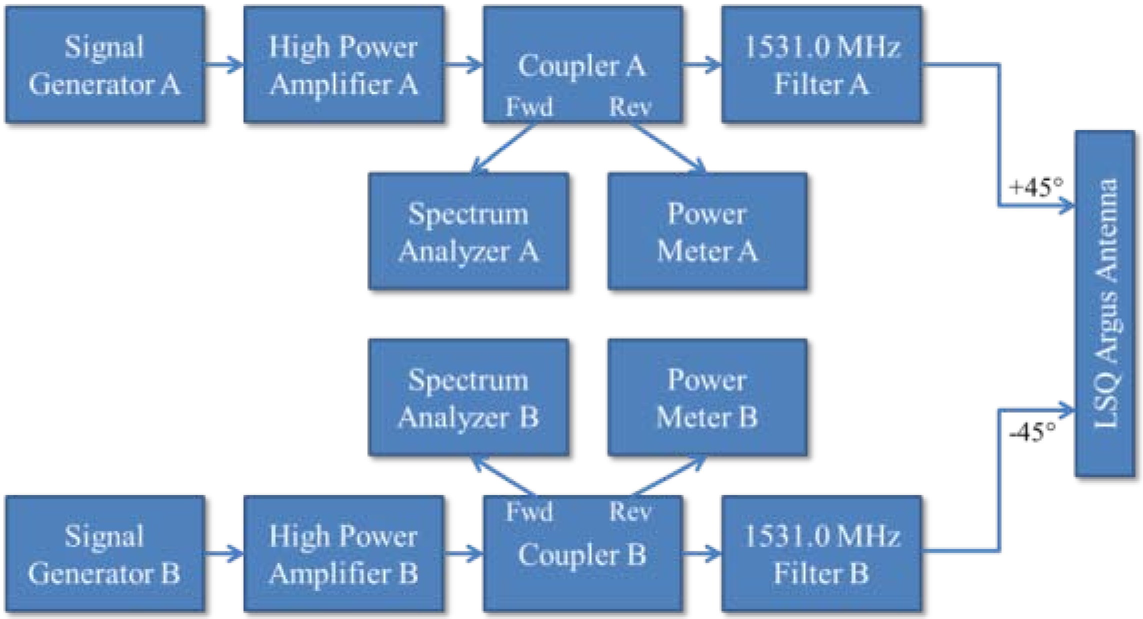

Figure 3 LightSquared Base Station RF Chains

3.2.2.2 Handset Signal Simulation

An Agilent signal generator (Model E4438C – handset LTE software version 10) was configured to generate the LightSquared handset LTE signals. LightSquared provided Agilent configuration parameters, as well as the handset filter. Once generated, the signal was amplified using an EMPOWER 2030 (100 W), filtered, then transmitted using a standard horn antenna mounted on the ceiling of the chamber. The handset signals have two 10 MHz bands with center frequencies of 1632.5 MHz and 1651.7 MHz. Figure 4 is a block diagram of the handset signal simulation setup. A detailed description of the handset signal simulation is found in Appendix G, and detailed signal generator settings are found in Appendix H.

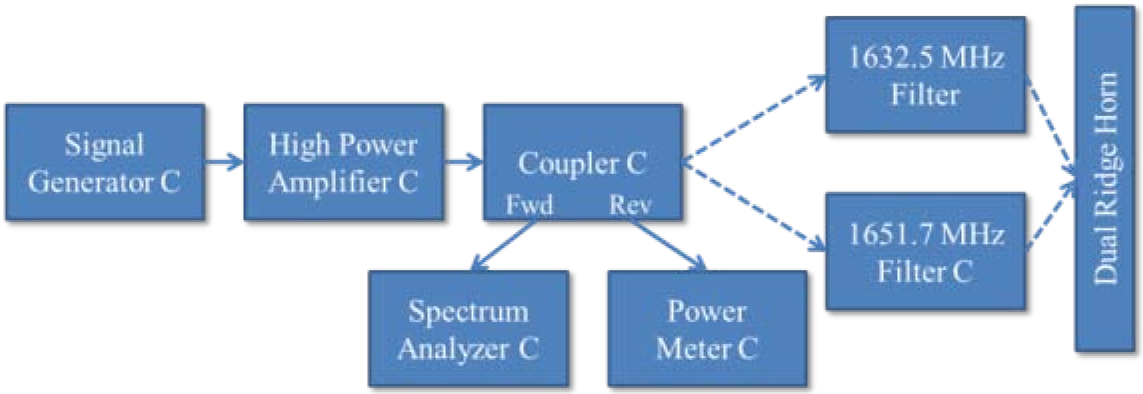

Figure 4 LightSquared Handset RF Chain

3.2.3 Physical Set-Up

In the Anechoic Chamber, military and commercial receivers were set up on opposite ends of the chamber to enable classified and unclassified data collection. All antennas were placed in the center of the chamber on a calibrated, raised platform with Radar Absorbing Material (RAM) between both sets of receivers and the antenna platform (Antenna Farm). Test participants, both federal and commercial, were responsible for setting up their own data recording equipment. Exact data on antenna's, low-noise amplifiers, cable lengths and receivers utilized for each test setup was recorded and documented by the government test team.

The LightSquared transmit antenna was placed on a mezzanine in the northwest corner of the chamber so it would transmit down to the antenna farm as shown in Figure 2. The GPS transmit antenna was located in the center of the room, hanging from the ceiling. The LightSquared handset antenna was also hanging from the ceiling, sufficiently offset from the GPS antenna. The UE antennas were placed on the antenna platform such that no antenna shielded another from either the GPS or LightSquared signal. Figure 5 is a diagram of the antenna farm and Figure 6 is a photograph of the antenna farm. In the case of handheld units with internal antennas, the entire unit was placed on the antenna platform.

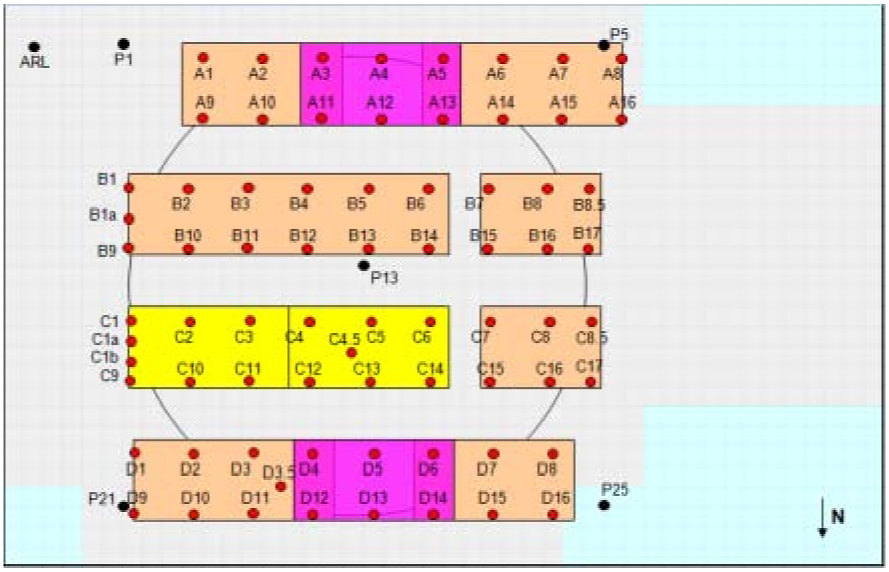

Figure 5 Diagram of Antenna Farm

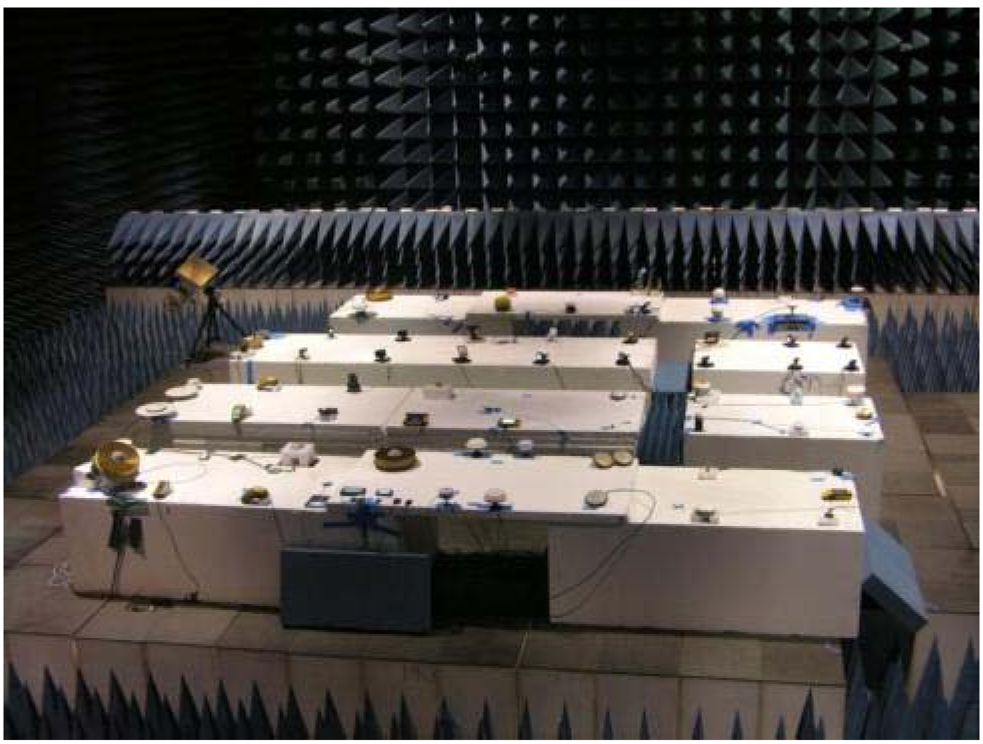

Figure 6 Antenna Farm as Populated for Wave 2 of Testing

3.2.4 Calibration and Chamber Mapping

The purpose of the chamber mapping was to measure RF power uniformity across the GPS antenna farm. With a normalized RF power uniformity contour, a relative power offset was then computed for each device based on antenna farm location. The middle location, identified as

P13 in Figure 5, was selected as the normalizing location. Mapping was conducted first with no devices on the GPS antenna farm and then with the farm fully populated. Comparing the two contours ensured that the addition of the devices did not significantly disrupt the pristine RF power uniformity.

Pretest mapping was performed using twenty six data points, including P1 thru P25 (spaced evenly on a five by five grid) and the ARL-defined reference point, as illustrated by Figure 7. The initial mapping was done without any Styrofoam or devices in the antenna farm, then, the Styrofoam was installed. Each device was placed on one of the locations shown in Figure 5.

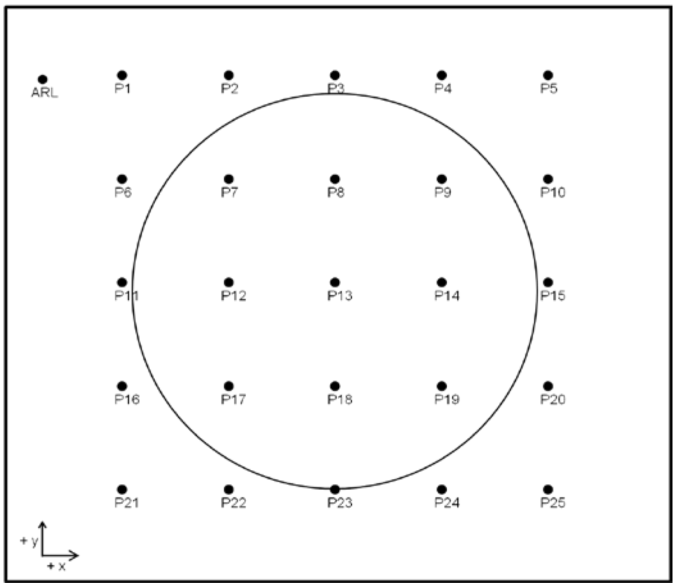

Figure 7 Grid of Initial Mapping Positions

For post-test mapping, the grid granularity was increased from 25 to 81 points over the same area. This provided finer resolution for the offset calculations. Both input ports (+45° and -45°) on the LightSquared base station antenna were used to transmit the ATC signal. Since polarity affects received power at a particular location, a separate mapping was done for each port. Final offset contours are shown for the LTE base station (+/- 45°) in Figure 8 and handset in Figure 9. For complete details of mapping procedure and offset numbers for each position see Appendix E.1.

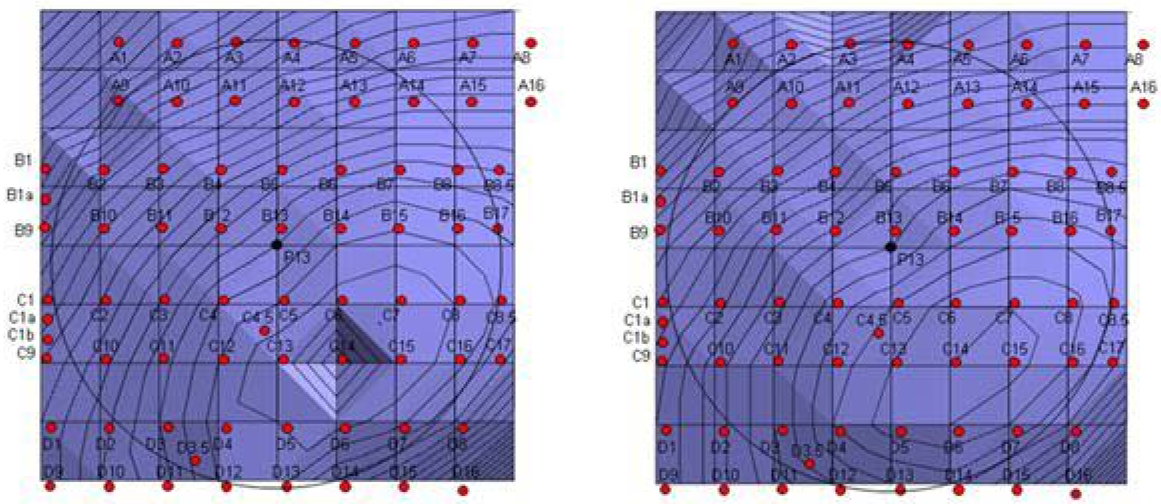

Figure 8 LTE Base Station Mapping, 0.2 dB Contours, +45 (1), -45 (r)

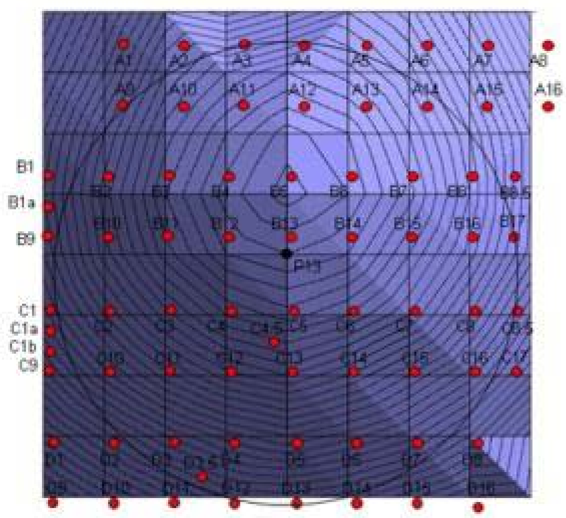

Figure 9 Handset Mapping, 0.2 dB Contours

Mapping data were collected on a LightSquared base station antenna, a surrogate LightSquared handset antenna and the GPS simulation antenna. The measurements confirmed that the transmit antenna's main beams illuminated the GPS antenna farm and the simulated GPS signals were uniform across the grid.

Calibration of the GPS simulator signal was accomplished to ensure minimum specifications values were adhered to across the antenna farm (see Table 2). Details of the GPS signal calibration can be found in Appendix E.2.

3.3 ANECHOIC CHAMBER TEST LIMITATIONS

Test limitations are as follows:

Antenna orientation and polarization – Antenna orientation can affect the level of interference for any particular receiver. The test team discussed potential methods of getting the same interference level for each device, but in the end determined that it was best to let each organization orient their device in the manner they saw fit. This resulted in a variety of antenna orientations, which is likely more realistic than some artificial constraint. Effects of interference are for the particular device, in that orientation may not be worst-case.

Manufacturing variation – UE tested were only singular devices. Software and hardware versions will vary in the field even with the same model of equipment. Therefore, results will vary based on the specific article tested and cannot necessarily be extrapolated to include all instances of a particular device model.

Lack of integrated systems – UE tested generally consisted of receivers only. Operational platforms or integrated systems were not tested. The nature of the testing precluded drawing specific conclusions about integrated systems and operational effects.

Propagation models – Distances were calculated using propagation models. Analysts used the Irregular Terrain Model (ITM) and Free Space Propagation Model (FSPM) in calculating distances. See Section 4 for further details on analysis; propagation model details are located in Appendix F.

Aggregate effects – This test considers only a single transmitter, not the overall effect of multiple transmitters, as would be expected in the actual environment. Aggregate effects of multiple transmitters are not considered.

Continuous distance – LightSquared LTE power levels were incremented in 1 dB steps, so a continuous simulated distance from the tower was not available.

3.4 ANECHOIC CHAMBER TEST EXECUTION

3.4.1 Timing and Control

For positive control and to facilitate data analysis, the test team used the Real-Time System Simulator (RTSS) provided by SPAWAR for overall synchronization and timing of test events. The RTSS was configured to control the AGNS and the Jammer Control Software (JCS) using common clocking signals and a reflective memory system. The RTSS, AGNS, and JCS were configured together using Shared Common Random Access Memory Network (SCRAMNet) reflective memory and 10 MHz and 1PPS clocking signals. The software used during this test was RTSS version 1.0.

Test profile timing was controlled by the JCS. Each JCS controlled one or more Agilent Signal Generators via XML control files using time synchronous pulses. Each XML file contained a sequence of timed events that were sent to the appropriate Agilent signal generator. The Agilent signal generators generated the LTE signals at the power level specified by the control file. Two Agilent signal generators were configured to generate the 10 MHz Low (1526-1536 MHz) LTE signal, and were synchronized to provide the same power levels at the same time. A third Agilent signal generator was configured to generate the handset LTE signals. Figure 10 shows a block diagram of the signal generation and timing. The Agilent models and software versions used were:

a. Agilent Model N5182A – 10 MHz low LTE software version 10
b. Agilent Model N5182A – 10 MHz low LTE software version 10
c. Agilent Model E4438C – handset LTE software version 10

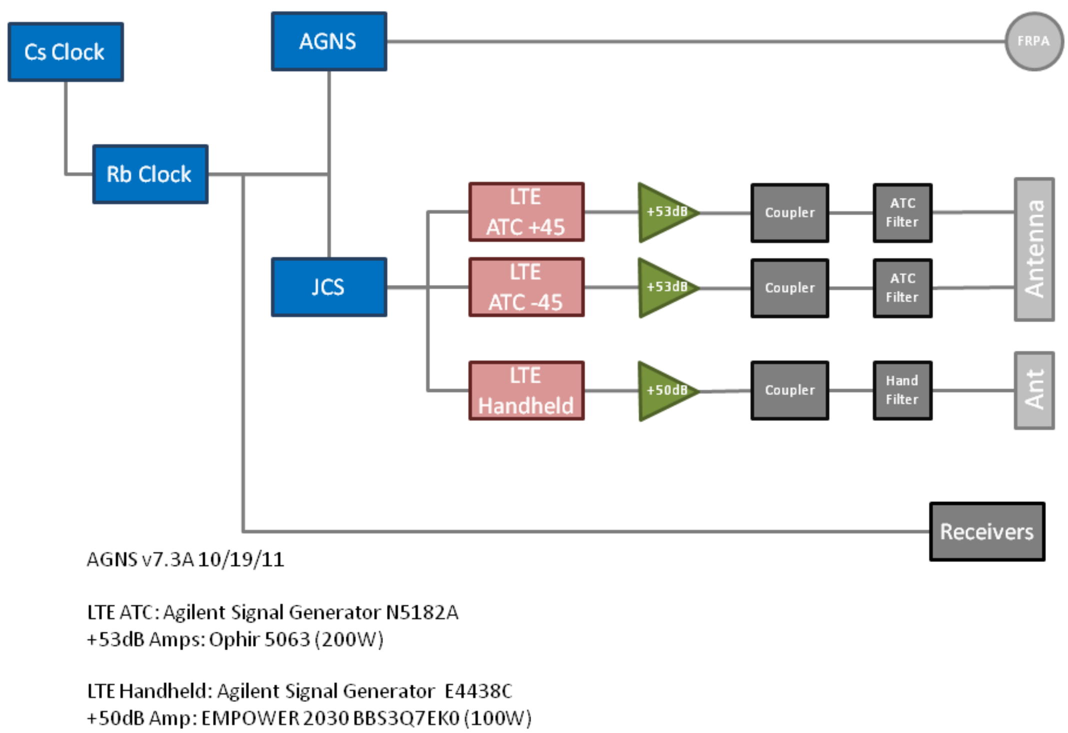

Figure 10 Anechoic Chamber Signal Generation and Timing Set-up

3.4.2 Test Events and Schedule

Testing was conducted in two waves due to the large number of receivers brought to the chamber. Each wave of tests required two days. A few hours between sets of tests were required to replace receivers and/or devices and recalibrate the grid. The first wave of test events consisted of Test Events (TE) 0–8, and the second set of test events consisted of TEs 9–17. TEs 9-17 were identical to TEs 0–8. The test events and schedule are listed in Table 3.

3.4.3 Test Event Description

3.4.3.1 Test Event TE 0 (repeated as TE 9)

TE 0 (TE 9) was a baseline test intended to characterize each receiver's response when varying the code power of the GPS signal. The LTE signal was turned to "standby" (no transmission) and the AGNS signal strength was varied from 5 dB above nominal to 10dB below nominal at 1 dB per minute. Each receiver's C/N_o was collected to ensure linear receiver response to varying power levels.

3.4.3.2 Test Event TE 1 (repeated as TE 10)

TE 1 (TE 10) characterized how the receivers responded to different LightSquared LTE base station power levels in the 10 MHz lower band. The AGNS signal strength was held constant for the duration of the test. The LTE power was set to Standby (no transmission) for the first 30 minutes to establish a baseline and then followed with a power ramp step function. The ramp function for the LTE base station and handset signals was defined as follows. The LTE signal was turned on to the minimum power level defined in this test (-85 dBm received power at the center of the antenna farm). The LTE signal was increased by 1 dB every 15 seconds until reaching -45 dBm. The LTE signal was then increased by 1 dB every 30 seconds until reaching maximum power of -10 dBm. The LTE signal was held at -10 dBm for approximately 3 minutes then decreased 1 dB every 30 seconds until reaching -45 dBm. The LTE signal decreased 1 dB every 15 seconds until reaching -85 dBm. The purpose for increasing the dwell time at higher power levels ensured all receivers had sufficient time to respond to each change. This test was repeated for a total of 3 trials, with 5 minutes of clean air (no LTE transmission) between each trial.

3.4.3.3 Test Event TE 2 (repeated as TE 11)

TE 2 (TE 11) characterized how the receivers responded to LightSquared's handset power levels on the LTE resource block closest to the GPS L1 frequency. The AGNS signal strength was held constant for the duration of the test. The LTE base station signal was kept in Standby mode (no transmission) for the entire test. The simulated handset signal had a 180 kHz bandwidth with f_c= 1628.45 MHz, consistent with a single LTE resource block. The test began with five minutes of GPS only transmission to establish a baseline followed by the handset transmission using the ramp function defined in TE1.

3.4.3.4 Test Event TE 3 (repeated as TE 12)

TE 3 (TE 12) characterized how the receivers responded to LightSquared's handset power levels incorporating the entire 10 MHz bandwidth at the lower handset channel frequency (f_c = 1632.5 MHz). The AGNS signal strength was held constant for the duration of the test. The LTE base station signal was kept in Standby mode (no transmission) for the entire test. The test began with five minutes of GPS only transmission to establish a baseline followed by the handset transmission using the ramp function defined in TE 1.

3.4.3.5 Test Event TE 4 (repeated as TE 13)

TE 4 (TE 13) characterized how the receivers responded to LightSquared's handset power levels incorporating the entire 10 MHz bandwidth at the upper handset channel frequency (f_c = 1651.7 MHz). The AGNS signal strength was held constant for the duration of the test. The LTE base station signal was kept in Standby mode (no transmission) for the entire test. The test began with five minutes of GPS only transmission to establish a baseline followed by the handset transmission using the ramp function defined in TE1.

3.4.3.6 Test Event TE 5 (repeated as TE 14)

TE 5 (TE 14) characterized how the receivers responded to a combined base station/handset test, using the handset lower channel by incorporating the entire 10 MHz bandwidth at the lower handset channel frequency (fc = 1632.5 MHz) and keeping the LTE base station turned on and set at -55 dBm received power at the center of the antenna farm. The AGNS signal strength was held constant for the duration of the test. The test began with five minutes of GPS only transmission to establish a baseline followed by the handset transmission using the ramp function defined in TE1.

3.4.3.7 Test Event TE 6 (repeated as TE 15)

TE 6 (TE 15) characterized how the receivers responded to a combined base station/handset test, using the handset upper channel by incorporating the entire 10 MHz bandwidth at the upper handset channel frequency (fc = 1651.7 MHz) and keeping the LTE base station turned on and set at -55 dBm received power at the center of the antenna farm. The AGNS signal strength was held constant for the duration of the test. The test began with five minutes of GPS only transmission followed by the handset transmission to establish a baseline using the ramping function defined in TE1.

3.4.3.8 Test Event TE 7 (repeated as TE 16)

TE7 (TE 16) characterized how the receivers responded to a combined base station/handset test, using the handset lower channel by incorporating the entire 10 MHz bandwidth at the lower handset channel frequency (fc = 1632.5 MHz) and keeping the LTE base station turned on and set at -30 dBm received power at the center of the antenna farm. The AGNS signal strength was held constant for the duration of the test. The test began with five minutes of GPS-only transmission to establish a baseline followed by the handset transmission using the ramping function defined in TE1.

3.4.3.9 Test Event TE 8 (repeated as TE 17)

TE8 (TE 17) characterized how the receivers responded to a combined base station/handset test, using the handset upper channel by incorporating the entire 10 MHz bandwidth at the upper handset channel frequency (fc = 1651.7 MHz) and keeping the LTE base station turned on and set at -30 dBm received power at the center of the antenna farm. The AGNS signal strength was held constant for the duration of the test. The test began with five minutes of GPS only transmission to establish a baseline followed by the handset transmission using the ramp function defined in TE1.

Table 3 Summary of Anechoic Chamber Test Events

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day
0	OFF	OFF	AGNS 24 SVs -GPS signal increased 1 dBW/min to -153.5 dBW -GPS signal reduced 1 dBW/min to -168.5 dBW -GPS signal increased 1 dBW/min to -158.5 dBW	31 Oct 11 (Day 1)
1	LTE 10 MHz; F_c=1531 MHz; +45/-45 Polarization	LTE: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1dB/30 sec); -45 dBm to -85 dBm (1dB/15 sec);	AGNS 24 SVs Spec Constant Power	31 Oct 11 (Day 1)
2	LTE OFF; Handset 180 kHz, F_c=1628.45 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	31 Oct 11 (Day 1)
3	LTE OFF; Handset 10 MHz, F_c=1632.5 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	31 Oct 11 (Day 1)
[redacted]				
4	LTE OFF; Handset 10 MHz, F_c=1651.7 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1 Nov 11 (Day 2)

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day
5	LTE 10MHz, F_c=1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c=1632.5 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1 Nov 11 (Day 2)
6	LTE 10MHz, F_c=1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c=1651.7 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1 Nov 11 (Day 2)
7	LTE 10MHz, F_c=1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c=1632.5 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1 Nov 11 (Day 2)
8	LTE 10MHz, F_c=1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c=1651.7 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1 Nov 11 (Day 2)
9	OFF	OFF	AGNS 24 SVs -GPS signal increased 1 dBW/min to -153.5 dBW -GPS signal reduced 1 dBW/min to -168.5 dBW -GPS signal increased 1 dBW/min to -158.5 dBW	2 Nov 11 (Day 3)

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TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day
10	LTE 10 MHz; F_c =1531 MHz; +45/-45 Polarization	LTE: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2 Nov 11 (Day 3)
11	LTE OFF; Handset 180 kHz, F_c=1628.45 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2 Nov 11 (Day 3)
12	LTE OFF; Handset 10 MHz, F_c=1632.5 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)
13	LTE OFF; Handset 10 MHz, F_c=1651.7 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)
14	LTE 10MHz, F_c=1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1632.5 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)

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TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day
15	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)
16	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1632.5 MHz	LTE: -30 dBm Constant; HANDSET:- -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)
17	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3 Nov 11 (Day 4)

4. DATA ANALYSIS

4.1 DATA ANONYMITY PROCESS

In order to protect the source of the collected receiver data and satisfy non-disclosure requirements, an anonymity process was implemented such that individual participants would not be able to identify the source of the processed data, except for their own receivers.

Each participant was given an identification number for each receiver (or receiver/antenna configuration) to be tested. These numbers were known only to the government test management team and the owner of that specific receiver. Numbers were assigned randomly, such that no grouping is implied between owners, receiver models or types, location, or any other observable characteristic. This could lead, for example, to having two receivers of the same type, operated by different participants, being assigned widely different numbers with no apparent commonality.

Standard data file names were used, which consisted only of the receiver number and test day. Government and commercial testers were requested to provide all their data in a single file per receiver per day, and these were collected from each participant by the test team at the end of each day. The test team maintained a file folder for each participant, and each participant was prevented from observing the file names and folder contents of the other participants.

During data collection, participants were responsible for protecting their own data. Since all the commercial participants were physically grouped together, they provided their own means to prevent any inadvertent disclosure.

4.2 ANALYSIS ASSUMPTIONS AND CONDITIONS

4.2.1 Propagation Models

Propagation model choice can significantly affect test data analysis results. The Free Space Propagation Loss (FSPL) model represents the near worst-case impact of transmitted interference power since it assumes an unobstructed path from transmitter to receiver. It is possible, however, for the presence of a stronger ground reflection to lead to higher received power levels than predicted using FSPL and this has been observed in earlier LightSquared testing.

Actual power data collected during the Technical Working Group Las Vegas Live Sky showed 18.66% of points at or above expected FSPL power levels for the Rural setting (Figure 11); 2.03% of points at or above FSPL for the Urban setting (Figure 12); and 2.44% of points at or above FSPL levels for the Suburban setting (Figure 13). Additional analysis of this data is provided in the TWG report.[12] Figures 11-13 also compare measured power to expected power using the Irregular Terrain Model (ITM) and Walfisch-Ikegami Line of Sight (WILOS) model.

[12] *The Technical Working Group Final Report into LightSquared Interference with GPS*, 30 Jun 2011

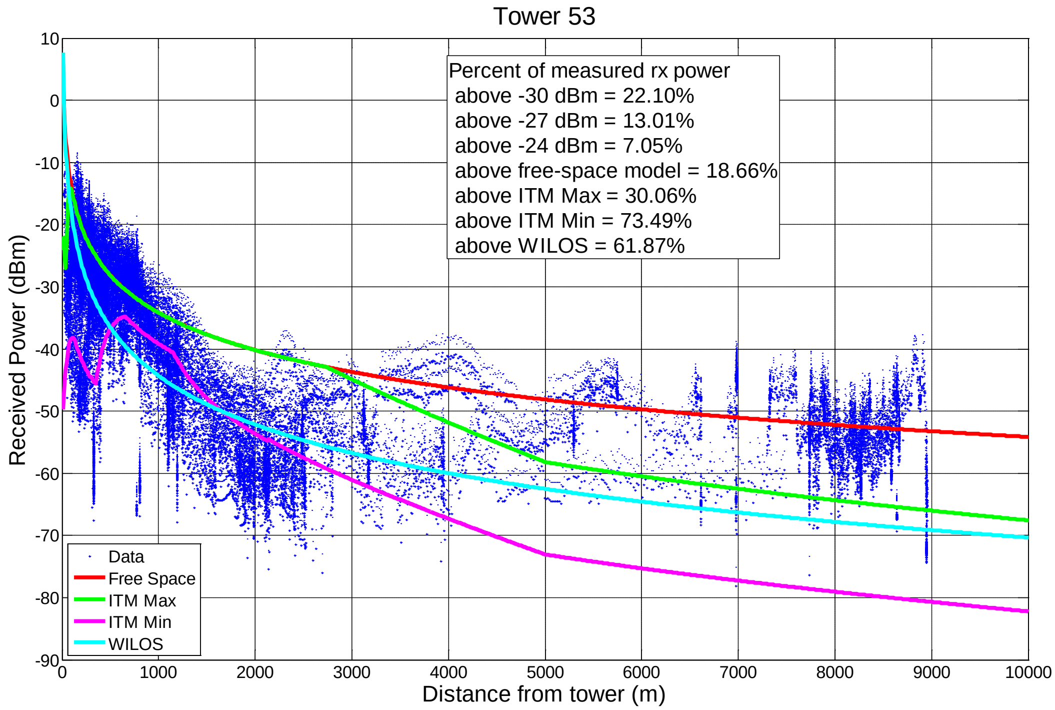

Figure 11 Las Vegas Test Results – Rural Setting

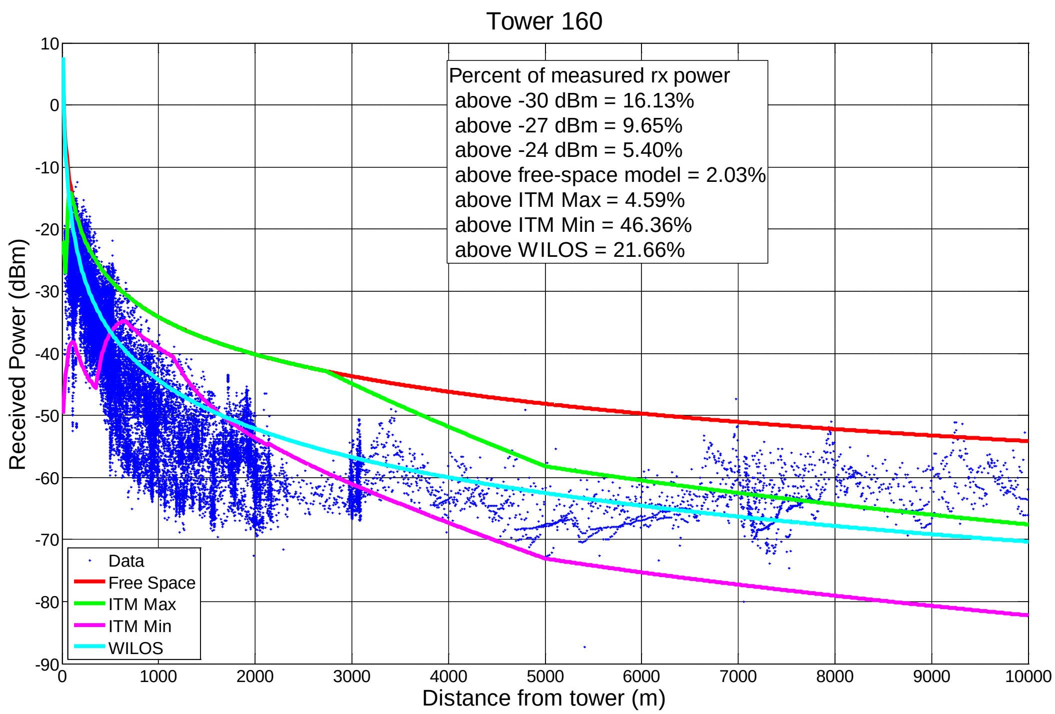

Figure 12 Las Vegas Test Results – Urban Setting

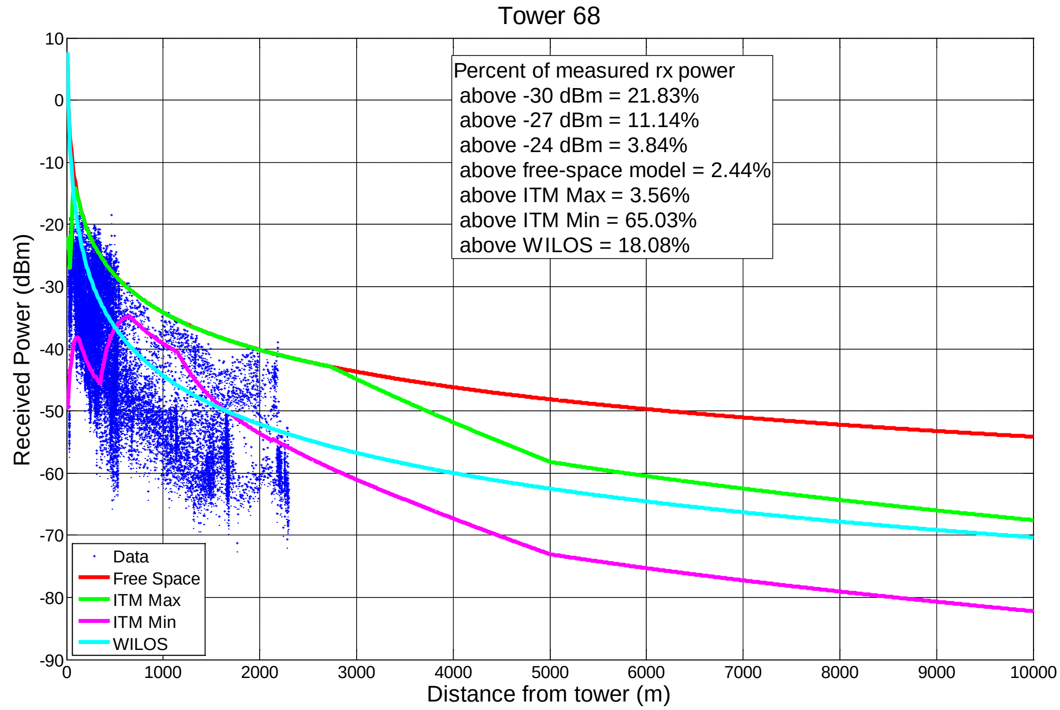

Figure 13 Las Vegas Test Results – Suburban Setting

The NPEF's LightSquared ATC Follow-on Test Plan[13] outlined the analysis of data using 13 separate propagation models. These models were Free Space Propagation and 12 Irregular Terrain Models provided by NTIA. To streamline analysis, the team used Free Space, Maximum Power ITM and Minimum Power ITM to analyze the data. Conclusions in Section 5 utilize the Maximum Power ITM. Figure 14 shows a comparison of the models used. Appendix F provides additional detail on all 12 propagation models as well as how the Maximum and Minimum ITM models were generated.

[13] *Test Plan for the LightSquared Ancillary Terrestrial Component Effects on GPS Receivers: Follow-on Test (Anechoic Chamber),* NPEF, 23 Oct 2011(Note: This document is FOUO)

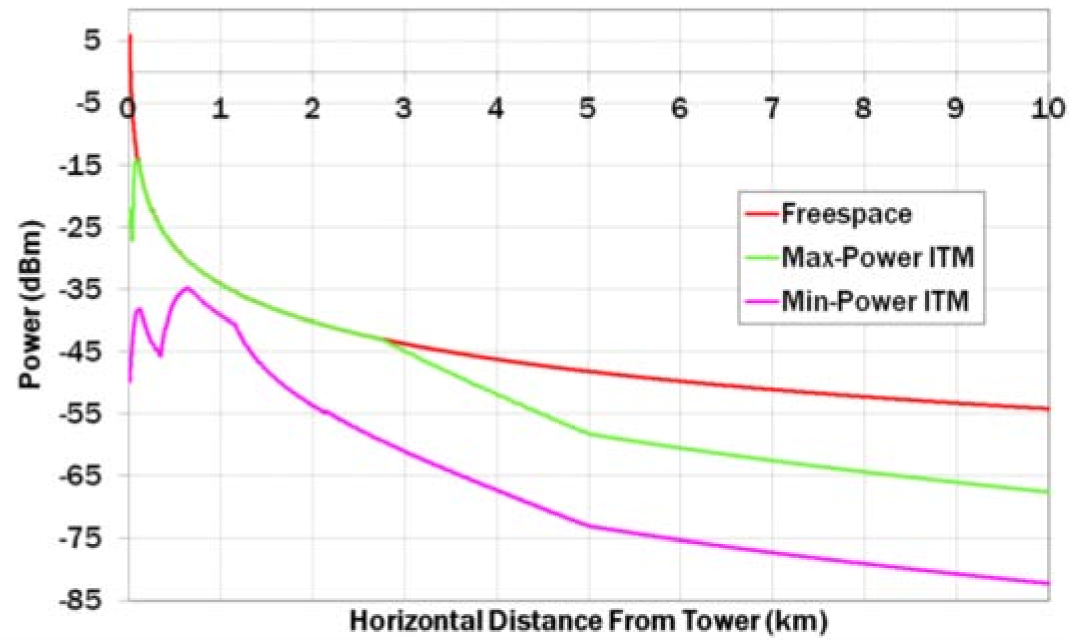

Figure 14 Propagation Models Used for Data Analysis

4.2.2 Receiver Antenna Position

GPS receivers have circularly polarized antennas. Each receiver antenna was oriented to the LightSquared ATC transmit antenna and LightSquared simulated handset antenna in a random fashion. Due to the sheer number of devices it was not feasible to regulate the interference received by every device under test based on antenna orientation. For analysis purposes it is assumed that gain for each GPS receiver antenna is negligible. In reality receivers may be impacted more (or less) due to an increase (or decrease) in received LightSquared ATC or handset power due to a different antenna orientation. It is assumed that the participants configured their systems and antennas such that their receivers were operating in a typical manner.

4.2.3 LightSquared Authorized Power

Although LightSquared is currently authorized to transmit at 72 dBm effective isotropically-radiated power (EIRP) per sector, the data was analyzed using the NCO tasker power level of no greater than 62 dBm EIRP.

4.2.4 Noise Environment

As noted previously, several aspects of the test design may influence the resulting estimates of effective range at which degradation occurs. Since the tests were performed in an anechoic chamber the radio frequency (RF) environment is much 'cleaner' than found in operational settings. Normal ambient noise sources were not modeled or simulated.

4.2.5 Antenna-Receiver Configuration

As for the data collection configuration, the participants were entirely responsible for setup and data recording. It is assumed that they configured their systems and antennas such that their receivers were operating in a typical manner.

4.2.6 General

All of the analysis has erred on the side of a conservative representation of real-world performance. Actual performance is expected to be no better than the test results presented, but could be much worse due to items such as GPS satellite variation, receiver antenna gain, foliage, multipath, and ionospheric disturbances.

4.3 DATA ANALYSIS METHODOLOGY

Data reduction and analysis were performed in a manner designed to provide consistent treatment of data and uniform presentation of results for all receiver types. The process included methods for gathering data from the test participants, analysis and modeling to produce a received-power timeline at each test point location for each test event, and comparison of receiver-derived measurements to the analytically-derived received power levels.

4.3.1 Data Collection Process

A total of 21 organizations participated in the test. Each participant was responsible for collecting data from their own receivers. Coordination efforts began many weeks before the test, identifying participants, receiver types, and test support requirements. Personnel at the EMVAF managed the security, administrative and test support requests in order to ensure all participants' needs were met.

Each participant provided one or more receivers with associated antenna and data collection equipment. Electrical power was supplied by the EMVAC facility, although some battery-operated equipment was also used.

Each participant was provided space on the antenna farm to place antennas and any other equipment required to be in close proximity, such as receivers and power supplies. All this additional equipment was placed below the tables where the antennas were mounted, and were covered by RAM in order to minimize reflections.

The configuration was documented by the test team for each set of tests. Each individual antenna setup was verified and its position recorded for use during data analysis. No configuration changes were permitted once setup was complete. Receiver configurations were documented, including model numbers, hardware and software version numbers.

Few constraints were placed on the data collection process. The important aspect was the use of standardized data messages, in order to support automated data reduction and presentation. Given the short period of time available for data analysis, this was essential to completing the task on time.

Participants were provided with a schedule and updated during twice-daily briefings. Each test day began with a group briefing to review the plan for the day, answer questions and identify problems. Testing commenced shortly thereafter, with “clean air” transmissions (no LTE or handset transmissions) for approximately 30 minutes. Teams initialized their receivers and data collection equipment, and tests ran continuously throughout the day, according to the events described in Appendix B.2. During the test, a radio was provided in each of the data collection areas and used to announce the start and end of each test event.

No access to the antenna farm was permitted during the test events to ensure the test setup was not impacted through the course of test events. In between test events some access to the antenna farm was granted under the supervision of the Test Director to restart devices, log data files and replace batteries.

Data were collected primarily in standard formats, including National Marine Electronics Association (NMEA) format and DOD standard interface data formats. Both of these formats include carrier-to-noise density (C/N_o) measurements made by the receiver, which may be used to estimate received signal power levels and are the primary means to identify degradation of receiver performance. Each record was time-tagged by the receiver using GPS time in seconds.

At the conclusion of each test day, a wrap-up briefing was conducted to review any test issues. Data files were provided to the test team by each participant for each receiver. Data anonymity was ensured through the process described in Section 4.1.

4.3.2 Analysis Tools and Techniques

Automated tools (mainly MATLAB scripts) were used to produce data files that contained a time-ordered list of C/N_o measurements. The receivers were each identified by an arbitrary number, instead of model number or manufacturer, in order not to attribute any performance data presented in this report to any specific receiver.

Propagation effects were estimated using two different models. The free space propagation model used a simple calculation of power attenuation based on the basic physical model without reflections or obstructions. The irregular terrain model attempts to account for those effects, which can cause improved or degraded performance, compared to the free-space model. Neither model attempts to provide an estimate of performance in a specific geographical location.

4.3.3 Analysis Process

After raw data was collected from the test participant it underwent conversion, processing and verification before final plotting occurred. The full process is depicted in Figure 15.

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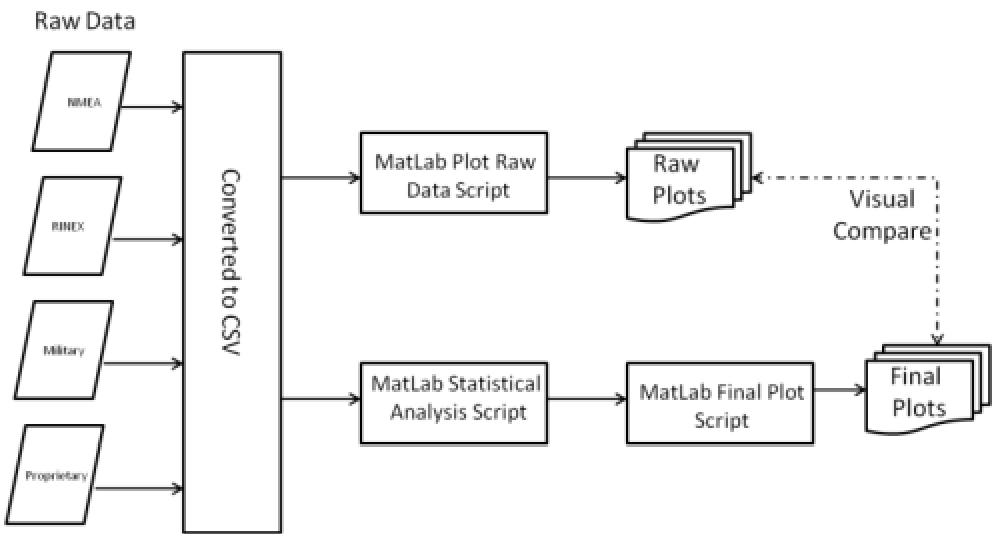

Figure 15 Data Processing Flow

Raw data was initially converted into a standard Comma Separated Value (CSV) format to expedite the processing of the data. Converted data then took two paths. The first path plotted the raw data as it was received. Figure 16 is an example of the raw data.

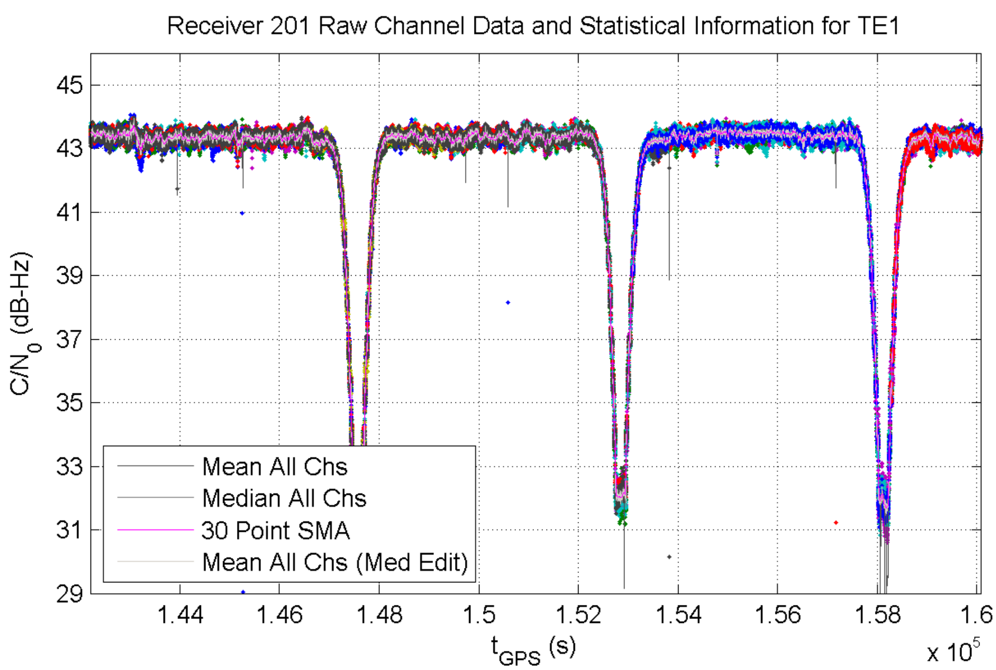

Figure 16 Example of Raw Data Plot

In parallel with the raw data plots, the data were analyzed utilizing a statistical analysis script. This script took the mean of all channels during the baseline ("clean air") test times after using a median edit process to exclude outlier data. This value was used as the C/N_o Baseline value.

The analysis script then applied a 30-second sliding-window mean filter to the C/N_o data and found the point at which the filtered C/N_o remained at least 1 dB below the Baseline value (C/N_o $=C/N_o$ Baseline – 1). The GPS time for this event was then reported. LTE transmitted power was adjusted for each receiver in accordance with the calibration report (Appendix E.1, Table 2) and filtered using a 30-second sliding window mean, similar to the C/N_o data. The GPS time for 1 dB of degradation was then correlated with the filtered LTE power data. Figure 17 depicts an example of the final processed data which includes C/N_o , C/N_o Baseline, GPS Time, 1 dB degradation and LTE Power.

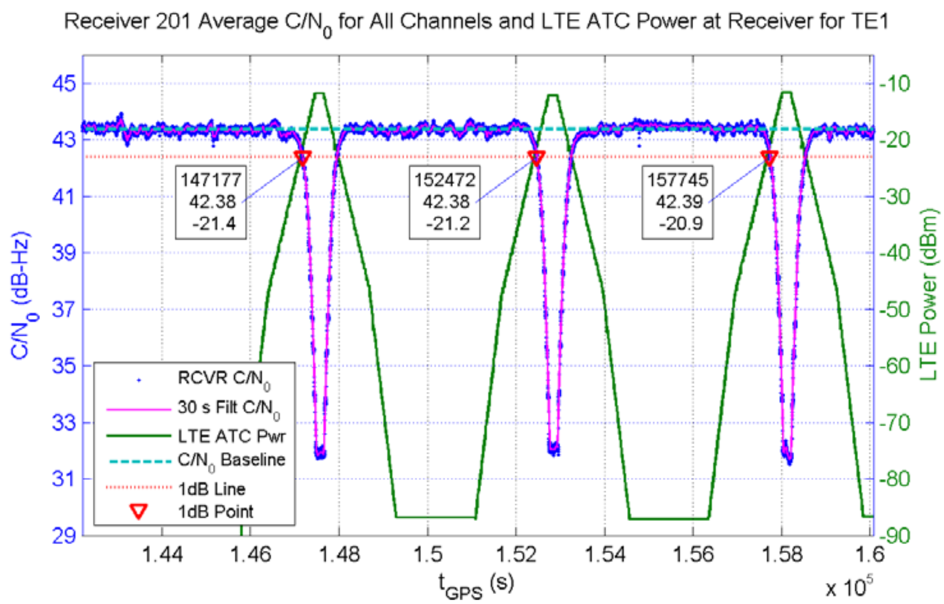

Figure 17 Example of Final Receiver Plot

5. SUMMARY OF RESULTS AND CONCLUSIONS

5.1 ANECHOIC CHAMBER TEST RESULTS

5.1.1 General Navigation Results

During the chamber test 102 general navigation devices were tested, each test event produced a different number of usable data. Contributing factors resulting in non-usable data include: 1) receiver not properly outputting C/N_o, 2) receiver not being ready at the start of a test event, and 3) data corrupted during test. Additionally, duplicate receiver/antenna configurations were removed from the results of each Test Event summary.

5.1.1.1 Test Events 0 and 9

Test Events 0 and 9 demonstrated the receiver C/N_o response to changes in satellite power. This test provided confidence that a receiver's C/N_o changed in a linear fashion. Appendix D.0 provides the detailed results for these test events. Table 4 provides a summary of the findings.

Table 4 Test Events 0 & 9 General Navigation Summary

TEST EVENTS	RECEIVERS TESTED	USABLE DATA	RECEIVERS LINEAR RESPONSE
0 and 9	102	94	94

5.1.1.2 Test Events 1 and 10

Test Events 1 and 10 were the primary objective of the follow-on test effort. This test provided details on how GPS receivers were impacted by LightSquared ATC transmission in the Lower 10 MHz (1526 – 1531 MHz) band. A total of 92 devices/configurations had useable data for Test Events 1 and 10. Appendix D.1 provides the detailed results from these test events. Table 5 and Figure 18 provide a summary of the results.

Table 5 Test Events 1 & 10 General Navigation Summary

ATC POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
< -45	2	2%
-45 to -40	3	3%
-40 to -35	3	3%
-35 to -30	6	7%
-30 to -25	15	16%
-25 to -20	18	20%
-20 to -15	22	24%
-15 to -10	15	16%
> -10	8	9%

Table 6 provides a summary and comparison of federal agency requested devices versus commercially requested devices. Although the NPEF did not limit federal or commercial participants from nominating receivers, the results present near equivalent impacts.

Table 6 Federal Government and Commercial Comparison

	NUMBER of RECEIVERS	RECEIVERS DEGRADED 1dB at <15dBm	PERCENTAGE DEGRADED 1dB
FEDERAL GOVERNMENT	41	29	71%
COMMERCIAL	51	40	78%

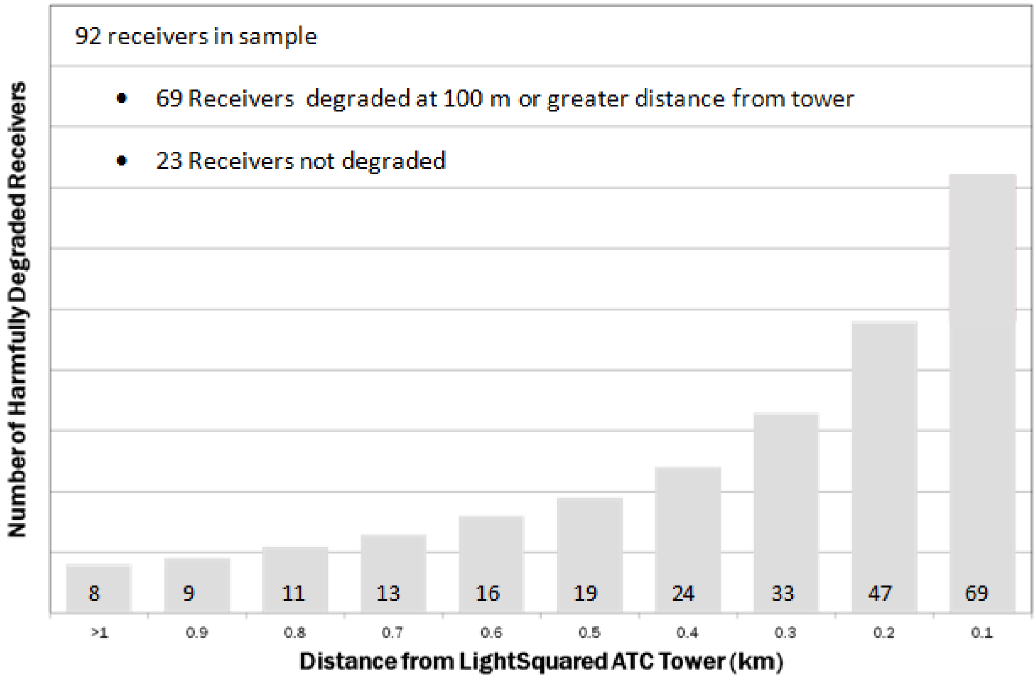

Figure 18 Test Events 1 & 10 General Navigation Histogram Summary

5.1.1.3 Test Events 3 and 12

Test Events 3 and 12 were designed to determine if GPS receivers were potentially impacted by the Lower 10 MHz handset signal (1627.5 – 1637.5 MHz). Appendix D.2 provides the detailed results from these test events. A total of 91 devices/configurations had useable data for Test Events 3 and 12. Table 7 provides a summary of the results. The last row in Table 7 (handset power of >-10 dBm) is the number of receivers not degraded by the handset signal.

Table 7 Test Events 3 & 12 General Navigation Summary

HANDSET POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
-55 to -45	0	0%
-45 to -40	0	0%
-40 to -35	0	0%
-35 to -30	4	4%
-30 to -25	5	6%
-25 to -20	4	4%
-20 to -15	5	6%
-15 to -10	24	26%
> -10	49	54%

5.1.1.4 Test Events 4 and 13

Test Events 4 and 13 were designed to determine if GPS receivers were potentially impacted by the Upper 10 MHz handset signal (1646.7 – 1656.7 MHz). Appendix D.2 provides the detailed results from these test events. A total 86 devices/configurations had useable data for Test Events 4 and 13. Table 8 provides a summary of the results. The last row in Table 8 (handset power of >-10 dBm) is the number of receivers not degraded by the handset signal.

Table 8 Test Event 4 & 13 General Navigation Summary

HANDSET POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
-55 to -45	0	0%
-45 to -40	0	0%
-40 to -35	0	0%
-35 to -30	1	1%
-30 to -25	3	3%
-25 to -20	2	2%
-20 to -15	5	6%
-15 to -10	13	15%
> -10	62	72%

5.1.1.5 Test Events 5, 6, 7, 8, 14, 15, 16, and 17

Test Events 5, 6, 7, 8, 14, 15, 16 and 17 tested constant ATC power along with the Upper and Lower handset signal. Results from these events show that the impact is generally about the same or greater in the presence of both ATC and handset interference than with handset interference alone. For detailed results please refer to Appendix D.3 and D.4.

5.1.2 Other Devices

The EXCOM task statement encouraged the NPEF to test other receivers as long as doing so would not preclude prompt test completion. On that basis, the NPEF included several high precision and timing receivers as part of the test. The report executive summary and conclusions ignore these results. They are included only for test completeness. This section summarizes results of the testing for devices in the “Other” category. These were devices tested that did not fall into the “General Navigation” category. A complete list of devices can be found in Appendix C.

5.1.2.1 Test Events 0 and 9

Test Events 0 and 9 demonstrated the receiver C/N_o response to changes in satellite power. This test provided confidence that a receiver’s C/N_o changed in a linear fashion. Appendix D.0 provides the detailed results for these test events. Table 9 provides a summary of the findings.

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Table 9 Test Events 0 & 9 Other Receivers Summary

TEST EVENTS	RECEIVERS TESTED	USABLE DATA	RECEIVERS LINEAR RESPONSE
0 and 9	36	34	34

5.1.2.2 Test Events 1 and 10

Test Events 1 and 10 were the primary objective of the follow-on test effort. This test provided details on how GPS receivers were impacted by LightSquared ATC Transmission in the Lower 10 MHz (1526 – 1531 MHz) band. Appendix D.1 provides the detailed results from these test events. A total of 36 "Other" devices/configurations had useable data for Test Events 1 and 10. Table 10 and Figure 19 provide a summary of the results.

Table 10 Test Events 1 & 10 Other Receivers Summary

ATC POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
-55 to -45	4	11%
-45 to -40	7	19%
-40 to -35	0	0%
-35 to -30	6	17%
-30 to -25	4	11%
-25 to -20	4	11%
-20 to -15	5	14%
-15 to -10	2	6%
> -10	4	11%

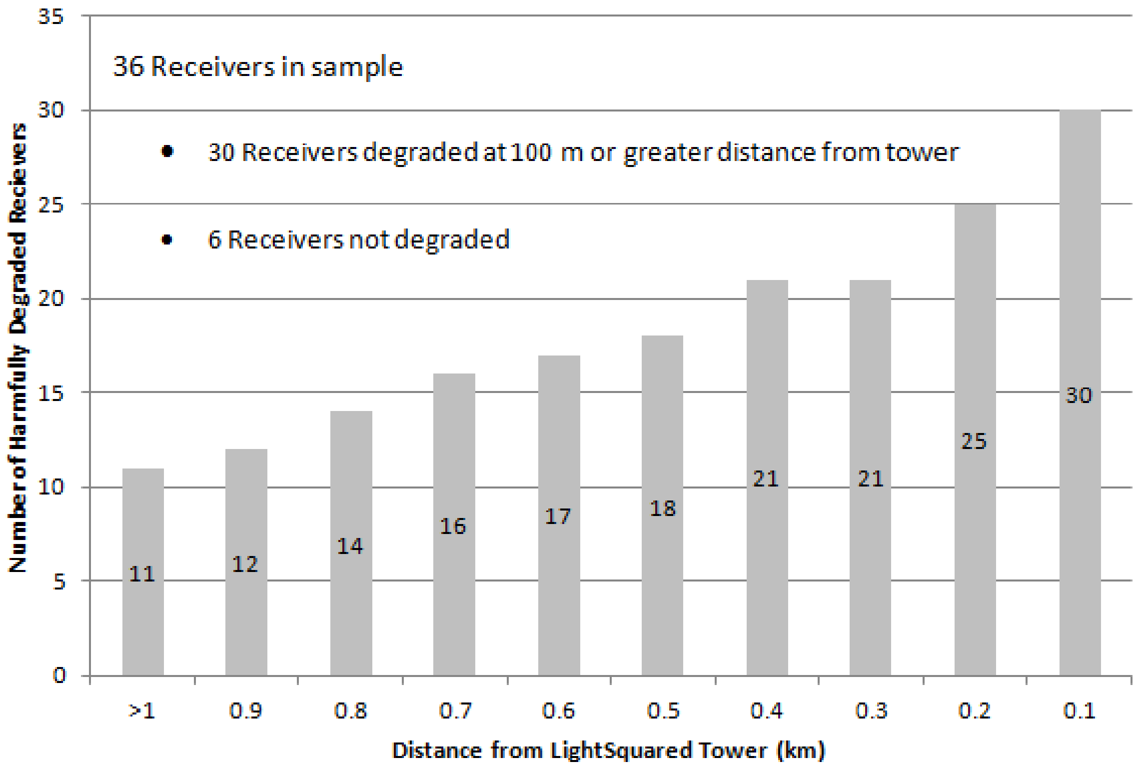

Figure 19 Test Events 1 & 10 Other Receivers Histogram Summary

5.1.2.3 Test Events 3 and 12

Test Events 3 and 12 were designed to determine if GPS receivers were potentially impacted by the Lower 10 MHz handset signal (1627.5 – 1637.5 MHz). Appendix D.2 provides the detailed results from these test events. A total of 36 "Other" devices/configurations had useable data for Test Events 3 and 12. Table 11 provides a summary of the results. The last row in Table 11 (handset power of >-10 dBm) is the number of receivers not degraded by the handset signal.

Table 11 Test Events 3 & 12 Other Receivers Summary

HANDSET POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
-55 to -45	4	11%
-45 to -40	1	3%
-40 to -35	0	0%
-35 to -30	2	5%
-30 to -25	8	22%
-25 to -20	2	5%
-20 to -15	2	5%
-15 to -10	5	14%
> -10	13	35%

5.1.2.4 Test Events 4 and 13

Test Events 4 and 13 were designed to determine if GPS receivers were potentially impacted by the Upper 10 MHz handset signal (1646.7 – 1656.7 MHz). Appendix D.2 provides the detailed results from these test events. A total of 30 “Other” devices/configurations had useable data for Test Events 4 and 13. Table 12 provides a summary of the results. The last row in Table 12 (handset power of >-10 dBm) is the number of receivers not degraded by the handset signal.

Table 12 Test Events 4 & 13 Other Receivers Summary

HANDSET POWER at RECEIVER (dBm)	RECEIVERS DEGRADED 1dB	PERCENTAGE DEGRADED 1dB
-55 to -45	1	3%
-45 to -40	0	0%
-40 to -35	1	3%
-35 to -30	1	3%
-30 to -25	0	0%
-25 to -20	0	0%
-20 to -15	0	0%
-15 to -10	2	7%
> -10	25	83%

5.1.2.5 Test Events 5, 6, 7, 8, 14, 15, 16, and 17

Test Events 5, 6, 7, 8, 14, 15, 16 and 17 tested constant ATC power against the Upper and Lower handset signal. Results from these events show that the impact is greater in the presence of both ATC and handset interference. For detailed results please refer to Appendices D.3 and D.4.

5.2 CONCLUSIONS

Conclusion 1: *Based on test results, LightSquared’s lower 10 MHz signal configuration causes harmful interference to the majority of general navigation GPS receivers tested.*

Test results demonstrated 69 of 92 General Navigation devices experienced harmful interference, defined as a 1 dB increase in the GPS receiver noise, with the lower 10 MHz (1526-1536 MHz) signal. No additional testing is required to determine that terrestrial high-power transmission in the MSS band impacts general navigation receivers.

Conclusion 2: *Immediate use of the Mobile Satellite Spectrum (MSS) for terrestrial service is not viable due to significant systems engineering and integration challenges.*

Current and previous tests have shown all categories of GPS receivers were impacted by high-power transmissions in the MSS band (1525-1559 MHz). The NPEF recommends denying the proposed LightSquared LTE signal plan deployment due to its corresponding GPS user impacts.

At this time, no proposed mitigations address interference from the ‘10H’signal. Although ‘10L’ mitigations have been proposed, they have not been tested and verified to have no impact on GPS receiver performance and the Position, Velocity, and Timing (PVT) applications for which they are used. If and when mitigations are available, a long term transition and implementation plan would be necessary to protect existing GPS services and users. In addition, both the NPEF Report and TWG Report noted that retrofits or upgrades to military and Federal Aviation Administration (FAA) applications would take a minimum of 10-15 years to implement. This minimum timeframe takes into account the necessary steps to design, test, manufacture, install, calibrate, and certify all affected GPS applications requiring upgrade, retrofit, or replacement. The unbudgeted costs associated with this process will be commensurate with its duration and the total number of end-user applications affected.

Conclusion 3: *Handset transmissions have the potential to impact General Navigation GPS receivers.*

Test data show some GPS receivers were susceptible to receiving interference from LightSquared handset transmissions in the 1627.5 – 1656.7 MHz band. Handset test data collected are sufficient, but additional analysis is required. This analysis would include the characterization of actual LightSquared handsets and aggregate radio frequency interference (RFI) modeling of multiple handset users in a given region.

Appendix A. LIST OF ACRONYMS AND CONSTANTS

Acronym	Definition
10H	1545.2 – 1555.2 MHz
10L	1526.0 – 1536.0 MHz
1PPS	One Pulse per Second
A-S	Anti-Spoofing
AGNS	Advanced Global Navigation Simulator
ARL	Army Research Laboratory
ATC	Ancillary Terrestrial Component
C/A	Coarse Acquisition
C/N_o	Carrier to Noise Ratio
CEA	Central Engineering Activity
CSV	Comma Separated Value
CW	Continuous-Wave
dB	Decibel
dBm	Decibels referenced to 1 milliwatt
dBW	Decibels referenced to 1 Watt
DoD	Department of Defense
DOT	Department of Transportation
EIRP	Effective Isotropically-Radiated Power
EMVAF	Electromagnetic Vulnerability Assessment Facility
EXCOM	National Executive Committee (EXCOM) for Space-Based Positioning, Navigation, and Timing
FAA	Federal Aviation Administration
FSPL	Free Space Propagation Loss
GHz	Gigahertz
GPS	Global Positioning System
ICD	Interface Control Document
IEC	Interstate Electronics Corporation
IMU	Inertial Measurement Unit
INL	Idaho National Labs
INS	Inertial Navigation Systems
IS	Interface Specification
ITM	Irregular Terrain Model
JPL	Jet Propulsion Laboratory
L1	GPS signal centered on 1575.42 MHz
LTE	Long Term Evolution
MEAT	Mobile Engineering All-inclusive Test
MHz	Megahertz
MGUE	Modernized GPS User Equipment
MSS	Mobile Satellite Service
N/A	Not Applicable

Acronym	Definition
NASA	National Aeronautics and Space Administration
NMEA	National Maritime Electronic Association
NPEF	National PNT Engineering Forum
PNT	Positioning, Navigation and Timing
Pos	Position
PRN	Pseudorandom Noise
P-Code	Precision-Code
RAM	Radar Absorbing Material
RF	Radio Frequency
RTSS	Real-Time System Simulator
SA	Selective Availability
SAASM	Selective Availability/Anti-Spoofing Module
SCRAMNet	Shared Common Random Access Memory Network
Sec	Second
SMC	Space and Missile Systems Center
SPAWAR	Space and Naval Warfare
SV	Space Vehicle
TE	Test Event
TTFF	Time to First Fix
TWG	Technical Working Group
UE	User Equipment
WAGE	Wide-Area GPS Enhancement
WILOS	Walfisch-Ikegami Line of Sight
WSMR	White Sands Missile Range
Y-Code	Encrypted P-Code

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TOW – GPS Time of Week in seconds

P_T – Power Transmitter (dBm)

P_{T1dB} – Power Transmitter at which 1dB degradation of C/N_o (dBm) occurs

P_R – Power at Receiver (dBm)

G_T – Gain Transmit Antenna (dBm)

G_A – Gain Receive Antenna (dBm)

d – Distance transmit antenna to receive antenna (meters)

f – Frequency of signal

c – Speed of Light: $2.998 \times 10^8 \frac{m}{s}$

λ – Wavelength: $\frac{c}{f}$

I_T – Interference Threshold (dBm): $I_T = P_{T1dB} + G_T - 20\log\frac{(4\pi d)}{\lambda}$

C/N_o – Carrier-to-Noise-Density Ratio

C/N_oBL – Carrier-to-Noise-Density Ratio Baseline observed with LTE OFF

TTFF – Time to First Fix

X_{FSPL} – Free Space Propagation Model Effective Distance to 62 dBm Transmitter

X_{ITM} – Irregular Terrain Model Effective Distance to 62 dBm Transmitter

Lat – Latitudinal Position

Long – Longitudinal Position

EIRP = $P_T + G_T$

Appendix B. TEST EVENTS

B.1 LABORATORY TEST EVENTS

The following Table is a summary of test events executed during the SPAWAR Laboratory Testing

Table 1 Laboratory Test Events

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	NOTES
1	LTE 10 MHz; F_c =1531 MHz;	LTE: -85 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	-Includes 30 Minute Baseline with LTE OFF
2	OFF	OFF	AGNS Simulated Live Sky	-BASELINE
3	LTE 10 MHz; F_c =1531 MHz;	LTE: -85 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -85 dBm (1 dB/15 sec);	AGNS Simulated Live Sky	
4	OFF	OFF	Live Sky	-BASELINE
5	LTE 10 MHz; F_c =1531 MHz;	LTE: -85 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -85 dBm (1 dB/15 sec);	Live Sky	
6	OFF	OFF	AGNS 24 SVs Spec Constant Power	-BASELINE
7	LTE 10 MHz; F_c =1531 MHz;	LTE: -30 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Cold Start
8	LTE 10 MHz; F_c =1531 MHz;	LTE: -27 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Cold Start
9	LTE 10 MHz; F_c =1531 MHz;	LTE: -24 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Cold Start
10	LTE 10 MHz; F_c =1531 MHz;	LTE: -21 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Cold Start
11	OFF	OFF	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
12	LTE 10 MHz; F_c =1531 MHz;	LTE: -30 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
13	LTE 10 MHz; F_c =1531 MHz;	LTE: -27 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
14	LTE 10 MHz; F_c =1531 MHz;	LTE: -24 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
15	LTE 10 MHz; F_c =1531 MHz;	LTE: -21 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
16	LTE 10 MHz; F_c =1531 MHz; Handset: Dual 10 MHz; F_c = 1632.5 & 1651.7 MHz;	LTE: -30 dBm Constant; Handset: -40 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -40 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	NOTES
17	LTE 10 MHz; F_c =1531 MHz; Handset: Dual 10 MHz; F_c = 1632.5 & 1651.7 MHz;	LTE: -24 dBm Constant; Handset: -40 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -40 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
18	LTE 10 MHz; F_c =1531 MHz; Handset: Dual 5 MHz; F_c = 1632.5 & 1651.7 MHz;	LTE: -30 dBm Constant; Handset: -40 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -40 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
19	LTE 10 MHz; F_c =1531 MHz; Handset: Dual 5 MHz; F_c = 1632.5 & 1651.7 MHz;	LTE: -24 dBm Constant; Handset: -40 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -40 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
20	LTE 10 MHz; F_c =1531 MHz;	LTE: -45 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
21	LTE 10 MHz; F_c =1531 MHz;	LTE: -42 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
22	LTE 10 MHz; F_c =1531 MHz;	LTE: -39 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
23	LTE 10 MHz BW; F_c =1531 MHz;	LTE: -36 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
24	LTE 10 MHz BW; F_c =1531 MHz;	LTE: -33 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Warm Start
25	LTE 10 MHz; F_c =1531 MHz;	LTE: -45 dBm Constant;	AGNS 24 SVs Spec Constant Power	-TTFF Cold Start
26	LTE 10 MHz BW; F_c =1531 MHz;	LTE: -36 dBm Constant;	AGNS 24 SVs Spec Constant Power	- TTFF Cold Start
27	LTE 10 MHz BW; F_c =1531 MHz;	LTE: -21 dBm Constant;	AGNS 24 SVs Spec Constant Power	- TTFF Cold Start
28	LTE OFF; Handset: 10 MHz BW; F_c = 1632.5 MHz ;	Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
29	LTE OFF; Handset: 10 MHz BW; F_c = 1632.5 MHz;	Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
30	LTE OFF; Handset: 10 MHz BW; F_c = 1651.7 MHz;	Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	

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TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	NOTES
31	LTE 10 MHz BW; F_c =1531 MHz; Handset: 10 MHz BW; F_c = 1632.5 MHz;	LTE: -45 dBm Constant; Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
32	LTE 10 MHz BW; F_c =1531 MHz; Handset: 10 MHz BW; F_c = 1651.7 MHz;	LTE: -45 dBm Constant; Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
33	LTE 10 MHz BW; F_c =1531 MHz; Handset: 10 MHz BW; F_c = 1632.5 MHz;	LTE: -30 dBm Constant; Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	
34	LTE 10 MHz BW; F_c =1531 MHz; Handset: 10 MHz BW; F_c = 1651.7 MHz;	LTE: -30 dBm Constant; Handset: -60 dBm to -10 dBm (1 dB/15 sec); -10 dBm to -60 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	

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B.2 ANECHOIC CHAMBER TEST EVENTS

Table 2 below is a summary of test events executed during chamber testing. Tables 3-11 provide more details, and the accompanying Figures (Figure 1 through Figure 8) provide the ramp profiles. The embedded Excel files contain ramp profiles for all the test events.

Table 2 Anechoic Chamber Test Events

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day	Notes
0	OFF	OFF	AGNS 24 SVs -GPS signal increased 1 dBW/min to -153.5 dBW -GPS signal reduced 1 dBW/min to -168.5 dBW -GPS signal increased 1 dBW/min to -158.5 dBW	1	
1	LTE 10 MHz; F_c =1531 MHz; +45/-45 Polarization	LTE: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1dB/30sec); -45 dBm to -85 dBm (1dB/15sec);	AGNS 24 SVs Spec Constant Power	1	Test Repeated 3x (Test 1.1, 1.2,1.3)
2	LTE OFF; Handset 180 kHz, F_c =1628.45 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1	Test Repeated 1x
3	LTE OFF; Handset 10 MHz, F_c =1632.5 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	1	Test Repeated 1x
[redacted]					

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TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day	Notes
4	LTE OFF; Handset 10 MHz, F_c =1651.7 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2	Test Repeated 1x
5	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c F_c =1632.5 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2	Test Repeated 1x
6	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2	Test Repeated 1x
7	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1632.5 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2	Test Repeated 1x
8	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	2	Test Repeated 1x
[redacted]		[redacted]	[redacted]		[redacted]

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day	Notes
9	OFF	OFF	AGNS 24 SVs -GPS signal increased 1 dBW/min to -153.5 dBW -GPS signal reduced 1 dBW/min to -168.5 dBW -GPS signal increased 1 dBW/min to -158.5 dBW	3	
10	LTE 10 MHz; F_c =1531 MHz; +45/-45 Polarization	LTE: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3	Test Repeated 3x (Test 10.1, 10.2, 10.3)
11	LTE OFF; Handset 180 kHz, F_c =1628.45 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	3	Test Repeated 1x
12	LTE OFF; Handset 10 MHz, F_c =1632.5 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x
13	LTE OFF; Handset 10 MHz, F_c =1651.7 MHz	HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x

TEST EVENT	LTE Signal Configuration	Received LTE Signal Profile	GPS Configuration	Test Day	Notes
14	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1632.5 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x
15	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -55 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x
16	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1632.5 MHz	LTE: -30 dBm Constant; HANDSET:- -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x
17	LTE 10MHz, F_c =1531 MHz; +45/-45 Polarization Handset 10 MHz, F_c =1651.7 MHz	LTE: -30 dBm Constant; HANDSET: -85 dBm to -45 dBm (1 dB/15 sec); -45 dBm to -10 dBm (1 dB/30 sec); -10 dBm hold for 3 minutes; -10 dBm to -45 dBm (1 dB/30 sec); -45 dBm to -85 dBm (1 dB/15 sec);	AGNS 24 SVs Spec Constant Power	4	Test Repeated 1x

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Table 3 Test Event 0 (repeated as TE 9) –Baseline C/No Linearity; LTE OFF; GPS Simulation 24 SVs Ramped Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	0 Degrees
SV signal power	-GPS Received signal strength = -158.5 dBW -GPS signal increased 1 dBW per minute to -153.5 dBW -GPS signal reduced 1 dBW per minute to -168.5 dBW -GPS signal increased 1 dBW per minute to -158.5 dBW
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE OFF

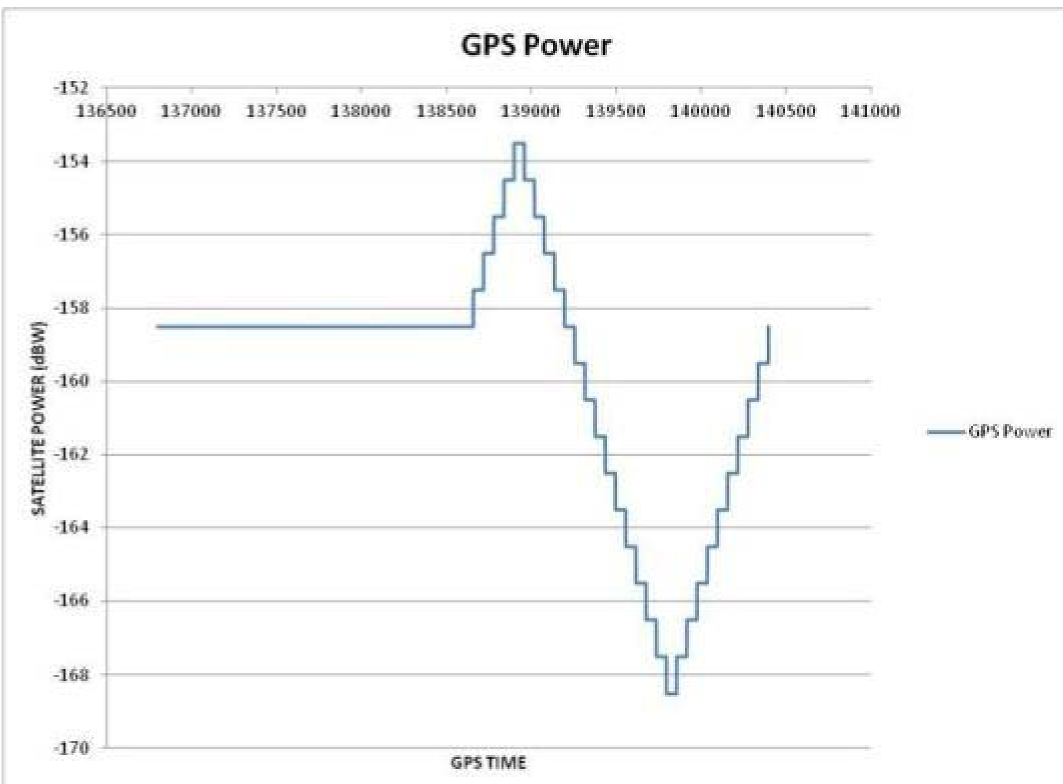

Figure 1 Ramp Profile for Test 0

Table 4 Test Event 1 (Repeated as TE 10) – LTE 10 MHz Ramp, Fc = 1531 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	0 Degrees
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- 30 minute LTE OFF Baseline first run (5minutes subsequent runs) - LTE ON 10 MHz, Fc = 1531 MHz at -85 dBm - LTE Signal Increased 1 dB per 15 seconds to -45 dBm - LTE Signal Increased 1 dB per 30 seconds to -10 dBm - LTE Signal held at -10 dBm for 3 minutes - LTE Signal Reduced 1 dB per 30 seconds to -45 dBm - LTE Signal Reduced 1 dB per 15 seconds to -85 dBm - LTE OFF

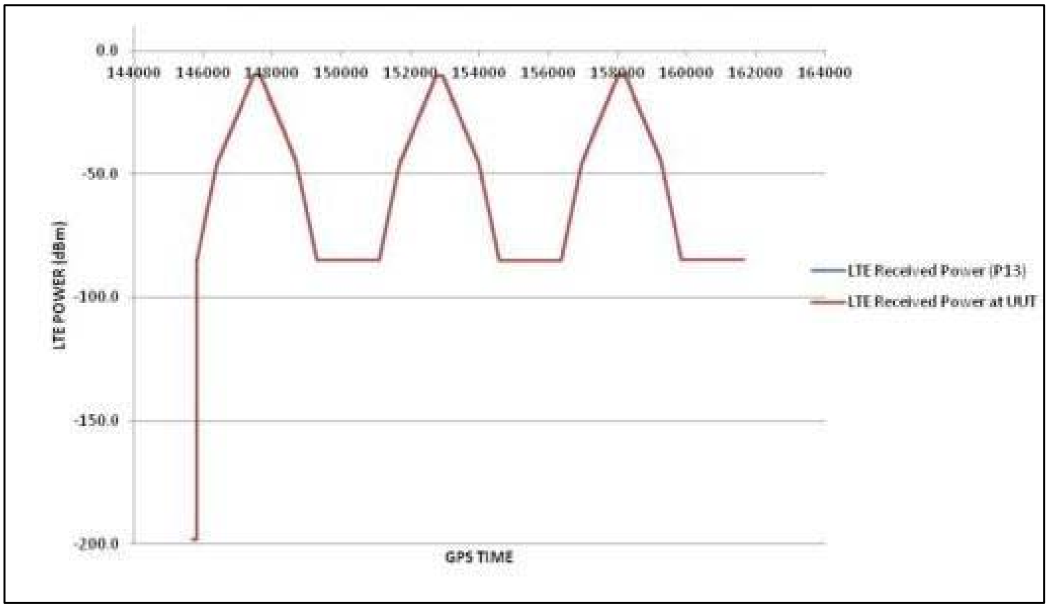

Figure 2 Ramp Profile for Test 1 (Repeated as TE 10)

Table 5 Test Event 2 (Repeated as Test Event 11) – LTE OFF; Handset 180 kHz Ramp, Fc = 1628.45 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	0 Degrees
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE OFF
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 180 kHz Fc = 1628.45 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

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Table 6 Test Event 3 (Repeated as TE 12) – LTE OFF; Handset 10 MHz Ramp, Fc = 1632.5 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE OFF
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1632.5 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

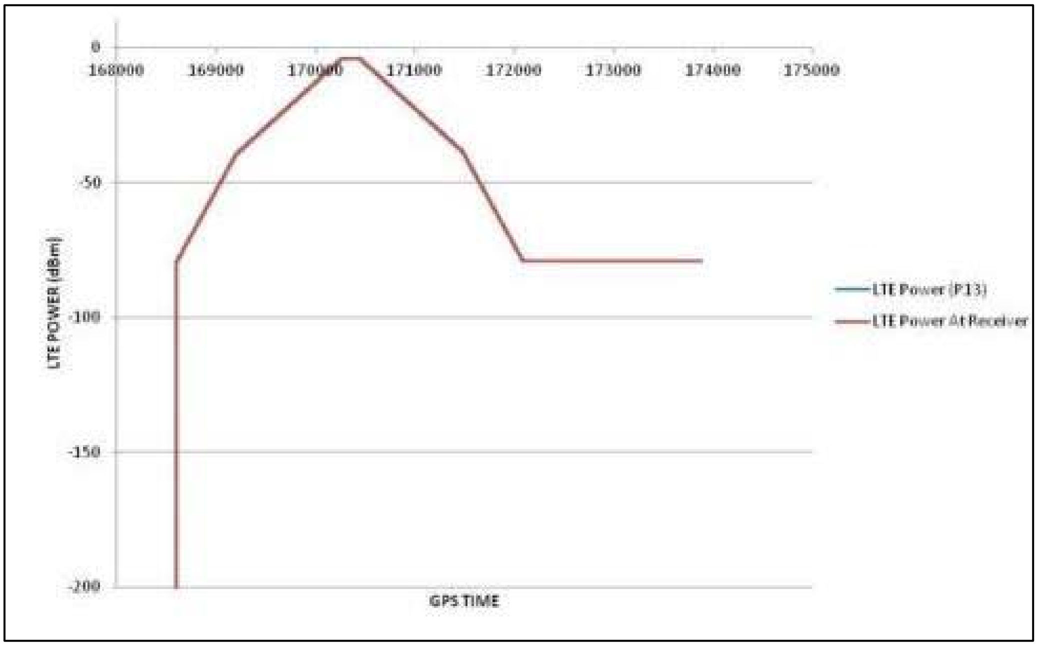

Figure 3 Ramp Profile for Test 3 (Repeated as TE 12)

Table 7 Test Event 4 (Repeated as TE 13) – LTE OFF; Handset 10 MHz Ramp, Fc = 1651.7 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE OFF
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1651.7 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

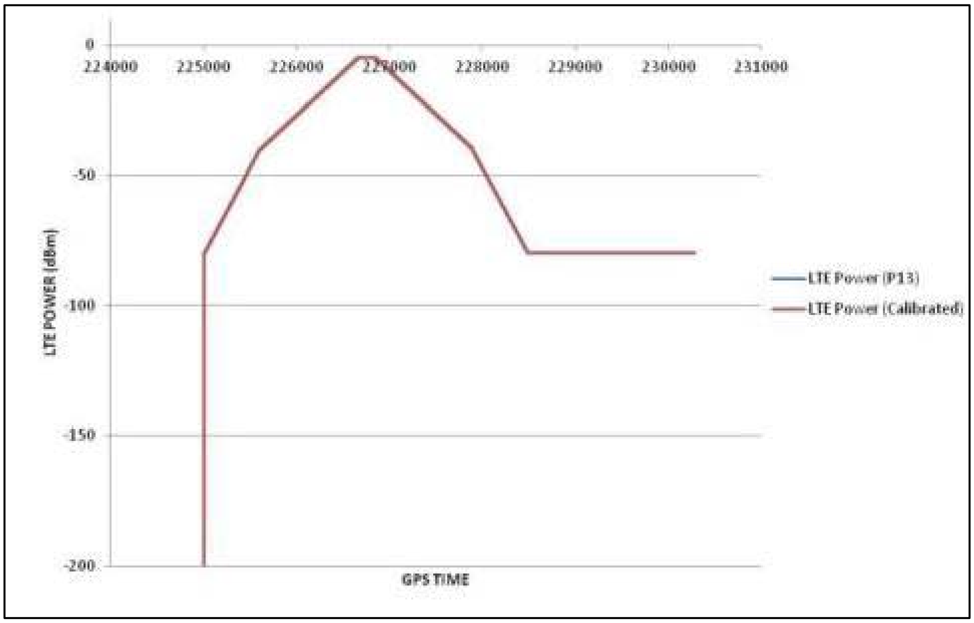

Figure 4 Ramp Profile for Test 4 (Repeated as TE 13)

Table 8 Test Event 5 (Repeated as TE 14) – LTE 10 MHz, -55 dBm constant, Fc = 1531 MHz; Handset 10 MHz Ramp, Fc = 1632.5 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE ON 10 MHz, Fc = 1531 MHz at -55 dBm
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1632.5 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

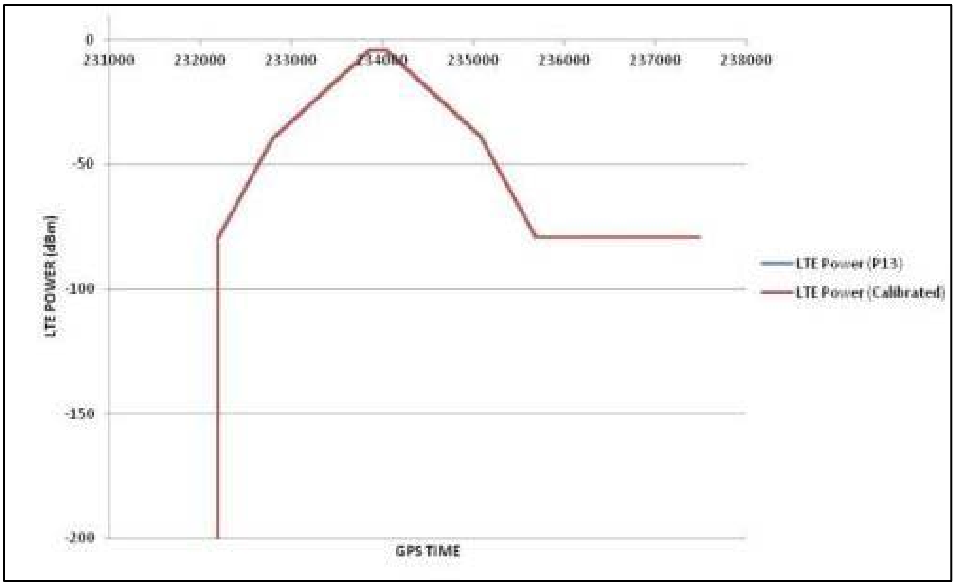

Figure 5 Ramp Profile for Test 5 (Repeated as TE 14)

Table 9 Test Event 6 (Repeated as TE15) – LTE 10 MHz, -55 dBm constant, Fc = 1531 MHz; Handset 10 MHz Ramp, Fc = 1651.7 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE ON 10 MHz, Fc = 1531 MHz at -55 dBm
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1651.7 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

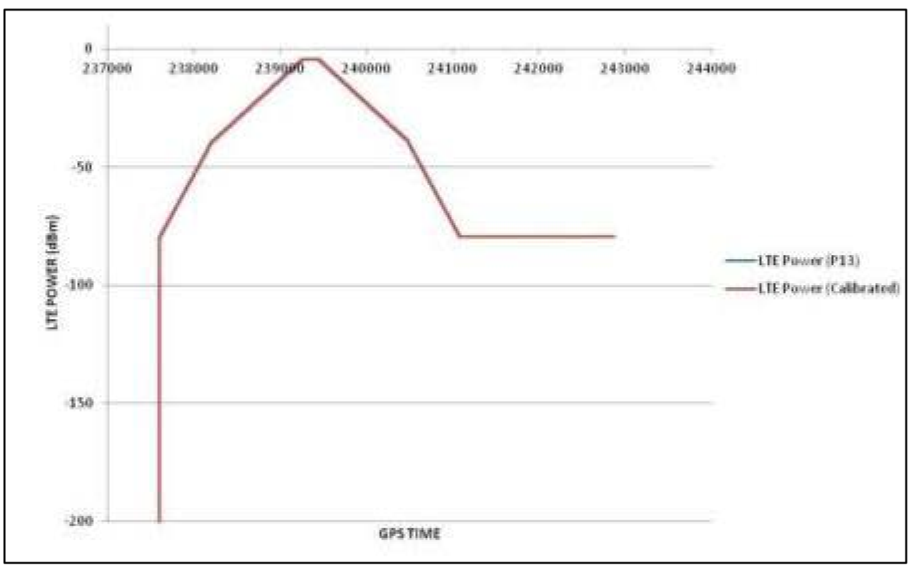

Figure 6 Ramp Profile for Test 6 (Repeated as TE 15)

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Table 10 Test Event 7 (Repeated as TE 16) – LTE 10 MHz, -30 dBm constant, Fc = 1531 MHz; Handset 10 MHz Ramp, Fc = 1632.5 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE ON 10 MHz, Fc = 1531 MHz at -30 dBm
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1632.5 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

Figure 7 Ramp Profile for Test 7 (Repeated as TE 16)

Table 11 Test Event 8 (Repeated as TE 17) – LTE 10 MHz, -30 dBm constant, Fc = 1531 MHz; Handset 10 MHz Ramp, Fc = 1651.7 MHz; GPS Simulation 24 SVs Constant Spec Power

Number of SVs	24 SVs simulated
Navigation message almanac data	Appendix I
Almanac File	Appendix I
GPS Week	1660
GPS Start time	SEE DETAILED PROFILE FILE
Simulator Elevation Mask	N/A
SV signal power	IS-GPS-200 Rev E, Table 3-V
SA	Off
A-S	On
WAGE	Off
Troposphere Model	Appendix D
Ionosphere Model	Single Frequency Model
Ionosphere Parameters	Appendix D
LTE Configuration	- LTE ON 10 MHz, Fc = 1531 MHz at -30 dBm
Handset Configuration	- Handset OFF (5 minutes) - Handset ON, 10 MHz Fc = 1651.7 MHz at -85 dBm - Handset Signal Increased 1 dB per 15 seconds to -45 dBm - Handset Signal Increased 1 dB per 30 seconds to -10 dBm - Handset Signal held at -10 dBm for 3 minutes - Handset Signal Reduced 1 dB per 30 seconds to -45 dBm - Handset Signal Reduced 1 dB per 15 seconds to -85 dBm - Handset OFF

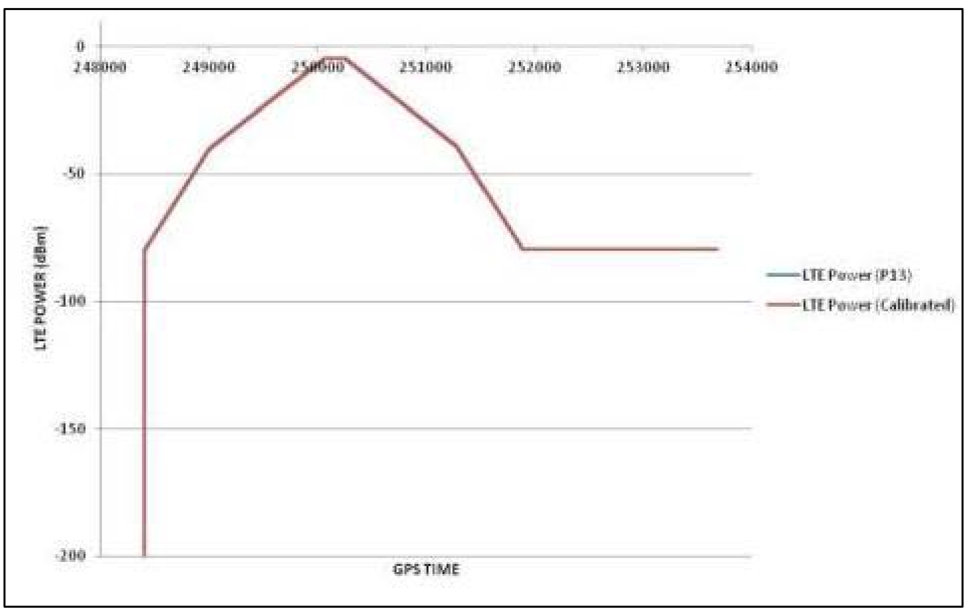

Figure 8 Ramp Profile for Test Event 8 (Repeated for TE 17)

Excel files with test ramp profiles:

LTE Profiles_DAY1 and DAY2_simplified.x

LTE Profiles_DAY3 and DAY4_simplified.x

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Appendix C. RECEIVERS UNDER TEST

Receivers were placed into one of three categories: General Location and Navigation, Military, and Other. "General Location and Navigation" includes receivers used for that purpose. "Military" category consists of military receivers – they were not given random test numbers and results are published in a separate report. "Other" category is all devices that don't fit into the other two categories – these were mainly survey, timing, agriculture, and other high precision devices.

For general location and navigation devices 101 devices were present for testing. One device was tested with a different configuration for a total of 102 total test cases. A separate test control number was assigned to the receiver-antenna pair, as well as devices that were multiples. Separate test control numbers were not assigned to devices that were tested during both waves in the same configuration.

- **General Location and Navigation (101 devices, 102 devices/configurations)**
- **Other (29 devices/44 devices/configurations)**

Appendix D. DETAILED RESULTS

Appendix D provides graphic results for the test events described in detail earlier in this document. The plots are provided in five separate files due to the file size. Contents of the files are as follows:

D.0 PLOTS FOR TEST EVENT 0 AND TEST EVENT 9

D.1 PLOTS FOR TEST EVENT 1 AND TEST EVENT 10

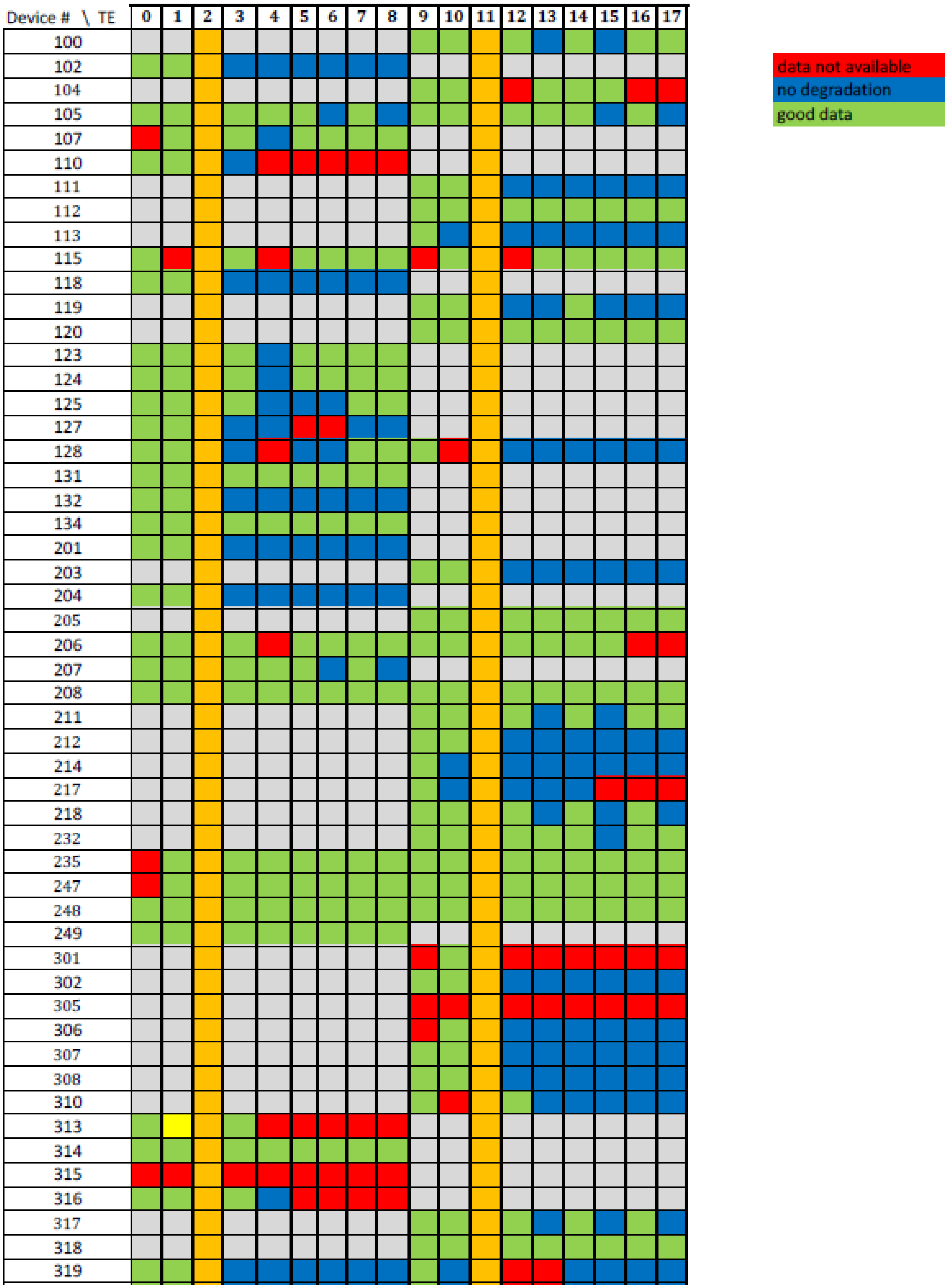
D.2 PLOTS FOR TEST EVENTS 3, 4 AND TEST EVENTS 12,13

D.3 PLOTS FOR TEST EVENTS 5, 6 AND TEST EVENTS 14, 15

D.4 PLOTS FOR TEST EVENTS 7, 8 AND TEST EVENTS 16, 17

The following tables are a graphical overview of the basic results for each device/test event.

GENERAL LOCATION/NAVIGATION



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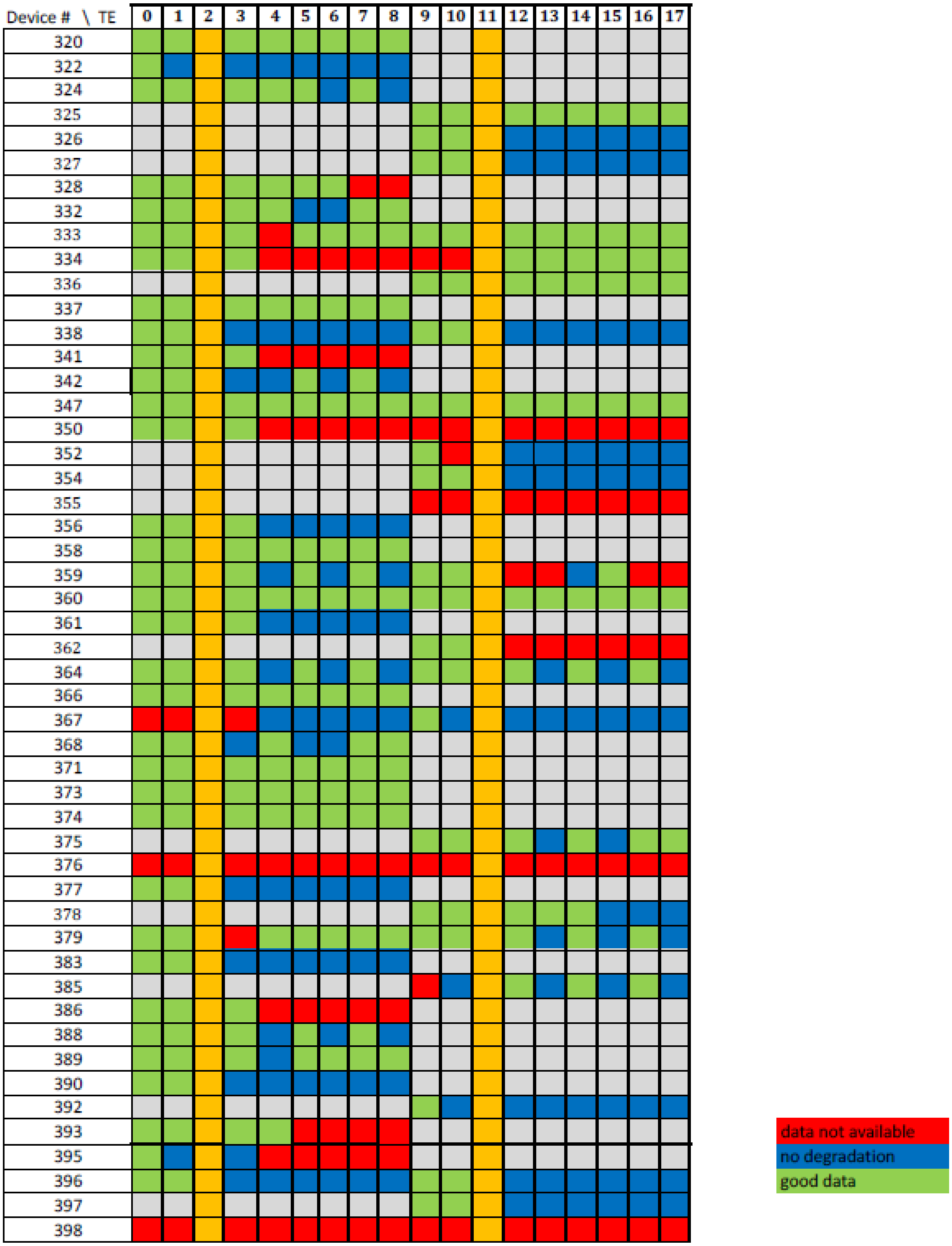
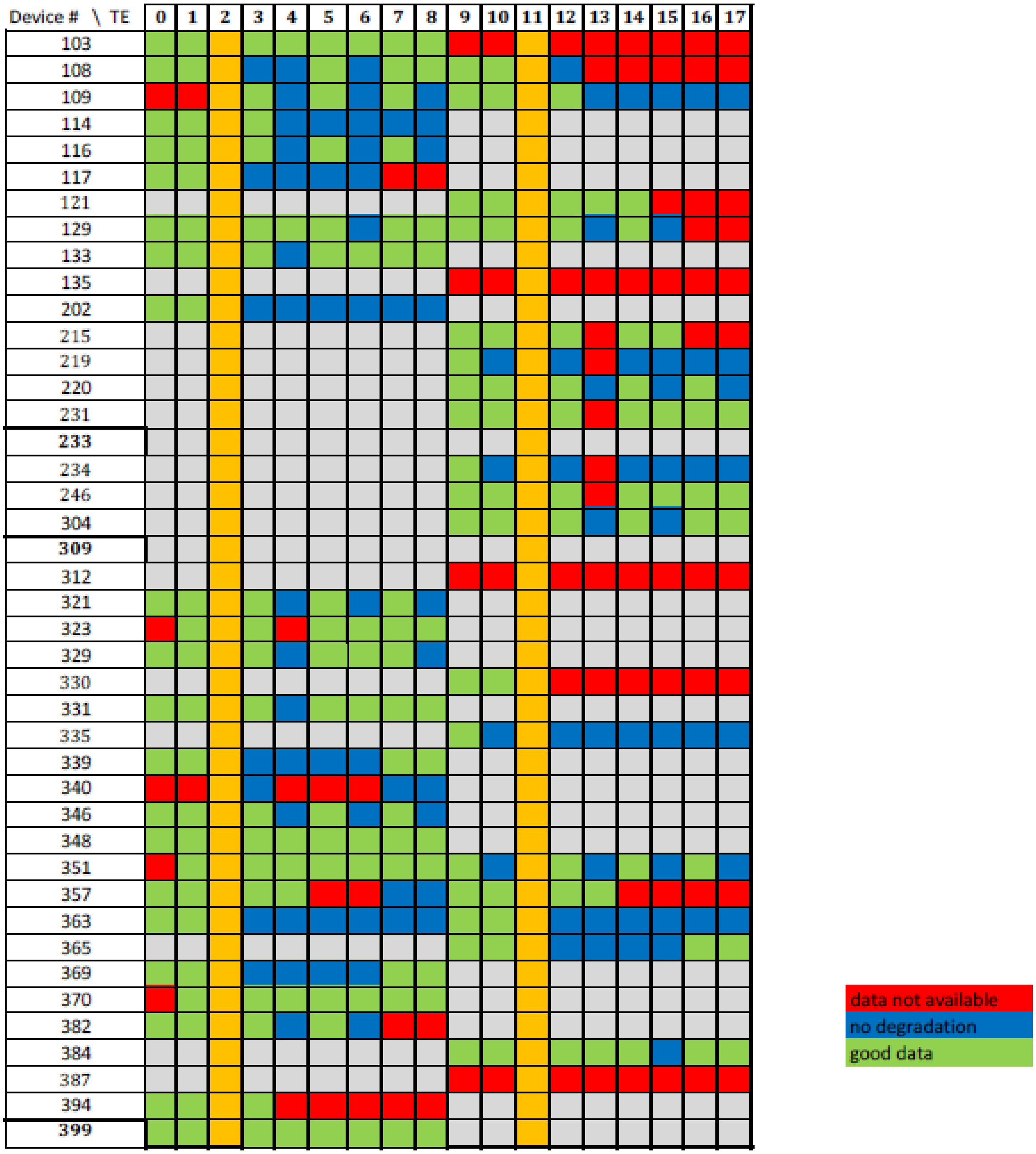

Device # \ TE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
320
322
324
325
326
327
328
332
333
334
336
337
338
341
342
347
350
352
354
355
356
358
359
360
361
362
364
366
367
368
371
373
374
375
376
377
378
379
383
385
386
388
389
390
392
393
395
396
397
398
data not available
no degradation
good data

OTHER


Device # \ TE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
103
108
109
114
116
117
121
129
133
135
202
215
219
220
231
233
234
246
304
309
312
321
323
329
330
331
335
339
340
346
348
351
357
363
365
369
370
382
384
387
394
399
data not available
no degradation
good data

Appendix E. SET-UP AND CALIBRATION

E.1 EMVAF CHAMBER MAPPING

Objective

The purpose of the chamber mapping was to measure RF power uniformity across the GPS antenna farm over a preselected area on the chamber floor. With a normalized RF power uniformity contour, a magnitude offset is computed for each device on the GPS antenna farm. The middle location identified as P13 in the GPS antenna farm was the normalizing unit. Mapping was conducted with no devices on the GPS antenna farm and with devices on the GPS antenna farm. Comparing the two contours ensures that the addition of the GPS antenna farm did not significantly disrupt the pristine RF power uniformity. Additionally, the RF power map was compared to the theoretical field map.

Mapping data were collected on a LightSquared base station antenna, a surrogate LightSquared handset antenna and the GPS simulation antenna. The measurements confirmed that the transmit antennas' main beams illuminated the GPS antenna farm and the simulated GPS signals were uniform across the grid.

Layout

The LightSquared interoperability test was conducted in a fully anechoic chamber with radar absorbing material (RAM) on the walls, floor and ceiling. Within the chamber a LightSquared base station antenna was placed in the North West corner. A surrogate handset antenna was placed near the ceiling close to the center of the chamber. The GPS broadcast antenna was also located near the ceiling and the center of the chamber but above the surrogate handset antenna. The GPS antenna farm was located above the floor RAM in a thirty foot by thirty foot square area in the middle of the chamber. The middle point within the GPS farm was designated P13 and subsequent device offsets were derived from P13. The GPS receiving devices were place on a three foot high piece of RF transparent Styrofoam.

Pretest mapping was performed using twenty six data points, P1 thru P25 and the ARL reference point. This grid mapped the received RF energy across the thirty foot by thirty foot antenna farm. They were arranged in five rows of five data points, as shown in Figure 1. The map occurred on a plane approximately four feet above the walk on RAM material; this is approximately one foot above the Styrofoam table. The initial mapping was done without any Styrofoam or devices in the antenna farm. With the Styrofoam tables installed (Figure 2a), all devices were place on one of 73 locations, as shown in Figure 2b. Each location's offset from P13 is listed in Table 1.

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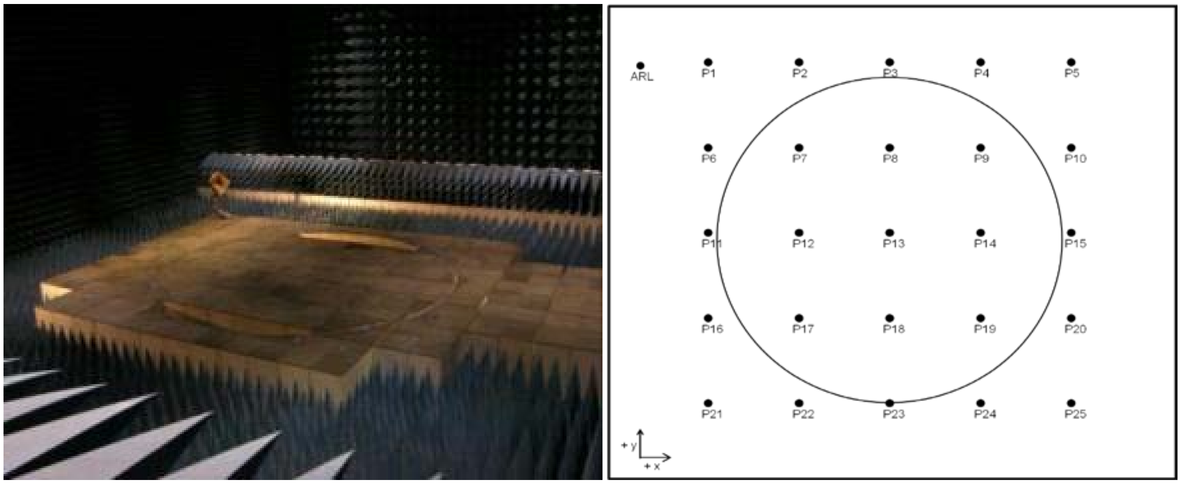

Figure 1. 5 x 5 Grid of Mapping Positions

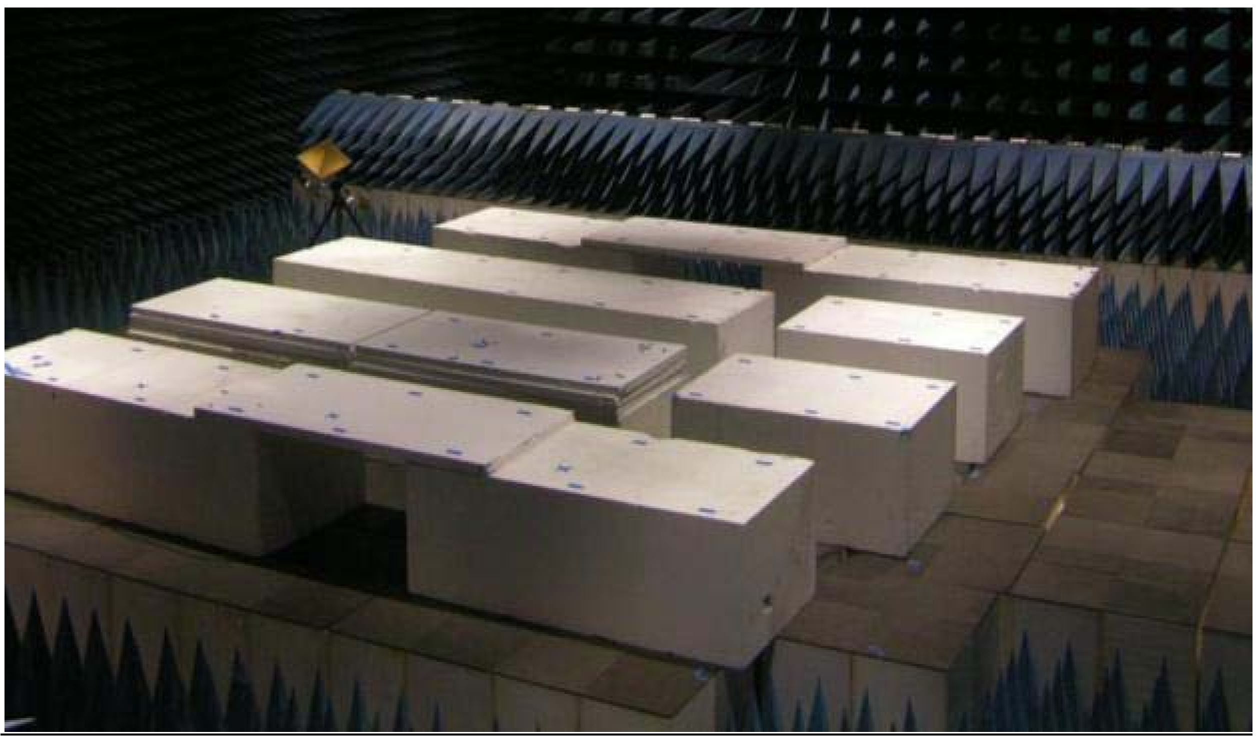

Figure 2a. Antenna Farm with Styrofoam Layout

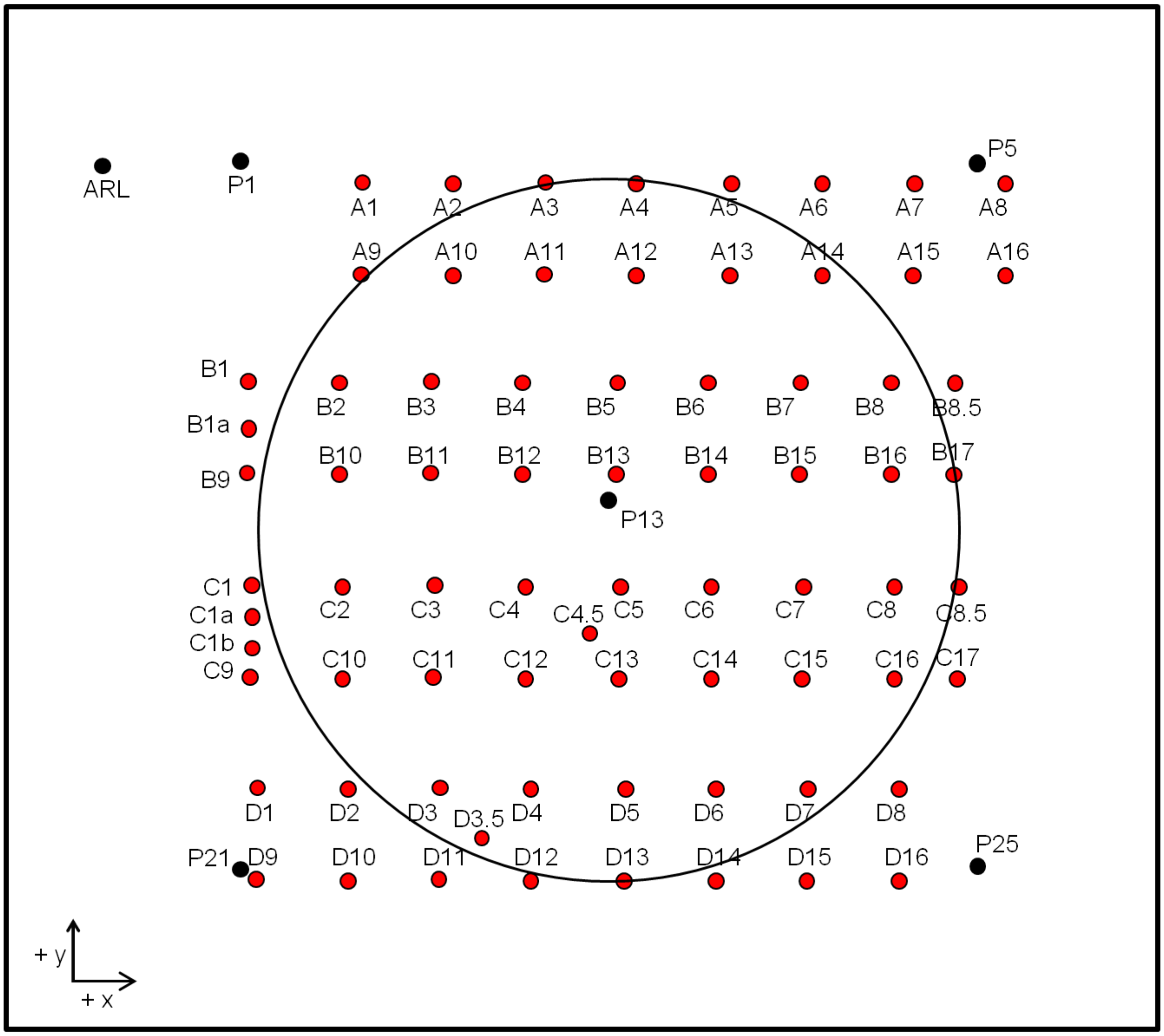

Figure 2b. Antenna Farm With GPS Antenna/Device Locations

Table 1. Distance Offsets from Antenna Locations to Mapping Position P13

Location	x Offset to P13 (ft)	y Offset to P13 (ft)
A1	-8.75	10.42
A2	-5.75	10.42
A3	-2.75	10.42
A4	0.25	10.42
A5	3.25	10.42
A6	6.25	10.42
A7	9.25	10.42
A8	12.25	10.42
A9	-8.75	7.42
A10	-5.75	7.42
A11	-2.75	7.42
A12	0.25	7.42
A13	3.25	7.42
A14	6.25	7.42
A15	9.25	7.42
A16	12.25	7.42
B1	-11.48	3.75
B1a	-11.48	2.25
B2	-8.48	3.75
B3	-5.48	3.75
B4	-2.48	3.75
B5	0.52	3.75
B6	3.52	3.75
B7	6.52	3.75
B8	9.52	3.75
B8.5	11.52	3.75
B9	-11.48	0.75
B10	-8.48	0.75
B11	-5.48	0.75
B12	-2.48	0.75
B13	0.52	0.75
B14	3.52	0.75
B15	6.52	0.75
B16	9.52	0.75
B17	11.52	0.75

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Table 1 (continued). Distance Offsets from Antenna Locations to Mapping Position P13

Location	x Offset to P13 (ft)	y Offset to P13 (ft)
C1	-11.48	-2.92
C1a	-11.48	-3.92
C1b	-11.48	-4.92
C2	-8.48	-2.92
C3	-5.48	-2.92
C4	-2.48	-2.92
C4.5	-0.48	-4.42
C5	0.52	-2.92
C6	3.52	-2.92
C7	6.52	-2.92
C8	9.52	-2.92
C8.5	11.52	-2.92
C9	-11.48	-5.92
C10	-8.48	-5.92
C11	-5.48	-5.92
C12	-2.48	-5.92
C13	0.52	-5.92
C14	3.52	-5.92
C15	6.52	-5.92
C16	9.52	-5.92
C17	11.52	-5.92
D1	-11.17	-9.58
D2	-8.17	-9.58
D3	-5.17	-9.58
D3.5	-3.67	-11.08
D4	-2.17	-9.58
D5	0.83	-9.58
D6	3.83	-9.58
D7	6.83	-9.58
D8	9.83	-9.58
D9	-11.17	-12.58
D10	-8.17	-12.58
D11	-5.17	-12.58
D12	-2.17	-12.58
D13	0.83	-12.58
D14	3.83	-12.58
D15	6.83	-12.58
D16	9.83	-12.58

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The base station transmit antenna was an ARGUS model HPX308R, serial number 67570030; it was mounted on the mezzanine inside the large chamber in the north west corner 49.7 feet from P13; it was the same antenna used during the test and once placed it was never moved. The antenna was placed tilting down toward the center of the chamber at a mechanical angle of 14^o from vertical, as shown in Figure 3. The ARGUS antenna bore sighted location A2 within the antenna farm. The ARGUS antenna had an electrical down tilt of 2^o according to the LightSquared personnel and documentation. There was a black pull tab at the bottom of the antenna indicating 2. The antenna had two separate polarization feeds, one at +45 degrees and one at -45 degrees. The base station mapping signal used the same RF circuit that was used for test event 0 through 17 but instead of transmitting the LTE simulated signal, a CW tone was transmitted. Each signal generator produced a close, but different tone; the +45 polarization's tone was at 1530.5 MHz and the -45 polarization's tone was at 1531.5 MHz. The drive signal for each was set at -50 dBm. Power delivered to the ARGUS antenna was -4.5 dBm to the +45 degree feed and -5.0 dBm to the -45 degree feed.

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Figure 3. LightSquared Argus LTE Antenna

The surrogate handset transmit antenna was an Electro-Metrics double-ridge horn, model EM-6961, SN-6431; it was mounted in the ceiling and suspended approximately 1.5 feet from the ceiling RAM tips. Ideally, both the surrogate handset antenna and the GPS constellation broadcast antenna should have been directly above P13. Since this was physically impossible, the surrogate handset antenna was positioned three feet south of P13 (closer to P8) and the GPS broadcast antenna was positioned five feet north of P13 (closer to P18), as shown in Figure 4. The same antennas were used during the test and, once placed, were never moved. The distance between the surrogate handset antenna and P13 was 25.9 feet. The handset mapping signal used the same RF circuit that was used for test event 0 through 17 but instead of transmitting the LTE signal, a CW tone at 1631 MHz was transmitted. The drive signal was set at -50 dBm. Power delivered to the double-ridge horn antenna was -10 dBm.

Figure 4. LightSquared Handset Surrogate Antenna (double ridge horn) and the GPS Broadcast Antenna

To minimize feedback from the surrogate handset antenna into the AGNS system two circulators (the third ports were terminated) were inserted into the AGNS transmission line to act as isolators providing an additional 40dB of feedback attenuation. With the handset antenna radiating at maximum power, this additional 40 dB of attenuation reduced feedback into the AGNS system to below noise floor level.

The mapping antenna used was an Antenna Research Associates SWH-21 horn antenna, serial number 15087, Figure 5. The antenna was placed on top of the walk-on material in and around the antenna farm at predefined mapping positions. To monitor the received power, an Agilent E4407B Spectrum Analyzer, serial number SG45101181, was connected to the antenna via a 75' Times Microwave Systems LMR-300 coaxial cable. To determine if power was being evenly distributed to the center of the chamber, the receive antenna was to be placed at twenty five different locations marked on the walk-on material. A twenty sixth location was the reference location just outside the antenna farm. The locations can be seen in Figure 2. The front of the receive antenna was approximately four feet above the walk on material. The tripod center was placed over each location marker. To match the transmit polarization from either the ARGUS antenna or the double ridge horn, the receive antenna was positioned normal to the transmit antenna. A shift of approximately +/- 1 foot from the tripod positioner occurred during polarization matching due to positioner limitations.

Figure 5. Mapping Receive Antenna at the ARL Reference Point

<u>Procedure</u>

To begin the process, each vector signal generator was set to transmit a CW tone, three different signal generators at three different frequencies. The spectrum analyzer receiver was set to a span of 20 MHz and a center frequency of 1531 MHz. The receive antenna was placed at position one. The antenna tripod was set up normal to the ARGUS antenna. A laser was placed in the throat of the antenna in order to indicate exactly where the horn antenna was bore sighted to. The positioner on the tripod was then adjusted to bore sight the receive antenna with the transmit antenna; depending on the transmit polarity being measured, the horn antenna was tilted to + or 45° to match polarization. The alignment laser was then removed. Next, distance was measured with a laser range finder from the front face of the receive antenna to the transmit antenna surface. The received mapping signal was recorded for + and -45°, respectively.

The spectrum analyzer receiver was then set to a center frequency of 1631 MHz. The receive horn was aligned to match polarization with the handset double-ridge horn antenna. The handset double ridge horn feed ran east-west; the receive horn feed was aligned to run east-west. The laser pointer was reinserted into the horn throat, the positioner was then adjusted to bore sight the receive antenna with the handset antenna in the ceiling. The alignment laser was then removed.

The distance was measured with a laser range finder from the front face of the receive antenna to the handset transmit antenna surface. The received mapping signal was recorded.

This process was repeated for all 25 mapping locations. In the post-test mapping the resolution of mapping points was increased from 25 points to 81 points.

Analysis

Analysis of the mapping data was performed by calculating Friis Equation losses, using applied power to the transmit antenna and distance to the mapping positions. These results were compared directly to the measured mapping data. Sources of error between the Friis Equation calculations and measured mapping data include:

- Up to +/- 0.2 dB for height differences between mapping measurement plane and the antenna farm/GPS devices locations
- Up to +/- 0.2 dB for mapping antenna shifting due to mechanical constraints of tripod positioner
- Up to +/- 1 dB for absolute accuracy for the receiving Agilent spectrum analyzer.
- Other sources of error include polarization mismatch and handset (double-ridge horn/base station (ARGUS) antenna gain away from bore sight especially around position P25 and, to a lesser extent, positions P1 and P24

A verification of the mapping data was performed using the Friis Equation. The calculated and collected mapping data matched within 2 dB in nearly all of the locations. The measured values appear to be slightly low. At the mapping edges near points P1, P24 and P25 the greatest deviations were measured. The mapping data were consistent with expected values due to the antenna pattern roll-off at the edges.

For the handset antenna (double-ridge horn) the pre-test and post-test mapping measurements matched within 3 db in nearly all locations. The edge roll off was consistent with what was expected.

A similar procedure was used to map the cluttered antenna field. The number of original sample points (25) was reduced to nine that were either on or very close to locations P1, P3, P5, P11, P13, P15, P21, P23, and P25. For the base station antenna (ARGUS), the cluttered field maps for wave 1 devices and wave 2 devices were relatively uniform across those locations with similar variability and approximately 3 dB lower than theoretical values. This indicated that no significant changes were evident as a result of adding the antenna farm to the mapping grid.

For the handset antenna (double-ridge horn), the cluttered field maps for wave 1 devices and wave 2 devices were better at the center of the group being within 3 db of expected and growing to as much as 5 db on the periphery as compared to Friis Equation. To collect the data on the periphery, the receive antenna was positioned to a lower angle increasing the probability of constructive interference from the receive antenna grid. On the outside edges the data suggests that the additional energy received from multipath makes these points hotter than theory predicts. The average appears to be similar to the calculated values for both waves.

Cross polarization was measured and verified at select locations. It was determined to be greater than 15dB but typically 20 to 30 dB, which is consistent with expected values.

Figures 6, 7 and 8 provide 1 dB contour maps, normalized from the center point, P13. Figures 9, 10 and 11 provide 0.2 dB contour maps, normalized from the center point, P13. Figures 9, 10 and 11 were used to populate Table 2 with received power offsets for all locations referenced to position P13 for 1531 MHz and 1632/1651 MHz.

Mapping data can be found after Table 2.

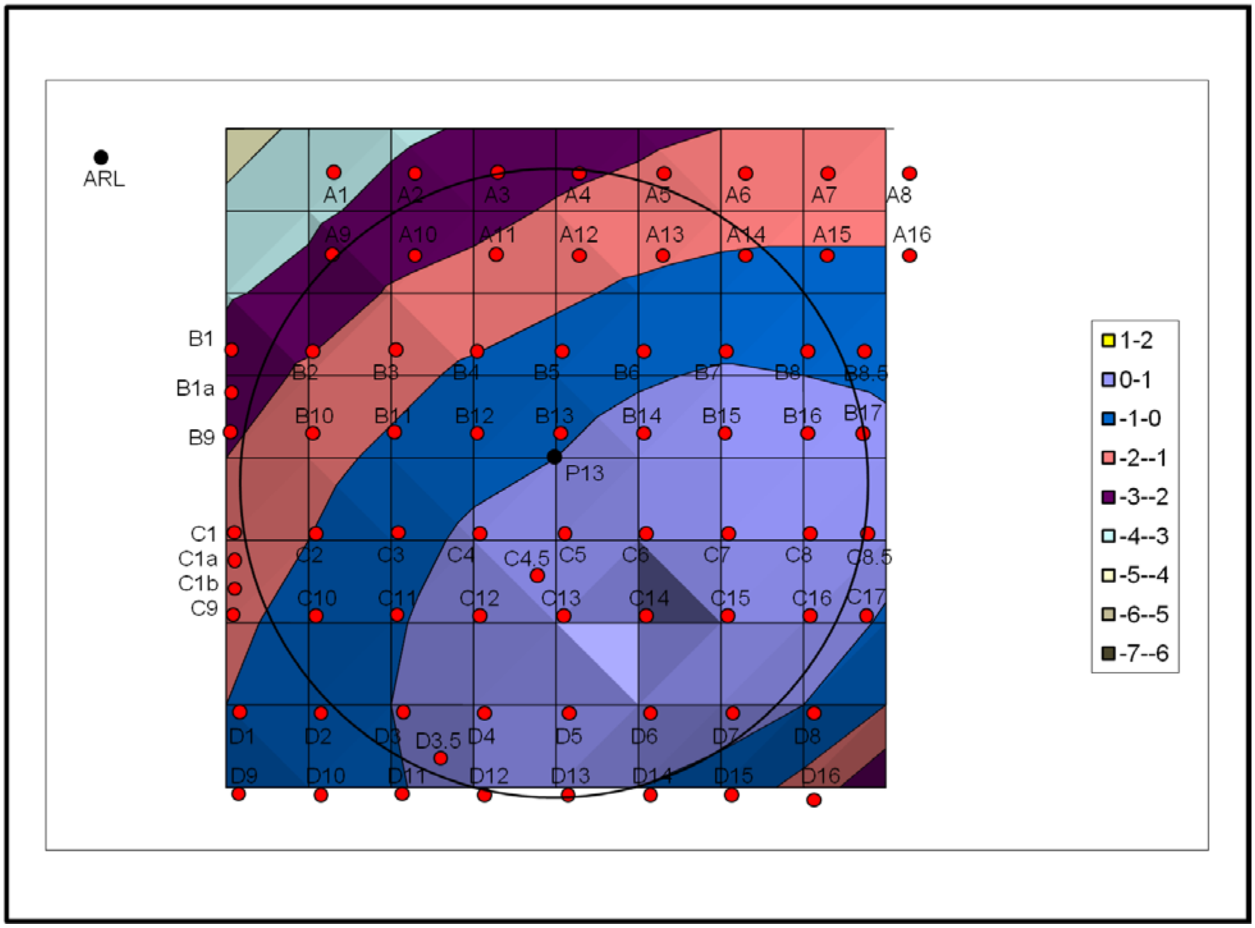

Figure 6. LTE Base Station (Argus Antenna) Mapping Data, +45 Slant, 1 dB Contours

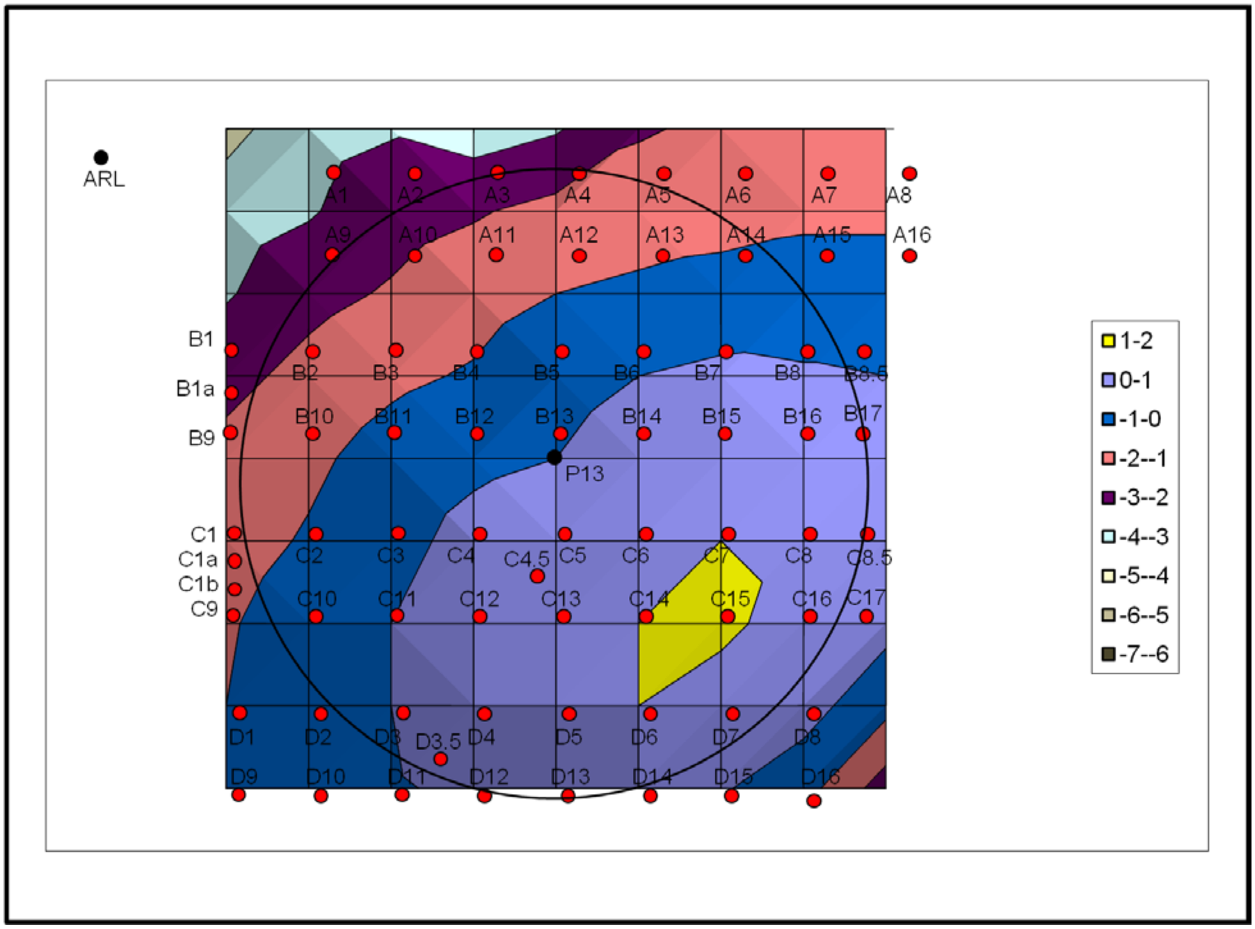

Figure 7. LTE Base Station (Argus Antenna) Mapping Data, -45 Slant, 1 dB Contours

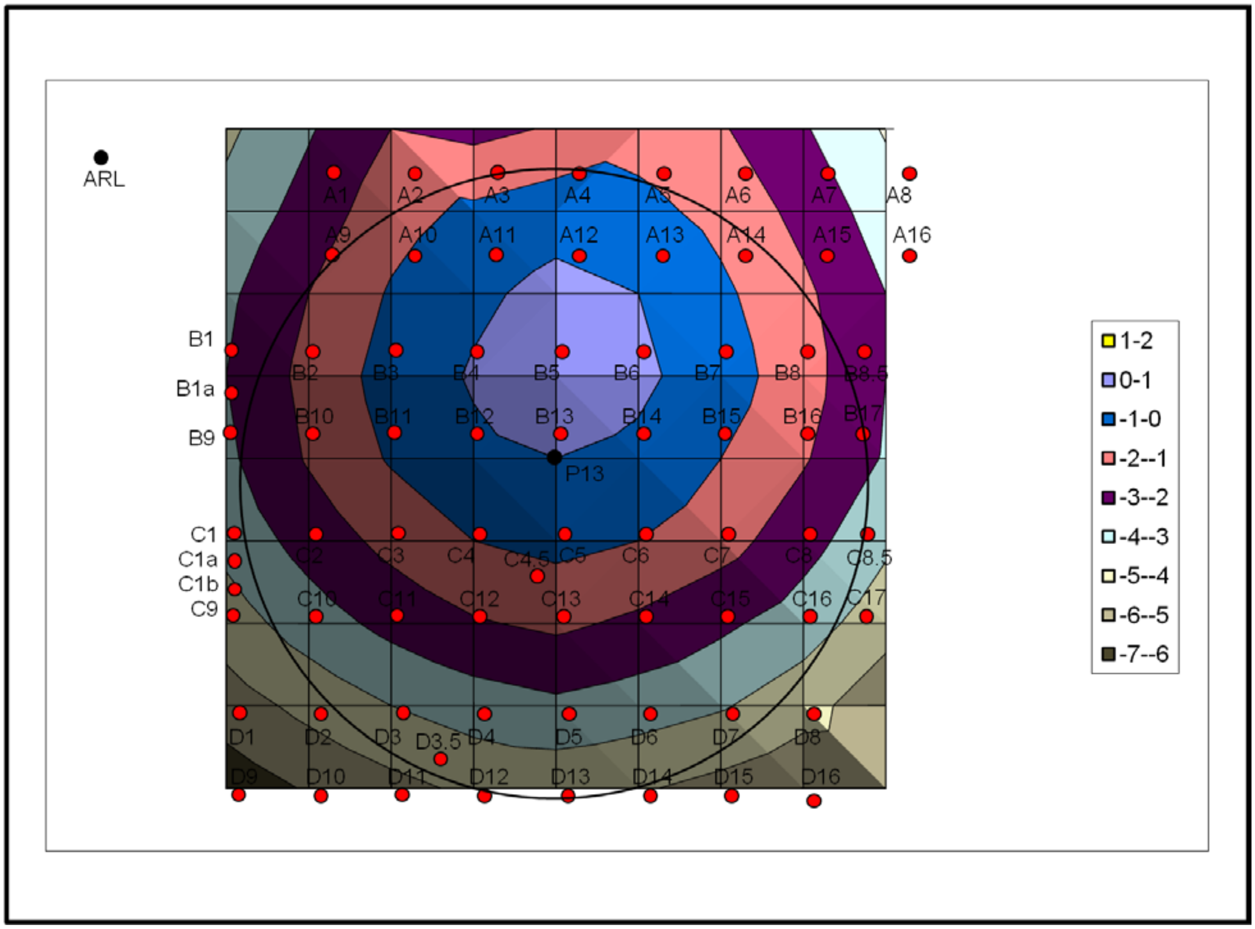

Figure 8. Handset (Double Ridge Horn) Mapping Data, Co-polarization, 1 dB Contours

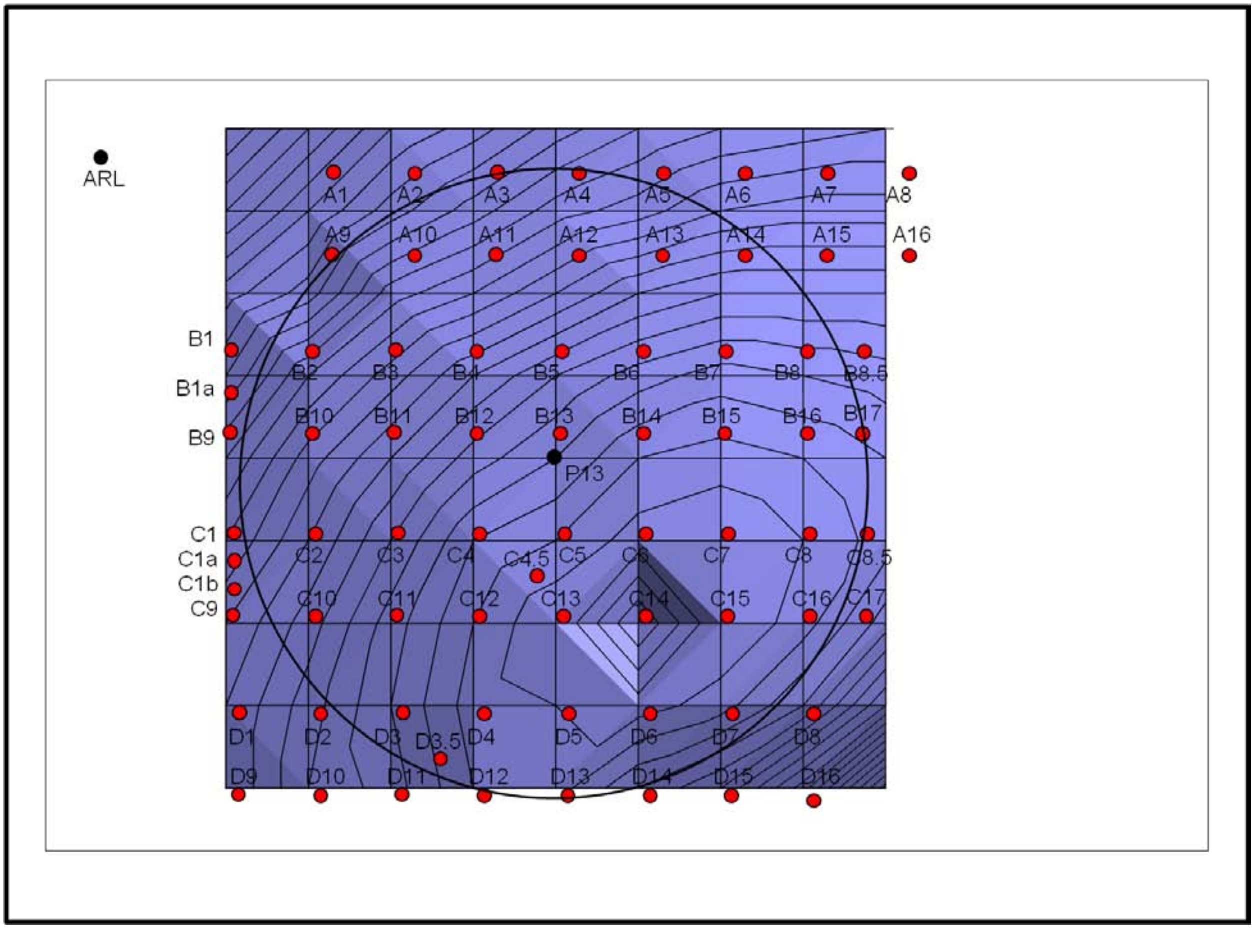

Figure 9. LTE Base Station (Argus Antenna) Mapping Data, +45 Slant, 0.2 dB Contours

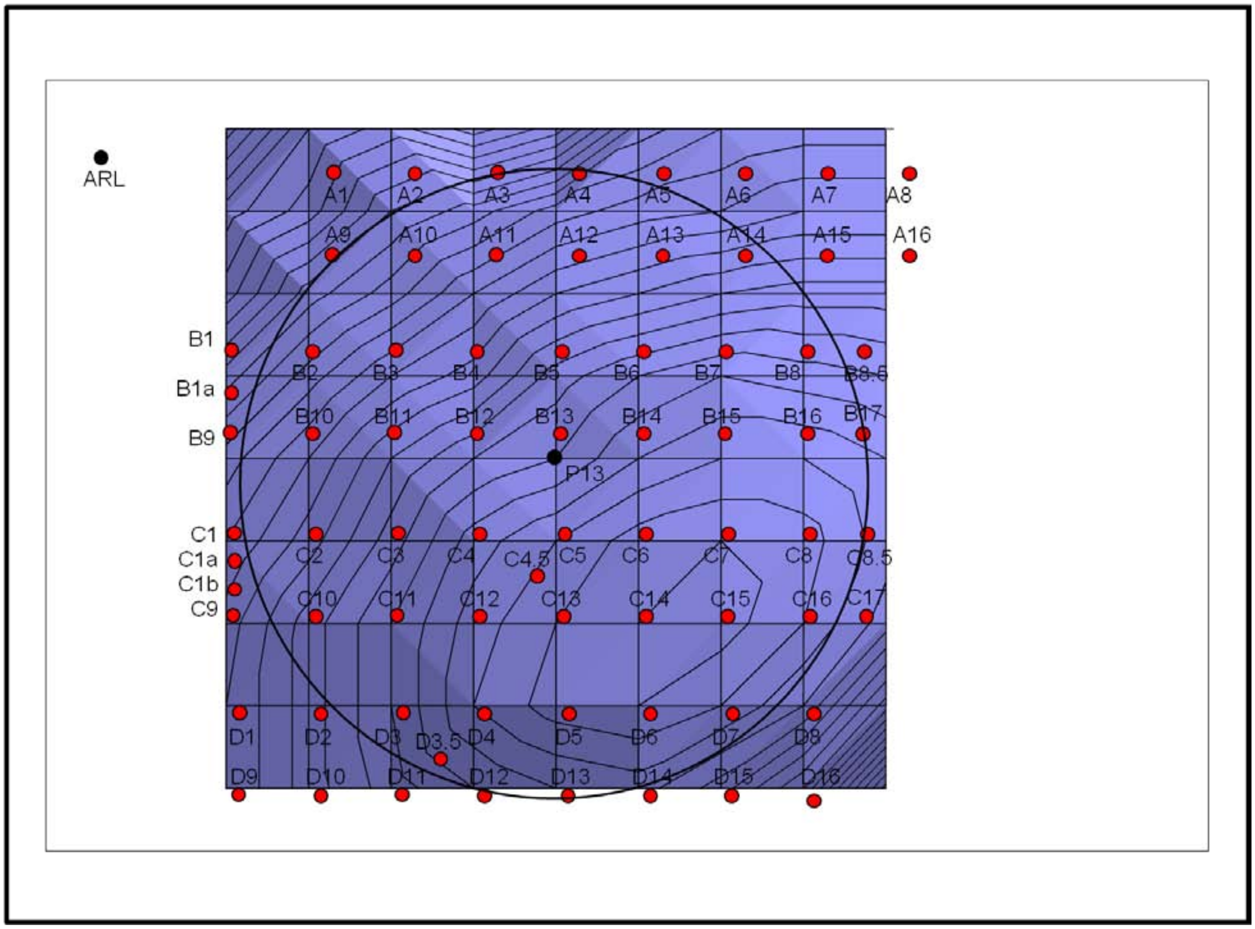

Figure 10. LTE Base Station (Argus Antenna) Mapping Data, -45 Slant, 0.2 dB Contours

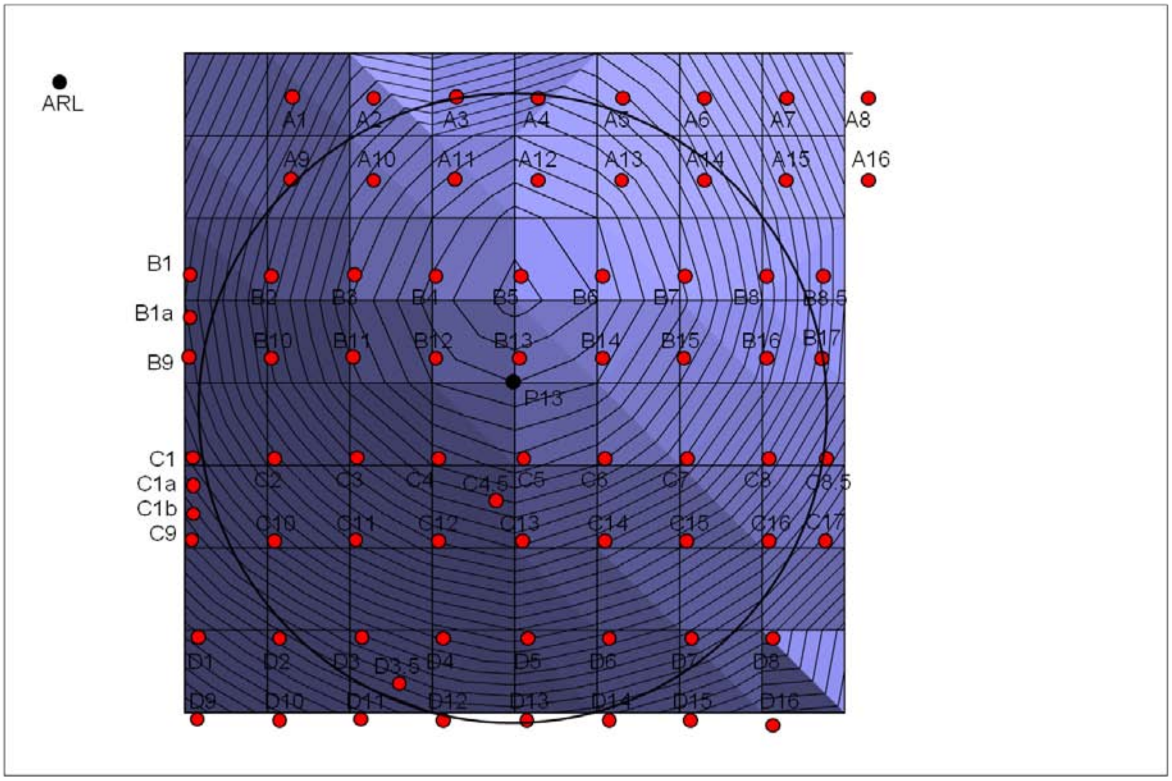

Figure 11. Handset (Double Ridge Horn) Mapping Data, Co-polarization, 0.2 dB Contours

Table 2. Received Power Offsets (from Mapping Position P13) for Antenna Locations

Location	at 1531 MHz	at 1632/1651 MHz
A1	-3.1	-2.5
A2	-2.7	-1.5
A3	-2.6	-1.4
A4	-2.1	-0.9
A5	-1.8	-1.2
A6	-1.6	-1.9
A7	-1.5	-2.9
A8	-1.5	-4.0
A9	-2.5	-1.9
A10	-2.1	-0.9
A11	-1.7	-0.3
A12	-1.4	-0.1
A13	-1.1	-0.5
A14	-0.9	-1.3
A15	-0.9	-2.4
A16	-0.9	-3.5
B1	-2.6	-2.9
B1a	-2.2	-2.9
B2	-1.9	-1.7
B3	-1.5	-0.7
B4	-1.0	0.0
B5	-0.6	+0.4
B6	-0.3	+0.1
B7	-0.1	-0.7
B8	-0.2	-1.7
B8.5	-0.2	-2.6
B9	-2.0	-3.0
B10	-1.4	-1.8
B11	-0.9	-0.8
B12	-0.4	-0.1
B13	-0.1	+0.1
B14	+0.3	-0.2
B15	+0.4	-0.9
B16	+0.4	-1.9
B17	+0.2	-2.7

Table 2 (continued). Received Power Offsets (from Mapping Position P13) for Antenna Locations

Location	at 1531 MHz	at 1632/1651
C1	-1.5	-3.5
C1a	-1.3	-3.8
C1b	-1.3	-4.0
C2	-1.0	-2.5
C3	-0.4	-1.6
C4	+0.2	-0.9
C4.5	+0.5	-1.3
C5	+0.5	-0.7
C6	+0.7	-1.0
C7	+0.8	-1.6
C8	+0.7	-2.7
C8.5	+0.5	-3.5
C9	-1.2	-4.3
C10	-0.6	-3.4
C11	-0.1	-2.6
C12	+0.4	-2.0
C13	+0.7	-1.8
C14	+0.8	-2.2
C15	+0.9	-2.8
C16	+0.6	-3.5
C17	+0.2	-4.3
D1	-0.9	-5.5
D2	-0.4	-4.7
D3	+0.1	-4.0
D3.5	+0.2	-4.6
D4	+0.5	-3.6
D5	+0.7	-3.4
D6	+0.7	-3.7
D7	+0.5	-4.1
D8	-0.1	-4.8
D9	-0.9	-6.6
D10	-0.4	-5.9
D11	0.0	-5.3
D12	+0.3	-4.9
D13	+0.4	-4.9
D14	+0.1	-5.1
D15	-0.4	-5.5
D16	-1.5	-6.0

Mapping Data – Base Station

	Point	Distance to Tx (ft) +45	Distance to Tx (ft) -45	Distance to Tx (ft) Avg	Measured Pwr at Rx (dBm) 1531 MHz +45	Measured Pwr at Rx (dBm) 1531 MHz -45	Measured Power delivered to Tx (dBm) +45	Measured Power delivered to Tx (dBm) -45	Argus - Tx Gain (dB) 1531 MHz +45	Argus - Tx Gain (dB) 1531 MHz -45	Receive Cable (dB) 1531 MHz	Receive Ant Gain (dB) 1531 MHz	Point	Space Loss (dB)	Calculated Pwr at Ant 1531 MHz +45	Calculated Pwr at Ant 1531 MHz -45		Deviation from theory (calculated - measured) 1531 MHz +45	Deviation from theory (calculated - measured) 1531 MHz -45	
Initial Mapping	1	65.3	65.3	65.3	-43.6	-43.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	1	62.1	-41.0	-41.5		2.58	1.68	measured value is low
	2	61.7	61.7	61.7	-42.4	-42.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	2	61.6	-40.5	-41.0		1.87	1.07	
	3	58.8	58.8	58.8	-41.7	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	3	61.2	-40.1	-40.6		1.59	0.69	
	4	56.8	56.7	56.8	-41.2	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	4	60.9	-39.8	-40.3		1.40	0.50	
	5	54.9	54.8	54.9	-41.1	-40.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	5	60.6	-39.5	-40.0		1.59	0.69	
	6	61.3	61.3	61.3	-42.4	-42.0	-4.5	-5.0	16.7	16.7	-6.2	15.1	6	61.6	-40.5	-41.0		1.93	1.03	
	7	57.8	57.8	57.8	-41.2	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	7	61.1	-40.0	-40.5		1.24	0.34	
	8	54.7	54.7	54.7	-40.5	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	8	60.6	-39.5	-40.0		1.02	0.12	
	9	52.0	51.9	52.0	-39.9	-39.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	9	60.1	-39.0	-39.5		0.86	-0.04	
	10	50.4	50.3	50.4	-39.9	-39.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	10	59.9	-38.8	-39.3		1.14	0.24	
	11	56.8	56.8	56.8	-41.2	-40.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	11	60.9	-39.8	-40.3		1.39	0.59	
	12	53.0	53.0	53.0	-40.1	-39.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	12	60.3	-39.2	-39.7		0.89	-0.01	
	13	49.7	49.6	49.7	-39.2	-38.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	13	59.7	-38.6	-39.1		0.56	-0.34	
	14	47.0	47.0	47.0	-38.8	-38.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	14	59.3	-38.2	-38.7		0.63	-0.37	
	15	44.9	44.9	44.9	-39.1	-38.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	15	58.9	-37.8	-38.3		1.33	0.33	
	16	52.6	52.6	52.6	-40.4	-40.0	-4.5	-5.0	16.7	16.7	-6.2	15.1	16	60.2	-39.1	-39.6		1.26	0.36	
	17	48.6	48.6	48.6	-39.3	-38.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	17	59.6	-38.5	-39.0		0.84	-0.06	
	18	44.9	44.9	44.9	-38.6	-38.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	18	58.9	-37.8	-38.3		0.83	-0.17	
	19	41.8	41.8	41.8	-38.4	-37.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	19	58.2	-37.1	-37.6		1.25	0.25	
	20	39.6	39.5	39.6	-39.2	-38.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	20	57.8	-36.7	-37.2		2.53	1.53	
	21	48.8	48.7	48.8	-40.2	-39.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	21	59.6	-38.5	-39.0		1.72	0.82	
	22	44.6	44.5	44.6	-39.3	-38.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	22	58.8	-37.7	-38.2		1.60	0.70	
	23	40.7	40.6	40.7	-38.7	-38.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	23	58.0	-36.9	-37.4		1.79	0.89	
	24	37.1	37.0	37.1	-39.4	-38.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	24	57.2	-36.1	-36.6		3.30	2.30	the measured value is Low
																	Average	1.46	0.55	
Cluttered Mapping	Wave 1																			
	1			65.2	-44.8	-45.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	1	62.1	-41.0	-41.5		3.79	3.99	measured value is low
	2																			
	3			59.4	-43.9	-43.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	3	61.3	-40.2	-40.7		3.70	3.10	
	4																			
	5			55.2	-43.1	-43.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	5	60.7	-39.6	-40.1		3.54	3.34	
	6			61.3	-44.4	-45	-4.5	-5.0	16.7	16.7	-6.2	15.1	6	61.6	-40.5	-41.0		3.93	4.03	
	7																			
	8			54.6	-41.8	-42.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	8	60.6	-39.5	-40.0		2.33	2.53	
	9																			
	10			50.3	-41.3	-41.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	10	59.9	-38.8	-39.3		2.54	2.64	
	11			56.5	-42.7	-42.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	11	60.9	-39.8	-40.3		2.93	2.63	
	12																			
	13			48.7	-40.7	-41.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	13	59.6	-38.5	-39.0		2.23	2.23	
	14																			
	15			44.3	-40.2	-40.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	15	58.8	-37.7	-38.2		2.55	2.45	
	16			51.8	-42	-42.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	16	60.1	-39.0	-39.5		2.99	2.79	
	17																			
	18			43.6	-39.7	-40	-4.5	-5.0	16.7	16.7	-6.2	15.1	18	58.6	-37.5	-38.0		2.19	1.99	
	19																			
	20			38.3	-40.1	-40.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	20	57.5	-36.4	-36.9		3.71	3.81	
	21			47.6	-41.5	-42	-4.5	-5.0	16.7	16.7	-6.2	15.1	21	59.4	-38.3	-38.8		3.22	3.22	
	22																			
	23			39	-39.7	-40.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	23	57.6	-36.5	-37.0		3.15	3.15	
	24																			
	25			46.7	-41.6	-42	-4.5	-5.0	16.7	16.7	-6.2	15.1	25	59.2	-38.1	-38.6		3.49	3.39	the measured value is Low
																	Average	3.09	3.02	
							computed for -50 drive	computed for -50 drive												
Reference Map		drive					-4.5	-5.0												
	center												center							
	mod	-32.3	-32.2	48.6	-21.1	-21.1	13.2	12.8	16.7	16.7	-6.2	15.1	mod	59.6	-20.8	-21.2		0.34	-0.06	
	mod	-57.3	-57.2	48.6	-46.1	-46.1	-11.8	-12.2	16.7	16.7	-6.2	15.1	mod	59.6	-45.8	-46.2		0.34	-0.06	
	mod	-12.2	-11.8	48.6	-1.1	-1.1	33.3	33.2	16.7	16.7	-6.2	15.1	mod	59.6	-0.7	-0.8		0.44	0.34	
	cw	-12.2	-11.8	48.6	-1.0	-1.0	33.3	33.2	16.7	16.7	-6.2	15.1	cw	59.6	-0.7	-0.8		0.34	0.24	
	reference												reference							
	cw	-50	-50	67.7	-43.7	-43.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	cw	62.4	-41.3	-41.8		2.36	1.86	
	mod	-12.2	-11.8	67.7	-5.9	-5.9	33.3	33.2	16.7	16.7	-6.2	15.1	mod	62.4	-3.5	-3.6		2.36	2.26	
	combined cw Rx horiz	-50	-50	67.7	-48.0		-4.5	-5.0	16.7	16.7	-6.2	15.1	d cw Rx horiz	62.4	-41.3	-41.8		6.66		
	combined mod Rx horiz	-12.2	-11.8	67.7	-7.1		33.3	33.2	16.7	16.7	-6.2	15.1	mod Rx horiz	62.4	-3.5	-3.6		3.56		
Cluttered	Wave 2																			

Mapping	ARL reference	67.6	-45.7	-45.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	ARL reference	62.4	-41.3	-41.8		4.38	3.58	
	1	65.1	-44.8	-46.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	1	62.1	-41.0	-41.5		3.80	4.80	
	2																	
	3	59.6	-44.3	-44.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	3	61.3	-40.2	-40.7		4.07	4.07	
	4																	
	5	55.7	-43	-43.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	5	60.7	-39.6	-40.1		3.36	3.56	
	6	61.2	-44.5	-44.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	6	61.6	-40.5	-41.0		4.04	3.94	
	7																	
	8	54.4	-42.3	-42.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	8	60.5	-39.4	-39.9		2.86	2.86	
	9																	
	10	50.2	-41.5	-41.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	10	59.8	-38.7	-39.2		2.76	2.66	
	11	56.4	-43	-43.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	11	60.8	-39.7	-40.2		3.25	2.85	
	12																	
	13	48.7	-40.4	-41.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	13	59.6	-38.5	-39.0		1.93	2.23	
	14																	
	15	44.1	-40	-40.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	15	58.7	-37.6	-38.1		2.39	2.39	
	16	51.4	-42	-41.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	16	60.0	-38.9	-39.4		3.06	2.36	
	17																	
	18	43.7	-39.5	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	18	58.6	-37.5	-38.0		1.97	2.07	
	19																	
	20	38.3	-39.8	-40.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	20	57.5	-36.4	-36.9		3.41	3.41	
	21	47.6	-41.5	-42.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	21	59.4	-38.3	-38.8		3.22	3.32	
	22																	
	23	38.8	-39.6	-40.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	23	57.6	-36.5	-37.0		3.10	3.20	
	24																	
	25	34	-41.3	-41.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	25	56.5	-35.4	-35.9		5.95	5.75	the measured value is
															Average	3.35	3.32	Low
Final Mapping	ARL	67.6	-44.4	-44.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	ARL	62.4	-41.3	-41.8		3.08	2.78	
	1	65.3	-43.4	-43.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	1	62.1	-41.0	-41.5		2.38	2.38	
	1.5	63.6	-42.8	-43	-4.5	-5.0	16.7	16.7	-6.2	15.1	1.5	61.9	-40.8	-41.3		2.01	1.71	
	2	61.9	-42.2	-42.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	2	61.7	-40.6	-41.1		1.64	1.64	
	2.5	60.5	-41.9	-43.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	2.5	61.5	-40.4	-40.9		1.54	2.24	
	3	59.2	-41.5	-42.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	3	61.3	-40.2	-40.7		1.33	2.03	
	3.5	58	-41.2	-41.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	3.5	61.1	-40.0	-40.5		1.21	1.21	
	4	56.8	-41	-41.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	4	60.9	-39.8	-40.3		1.19	1.09	
	4.5	55.8	-40.9	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	4.5	60.8	-39.7	-40.2		1.24	1.14	
	5	55	-40.8	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	5	60.6	-39.5	-40.0		1.27	1.27	
	1A	63.6	-42.8	-43.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	1A	61.9	-40.8	-41.3		2.01	1.81	
	1.5A	62	-42.2	-42.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	1.5A	61.7	-40.6	-41.1		1.63	1.63	
	2A	60.2	-41.7	-42	-4.5	-5.0	16.7	16.7	-6.2	15.1	2A	61.4	-40.3	-40.8		1.38	1.18	
	2.5A	58.8	-41.3	-41.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	2.5A	61.2	-40.1	-40.6		1.19	1.09	
	3A	57	-40.9	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	3A	60.9	-39.8	-40.3		1.06	0.96	
	3.5A	56.3	-40.7	-41.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	3.5A	60.8	-39.7	-40.2		0.97	0.87	
	4A	54.9	-40.4	-41	-4.5	-5.0	16.7	16.7	-6.2	15.1	4A	60.6	-39.5	-40.0		0.88	0.98	
	4.5A	54.1	-40.3	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	4.5A	60.5	-39.4	-39.9		0.91	0.91	
	5A	53.1	-40.3	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	5A	60.3	-39.2	-39.7		1.07	1.07	
	6	61.3	-42.1	-42.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	6	61.6	-40.5	-41.0		1.63	1.73	
	6.5	59.5	-41.7	-41.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	6.5	61.3	-40.2	-40.7		1.49	1.19	
	7	58	-40.9	-41.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	7	61.1	-40.0	-40.5		0.91	1.01	
	7.5	56.3	-40.6	-41	-4.5	-5.0	16.7	16.7	-6.2	15.1	7.5	60.8	-39.7	-40.2		0.87	0.77	
	8	54.7	-40.2	-40.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	8	60.6	-39.5	-40.0		0.72	0.62	
	8.5	53.2	-39.8	-40.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	8.5	60.3	-39.2	-39.7		0.56	0.66	
	9	52.2	-39.6	-40.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	9	60.2	-39.1	-39.6		0.52	0.62	
	9.5	51.3	-39.6	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	9.5	60.0	-38.9	-39.4		0.67	0.67	
	10	50.5	-39.6	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	10	59.9	-38.8	-39.3		0.81	0.81	
	6A	58.9	-41.6	-41.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	6A	61.2	-40.1	-40.6		1.47	1.27	
	6.5A	57.3	-40.8	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	6.5A	61.0	-39.9	-40.4		0.91	0.91	
	7A	55.4	-40.3	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	7A	60.7	-39.6	-40.1		0.71	0.71	
	7.5A	53.8	-39.8	-40.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	7.5A	60.4	-39.3	-39.8		0.46	0.66	
	8A	52.2	-39.4	-39.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	8A	60.2	-39.1	-39.6		0.32	0.32	
	8.5A	51	-39.1	-39.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	8.5A	60.0	-38.9	-39.4		0.22	0.22	
	9A	49.5	-38.9	-39.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	9A	59.7	-38.6	-39.1		0.28	0.28	
	9.5A	48.6	-39	-39.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	9.5A	59.6	-38.5	-39.0		0.54	0.54	
	10A	47.6	-39.1	-39.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	10A	59.4	-38.3	-38.8		0.82	0.82	
	11	56.8	-41	-41.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	11	60.9	-39.8	-40.3		1.19	0.99	
	11.5	54.9	-40.3	-40.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	11.5	60.6	-39.5	-40.0		0.78	0.78	
	12	53.1	-39.8	-40.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	12	60.3	-39.2	-39.7		0.57	0.47	
	12.5	51.3	-39.3	-39.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	12.5	60.0	-38.9	-39.4		0.37	0.37	
	13	49.8	-39.0	-39.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	13	59.8	-38.7	-39.2		0.33	0.43	
	13.5	48.3	-38.6	-39.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	13.5	59.5	-38.4	-38.9		0.20	0.30	
	14	46.8	-38.5	-39	-4.5	-5.0	16.7	16.7	-6.2	15.1	14	59.2	-38.1	-38.6		0.37	0.37	
	14.5	46	-38.6	-39	-4.5	-5.0	16.7	16.7	-6.2	15.1	14.5	59.1	-38.0	-38.5		0.62	0.52	
	15	44.9	-38.8	-39.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	15	58.9	-37.8	-38.3		1.03	0.93	

11A			54.7	-40.6	-41	-4.5	-5.0	16.7	16.7	-6.2	15.1	11A	60.6	-39.5	-40.0		1.12	1.02	
11.5A			52.6	-40	-40.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	11.5A	60.2	-39.1	-39.6		0.86	0.86	
12A			50.8	-39.4	-39.9	-4.5	-5.0	16.7	16.7	-6.2	15.1	12A	59.9	-38.8	-39.3		0.56	0.56	
12.5A			48.9	-38.8	-39.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	12.5A	59.6	-38.5	-39.0		0.29	0.29	
13A			47.4	-38.6	-39	-4.5	-5.0	16.7	16.7	-6.2	15.1	13A	59.3	-38.2	-38.7		0.36	0.26	
13.5A			45.7	-38.3	-38.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	13.5A	59.0	-37.9	-38.4		0.38	0.28	
14A			44.5	-38.2	-38.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	14A	58.8	-37.7	-38.2		0.51	0.41	
14.5A			43.1	-38.4	-38.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	14.5A	58.5	-37.4	-37.9		0.99	0.79	
15A			42.2	-38.7	-39.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	15A	58.3	-37.2	-37.7		1.47	1.37	
16			52.5	-40.2	-40.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	16	60.2	-39.1	-39.6		1.07	1.07	
16.5			50.6	-39.7	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	16.5	59.9	-38.8	-39.3		0.89	0.79	
17			48.6	-39.1	-39.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	17	59.6	-38.5	-39.0		0.64	0.64	
17.5			46.8	-38.6	-39.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	17.5	59.2	-38.1	-38.6		0.47	0.47	
18			45	-38.2	-38.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	18	58.9	-37.8	-38.3		0.41	0.51	
18.5			43.4	-39	-38.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	18.5	58.6	-37.5	-38.0		1.53	0.63	
19			41.8	-38.2	-38.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	19	58.2	-37.1	-37.6		1.05	0.85	
19.5			40.7	-38.5	-38.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	19.5	58.0	-36.9	-37.4		1.58	1.38	
20			39.3	-39.1	-39.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	20	57.7	-36.6	-37.1		2.49	2.19	
16A			50.7	-40	-40.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	16A	59.9	-38.8	-39.3		1.18	1.28	
16.5A			48.5	-39.5	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	16.5A	59.5	-38.4	-38.9		1.06	1.16	
17A			46.5	-39	-39.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	17A	59.2	-38.1	-38.6		0.93	1.03	
17.5A			44.6	-38.5	-39	-4.5	-5.0	16.7	16.7	-6.2	15.1	17.5A	58.8	-37.7	-38.2		0.79	0.79	
18A			42.7	-38.4	-38.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	18A	58.4	-37.3	-37.8		1.07	0.87	
18.5A			40.7	-38.3	-38.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	18.5A	58.0	-36.9	-37.4		1.38	1.18	
19A			39.5	-38.5	-38.8	-4.5	-5.0	16.7	16.7	-6.2	15.1	19A	57.8	-36.7	-37.2		1.84	1.64	
19.5A			38.1	-39	-39.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	19.5A	57.4	-36.3	-36.8		2.66	2.36	
20A			36.9	-40	-40.3	-4.5	-5.0	16.7	16.7	-6.2	15.1	20A	57.2	-36.1	-36.6		3.94	3.74	
21			48.7	-40	-40.6	-4.5	-5.0	16.7	16.7	-6.2	15.1	21	59.6	-38.5	-39.0		1.53	1.63	
21.5			46.7	-39.4	-40.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	21.5	59.2	-38.1	-38.6		1.29	1.49	
22			44.5	-39.1	-39.7	-4.5	-5.0	16.7	16.7	-6.2	15.1	22	58.8	-37.7	-38.2		1.41	1.51	
22.5			42.5	-38.6	-39.4	-4.5	-5.0	16.7	16.7	-6.2	15.1	22.5	58.4	-37.3	-37.8		1.31	1.61	
23			40.5	-38.5	-39.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	23	58.0	-36.9	-37.4		1.63	1.83	
23.5			38.1	-39	-39.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	23.5	57.4	-36.3	-36.8		2.66	2.26	
24			36.9	-39.4	-39.5	-4.5	-5.0	16.7	16.7	-6.2	15.1	24	57.2	-36.1	-36.6		3.34	2.94	
24.5			35.9	-40.3	-40.2	-4.5	-5.0	16.7	16.7	-6.2	15.1	24.5	56.9	-35.8	-36.3		4.47	3.87	
25			34	-41.9	-42.1	-4.5	-5.0	16.7	16.7	-6.2	15.1	25	56.5	-35.4	-35.9		6.55	6.25	the measured value is
																Average	1.26	1.20	Low

Mapping Notes:

Argus antenna size 1.35 meters
wavelength 0.2 meters

Far Field	$2D^2/\lambda$	18.23	meters	59.79	ft
	D^2/λ	9.11	meters	29.90	ft

Tx (physically pointing down 14 degrees, electrically pointing down 2 deg)
Argus Antenna, Model HPX308R, Serial number 67570030

Rx (aligned with laser pointer in throat of antenna)
ARA Horn SWH-21, SN 15087
Receive antenna was boresighted to Argus antenna
Distance between Rx and Argus antenna was measured from the front face of horn to front face of Argus with laser rangefinder
Height of receive antenna was approximately 52" for the +45 slant and 46" for the -45 slant
Receive antenna was mounted on a tripod with the center of the tripod positioned over the map point.
therefore, the distance between the two antennas was shorter by less than 2 ft.

Equations used:

space loss = $-27.55+20\log(f_{MHz}) + 20\mathrm{Log}(R_{(m)})$

Calculated Pwr = Pwr at Tx + Tx Gain - Space Loss + Rx Gain + Rec cable

Deviation from theory = Calculated - Measured

Mapping Data – Handset

	Point	Distance to Tx (ft) 1632 MHz		Avg	Measured Pwr at Rx (dBm) co-pol 1632 MHz	cross-pol 1632 MHz	co-pol 1652 MHz	Measured Power delivered to Tx (dBm) 1632 MHz	1652 MHz	Measured Tx Gain (dB)	Receive Cable (dB) 1632 MHz	Receive Ant Gain (dB) 1630 MHz
Initial Mapping	1	29.1		29.1	-49.6	-62.2	-49.8	-10.0	-10.0	8.5	-6.4	15.3
	2	27.1		27.1	-47.2			-10.0		8.5	-6.4	15.3
	3	26.5		26.5	-46.4		-46.3	-10.0	-10.0	8.5	-6.4	15.3
	4	27.5		27.5	-47.3			-10.0		8.5	-6.4	15.3
	5	29.2		29.2	-49.4		-49.4	-10.0	-10.0	8.5	-6.4	15.3
	6	28.0		28.0	-48.5			-10.0		8.5	-6.4	15.3
	7	26.4		26.4	-46.2			-10.0		8.5	-6.4	15.3
	8	25.7		25.7	-45.0			-10.0		8.5	-6.4	15.3
	9	26.2		26.2	-45.9			-10.0		8.5	-6.4	15.3
	10	27.8		27.8	-48.2			-10.0		8.5	-6.4	15.3
	11	28.0		28.0	-48.6		-48.8	-10.0	-10.0	8.5	-6.4	15.3
	12	26.4		26.4	-46.2			-10.0		8.5	-6.4	15.3
	13	25.9		25.9	-45.1		-45.2	-10.0	-10.0	8.5	-6.4	15.3
	14	26.7		26.7	-46.1			-10.0		8.5	-6.4	15.3
	15	28.6		28.6	-48.4		-48.6	-10.0	-10.0	8.5	-6.4	15.3
	16	29.7		29.7	-49.9			-10.0		8.5	-6.4	15.3
	17	28.0		28.0	-48.0			-10.0		8.5	-6.4	15.3
	18	27.3		27.3	-47.1			-10.0		8.5	-6.4	15.3
	19	28.1		28.1	-47.9			-10.0		8.5	-6.4	15.3
	20	30.0		30.0	-49.8		-52.0	-10.0	-10.0	8.5	-6.4	15.3
	21	32.1		32.1	-51.9			-10.0		8.5	-6.4	15.3
	22	30.5		30.5	-50.6			-10.0		8.5	-6.4	15.3
	23	29.7		29.7	-49.6		-49.8	-10.0	-10.0	8.5	-6.4	15.3
	24	30.6		30.6	-50.3			-10.0		8.5	-6.4	15.3
Cluttered	Wave 1											
Mapping	1			28.6	-51.2			-10.0		8.5	-6.4	15.3
	2											
	3			26	-48.3			-10.0		8.5	-6.4	15.3
	4											
	5			28.6	-51.5			-10.0		8.5	-6.4	15.3
	6			28	-50.3			-10.0		8.5	-6.4	15.3
	7											
	8			25.2	-46.6			-10.0		8.5	-6.4	15.3
	9											
	10			27.6	-50.1			-10.0		8.5	-6.4	15.3
	11			28.1	-50.4			-10.0		8.5	-6.4	15.3
	12											
	13			25.3	-49.2	-74.3		-10.0		8.5	-6.4	15.3
	14											
	15			28.2	-50.2			-10.0		8.5	-6.4	15.3
	16			29.6	-51.7			-10.0		8.5	-6.4	15.3
	17											
	18			27.7	-49.5			-10.0		8.5	-6.4	15.3
	19											
	20			30.2	-51.9			-10.0		8.5	-6.4	15.3
	21			32.6	-54.2			-10.0		8.5	-6.4	15.3
	22											
	23			30	-52.3			-10.0		8.5	-6.4	15.3
	24											
	25			31.8	-53.5			-10.0		8.5	-6.4	15.3
								computed				
Reference		drive						for -50 drive				
Map	center							-10.0				
	mod	-5.8		25.7	-1.1			34.2		8.5	-6.4	15.3
	cw	-50		25.7	-44.6			-10.0		8.5	-6.4	15.3
reference												
	mod	-5.8			-7.2			34.2		8.5	-6.4	15.3
	cw hp	-5.8			-7	-50		34.2		8.5	-6.4	15.3
Cluttered	Wave 2											
Mapping	ARL Reference			31.1	-53.1			-10.0		8.5	-6.4	15.3
	1			29	-52.6			-10.0		8.5	-6.4	15.3
	2											
	3			26.3	-48.2			-10.0		8.5	-6.4	15.3

Point	Space Loss (dB)	Calculated Pwr at Ant 1531 MHz 1632 MHz	1652 MHz		Deviation from theory (calculated - measured) 1531 MHz 1632 MHz	1652 MHz	
1	55.7	-48.3	-48.3		1.34	1.54	
2	55.0	-47.6			-0.44		
3	54.8	-47.4	-47.4		-1.05	-1.15	
4	55.2	-47.8			-0.47		
5	55.7	-48.3	-48.3		1.11	1.11	
6	55.3	-47.9			0.57		
7	54.8	-47.4			-1.22		
8	54.6	-47.2			-2.18		
9	54.8	-47.4			-1.45		
10	55.3	-47.9			0.33		
11	55.3	-47.9	-47.9		0.67	0.87	
12	54.8	-47.4			-1.22		
13	54.7	-47.3	-47.3		-2.15	-2.05	
14	54.9	-47.5			-1.41		
15	55.5	-48.1	-48.1		0.29	0.49	
16	55.8	-48.4			1.46		
17	55.3	-47.9			0.07		
18	55.1	-47.7			-0.61		
19	55.4	-48.0			-0.06		
20	55.9	-48.5	-48.5		1.27	3.47	
21	56.5	-49.1			2.79		
22	56.1	-48.7			1.93		
23	55.8	-48.4	-48.4		1.16	1.36	
24	56.1	-48.7			1.60		the measured value is
				Average	0.10	0.70	High
1	55.5	-48.1			3.09		
2							
3	54.7	-47.3			1.02		
4							
5	55.5	-48.1			3.39		
6	55.3	-47.9			2.37		
7							
8	54.4	-47.0			-0.41		
9							
10	55.2	-47.8			2.30		
11	55.4	-48.0			2.44		
12							
13	54.4	-47.0			2.15		
14							
15	55.4	-48.0			2.21		
16	55.8	-48.4			3.29		
17							
18	55.2	-47.8			1.67		
19							
20	56.0	-48.6			3.32		
21	56.6	-49.2			4.95		
22							
23	55.9	-48.5			3.77		
24							
25	56.4	-49.0			4.47		
				Average	2.67		
center							
mod	54.6	-3.0			-1.88	measured is hot	
cw	54.6	-47.2			-2.58	measured is hot	
reference							
mod							
cw hp							
ARL Referenc	56.2	-48.8			4.26		
1	55.6	-48.2			4.37		
2							
3	54.8	-47.4			0.82		

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	4									4				
	5	28.6	-51.3			-10.0	8.5	-6.4	15.3	5	55.5	-48.1		3.19
	6	27.5	-50.3			-10.0	8.5	-6.4	15.3	6	55.2	-47.8		2.53
	7									7				
	8	24.9	-46.5			-10.0	8.5	-6.4	15.3	8	54.3	-46.9		-0.41
	9									9				
	10	27.5	-50			-10.0	8.5	-6.4	15.3	10	55.2	-47.8		2.23
	11	27.9	-50.3			-10.0	8.5	-6.4	15.3	11	55.3	-47.9		2.40
	12									12				
	13	25.4	-47.3	-87	in noise	-10.0	8.5	-6.4	15.3	13	54.5	-47.1		0.22
	14									14				
	15	28	-50.1			-10.0	8.5	-6.4	15.3	15	55.3	-47.9		2.17
	16	29.5	-52.2			-10.0	8.5	-6.4	15.3	16	55.8	-48.4		3.82
	17									17				
	18	27.2	-49.3			-10.0	8.5	-6.4	15.3	18	55.1	-47.7		1.62
	19									19				
	20	29.6	-51.8			-10.0	8.5	-6.4	15.3	20	55.8	-48.4		3.39
	21	32.3	-54.1			-10.0	8.5	-6.4	15.3	21	56.6	-49.2		4.93
	22									22				
	23	30.6	-54.2			-10.0	8.5	-6.4	15.3	23	56.1	-48.7		5.50
	24									24				
	25	31.8	-53.8			-10.0	8.5	-6.4	15.3	25	56.4	-49.0		4.77
													Average	2.86
Final Mapping	ARL	31.1	-50.4			-10.0	8.5	-6.4	15.3	ARL	56.2	-48.8		1.56
	1	29.1	-48.5			-10.0	8.5	-6.4	15.3	1	55.7	-48.3		0.24
	1.5	28	-47.4			-10.0	8.5	-6.4	15.3	1.5	55.3	-47.9		-0.53
	2	27	-46.3			-10.0	8.5	-6.4	15.3	2	55.0	-47.6		-1.31
	2.5	26.6	-46.6			-10.0	8.5	-6.4	15.3	2.5	54.9	-47.5		-0.88
	3	26.4	-46.2			-10.0	8.5	-6.4	15.3	3	54.8	-47.4		-1.22
	3.5	26.8	-45.7			-10.0	8.5	-6.4	15.3	3.5	54.9	-47.5		-1.85
	4	26.7	-46.2			-10.0	8.5	-6.4	15.3	4	54.9	-47.5		-1.31
	4.5	28	-47.2			-10.0	8.5	-6.4	15.3	4.5	55.3	-47.9		-0.73
	5	29.1	-48.4			-10.0	8.5	-6.4	15.3	5	55.7	-48.3		0.14
	1A	28.6	-48			-10.0	8.5	-6.4	15.3	1A	55.5	-48.1		-0.11
	1.5A	27.8	-46.9			-10.0	8.5	-6.4	15.3	1.5A	55.3	-47.9		-0.97
	2A	26.7	-45.7			-10.0	8.5	-6.4	15.3	2A	54.9	-47.5		-1.81
	2.5A	26	-45.1			-10.0	8.5	-6.4	15.3	2.5A	54.7	-47.3		-2.18
	3A	26	-44.7			-10.0	8.5	-6.4	15.3	3A	54.7	-47.3		-2.58
	3.5A	26.4	-45			-10.0	8.5	-6.4	15.3	3.5A	54.8	-47.4		-2.42
	4A	26.9	-45.6			-10.0	8.5	-6.4	15.3	4A	55.0	-47.6		-1.98
	4.5A	27.5	-46.6			-10.0	8.5	-6.4	15.3	4.5A	55.2	-47.8		-1.17
	5A	28.5	-47.8			-10.0	8.5	-6.4	15.3	5A	55.5	-48.1		-0.28
	6	28.3	-47.5			-10.0	8.5	-6.4	15.3	6	55.4	-48.0		-0.52
	6.5	27.2	-46.3			-10.0	8.5	-6.4	15.3	6.5	55.1	-47.7		-1.38
	7	26.4	-45.2			-10.0	8.5	-6.4	15.3	7	54.8	-47.4		-2.22
	7.5	25.7	-44.5			-10.0	8.5	-6.4	15.3	7.5	54.6	-47.2		-2.68
	8	25.5	-44			-10.0	8.5	-6.4	15.3	8	54.5	-47.1		-3.12
	8.5	25.6	-44.3			-10.0	8.5	-6.4	15.3	8.5	54.5	-47.1		-2.85
	9	26.3	-45.1			-10.0	8.5	-6.4	15.3	9	54.8	-47.4		-2.28
	9.5	27.4	-46.1			-10.0	8.5	-6.4	15.3	9.5	55.1	-47.7		-1.64
	10	28.4	-47.3			-10.0	8.5	-6.4	15.3	10	55.5	-48.1		-0.75
	6A	27.8	-47.3			-10.0	8.5	-6.4	15.3	6A	55.3	-47.9		-0.57
	6.5A	31.9	-46			-10.0	8.5	-6.4	15.3	6.5A	56.5	-49.1		-3.06
	7A	26.3	-44.9			-10.0	8.5	-6.4	15.3	7A	54.8	-47.4		-2.48
	7.5A	25.8	-44.2			-10.0	8.5	-6.4	15.3	7.5A	54.6	-47.2		-3.02
	8A	25.5	-43.8			-10.0	8.5	-6.4	15.3	8A	54.5	-47.1		-3.32
	8.5A	25.7	-44.1			-10.0	8.5	-6.4	15.3	8.5A	54.6	-47.2		-3.08
	9A	26.4	-44.8			-10.0	8.5	-6.4	15.3	9A	54.8	-47.4		-2.62
	9.5A	27.2	-45.9			-10.0	8.5	-6.4	15.3	9.5A	55.1	-47.7		-1.78
	10A	28.4	-47.3			-10.0	8.5	-6.4	15.3	10A	55.5	-48.1		-0.75
	11	32.2	-47.5			-10.0	8.5	-6.4	15.3	11	56.5	-49.1		-1.64
	11.5	27.5	-46.2			-10.0	8.5	-6.4	15.3	11.5	55.2	-47.8		-1.57
	12	26.5	-45.2			-10.0	8.5	-6.4	15.3	12	54.8	-47.4		-2.25
	12.5	26.1	-44.5			-10.0	8.5	-6.4	15.3	12.5	54.7	-47.3		-2.82
	13	25.9	-44.3	-72		-10.0	8.5	-6.4	15.3	13	54.7	-47.3		-2.95
	13.5	26.2	-44.5			-10.0	8.5	-6.4	15.3	13.5	54.8	-47.4		-2.85
	14	26.8	-45.3			-10.0	8.5	-6.4	15.3	14	54.9	-47.5		-2.25
	14.5	31.5	-46.2			-10.0	8.5	-6.4	15.3	14.5	56.4	-49.0		-2.75
	15	28.3	-47.4			-10.0	8.5	-6.4	15.3	15	55.4	-48.0		-0.62
	11A	29	-48			-10.0	8.5	-6.4	15.3	11A	55.6	-48.2		-0.23
	11.5A	28	-46.9			-10.0	8.5	-6.4	15.3	11.5A	55.3	-47.9		-1.03
	12A	26.9	-46			-10.0	8.5	-6.4	15.3	12A	55.0	-47.6		-1.58

12.5A			26.5	-45.3			-10.0		8.5	-6.4	15.3	12.5A	54.8	-47.4		-2.15
13A			26.5	-45			-10.0		8.5	-6.4	15.3	13A	54.8	-47.4		-2.45
13.5A			26.8	-45.3			-10.0		8.5	-6.4	15.3	13.5A	54.9	-47.5		-2.25
14A			27.3	-45.9			-10.0		8.5	-6.4	15.3	14A	55.1	-47.7		-1.81
14.5A			28.2	-46.9			-10.0		8.5	-6.4	15.3	14.5A	55.4	-48.0		-1.09
15A			29.3	-48.1			-10.0		8.5	-6.4	15.3	15A	55.7	-48.3		-0.22
16			29.7	-48.8			-10.0		8.5	-6.4	15.3	16	55.8	-48.4		0.36
16.5			28.7	-47.8			-10.0		8.5	-6.4	15.3	16.5	55.5	-48.1		-0.34
17			27.7	-47			-10.0		8.5	-6.4	15.3	17	55.2	-47.8		-0.83
17.5			27.6	-46.4			-10.0		8.5	-6.4	15.3	17.5	55.2	-47.8		-1.40
18			27.3	-46.1			-10.0		8.5	-6.4	15.3	18	55.1	-47.7		-1.61
18.5			27.4	-46.5			-10.0		8.5	-6.4	15.3	18.5	55.1	-47.7		-1.24
19			28.2	-47.1			-10.0		8.5	-6.4	15.3	19	55.4	-48.0		-0.89
19.5			29	-47.8			-10.0		8.5	-6.4	15.3	19.5	55.6	-48.2		-0.43
20			30.1	-48.9			-10.0		8.5	-6.4	15.3	20	56.0	-48.6		0.34
16A			30.9	-49.8			-10.0		8.5	-6.4	15.3	16A	56.2	-48.8		1.02
16.5A			29.9	-49			-10.0		8.5	-6.4	15.3	16.5A	55.9	-48.5		0.50
17A			29.1	-48.3			-10.0		8.5	-6.4	15.3	17A	55.7	-48.3		0.04
17.5A			28.7	-47.8			-10.0		8.5	-6.4	15.3	17.5A	55.5	-48.1		-0.34
18A			28.3	-47.5			-10.0		8.5	-6.4	15.3	18A	55.4	-48.0		-0.52
18.5A			28.9	-47.8			-10.0		8.5	-6.4	15.3	18.5A	55.6	-48.2		-0.40
19A			29.4	-48.2			-10.0		8.5	-6.4	15.3	19A	55.8	-48.4		-0.15
19.5A			30	-48.9			-10.0		8.5	-6.4	15.3	19.5A	55.9	-48.5		0.37
20A			31.1	-50			-10.0		8.5	-6.4	15.3	20A	56.2	-48.8		1.16
21			32.2	-50.9			-10.0		8.5	-6.4	15.3	21	56.5	-49.1		1.76
21.5			31.3	-50.2			-10.0		8.5	-6.4	15.3	21.5	56.3	-48.9		1.30
22			30.5	-49.6			-10.0		8.5	-6.4	15.3	22	56.1	-48.7		0.93
22.5			30.1	-49.1			-10.0		8.5	-6.4	15.3	22.5	56.0	-48.6		0.54
23			29.9	-49			-10.0		8.5	-6.4	15.3	23	55.9	-48.5		0.50
23.5			30	-49.2			-10.0		8.5	-6.4	15.3	23.5	55.9	-48.5		0.67
24			30.8	-49.6			-10.0		8.5	-6.4	15.3	24	56.2	-48.8		0.84
24.5			31.4	-50.1			-10.0		8.5	-6.4	15.3	24.5	56.3	-48.9		1.18
25			32.7	-50.2			-10.0		8.5	-6.4	15.3	25	56.7	-49.3		0.92
															Average	-1.05

the measured value is High

Mapping Notes:

Tx antenna size	0.24	meters				Rx antenna size	0.60	meters	
wavelength	0.18	meters							
						Far field for Rx			
Far Field	$2D^2/\lambda$	0.63	meters	2.06	ft	3.88	meters	12.72	ft
	D^2/λ	0.31	meters	1.03	ft				

Tx (physically, the antenna face is pointing straight down from ceiling to floor, horn feed is pointing to the west side of the chamber)
Electro-Metrics, Model EM-6961, SN-6431
Antenna is 8 ft from GPS and at least 1 ft closer to the ground.

Rx (aligned with laser pointer in throat of antenna)
ARA Horn SWH-21, SN 15087
Receive antenna was boresighted to double ridge horn antenna
Distance between Rx and double ridge horn antenna was measured from the front face of horn to front face of horn with laser rangefinder
Height of receive antenna was 48" above the walk-on material when directly under the simulated handset antenna
Receive antenna was mounted on a tripod with the center of the tripod positioned over the map point.

Equations used:

space loss = $-27.55+20\log(f_{MHz}) + 20\mathrm{Log}(R_{(m)})$

Calculated Pwr = Pwr at Tx + Tx Gain - Space Loss + Rx Gain + Rec cable

Deviation from theory = Calculated - Measured

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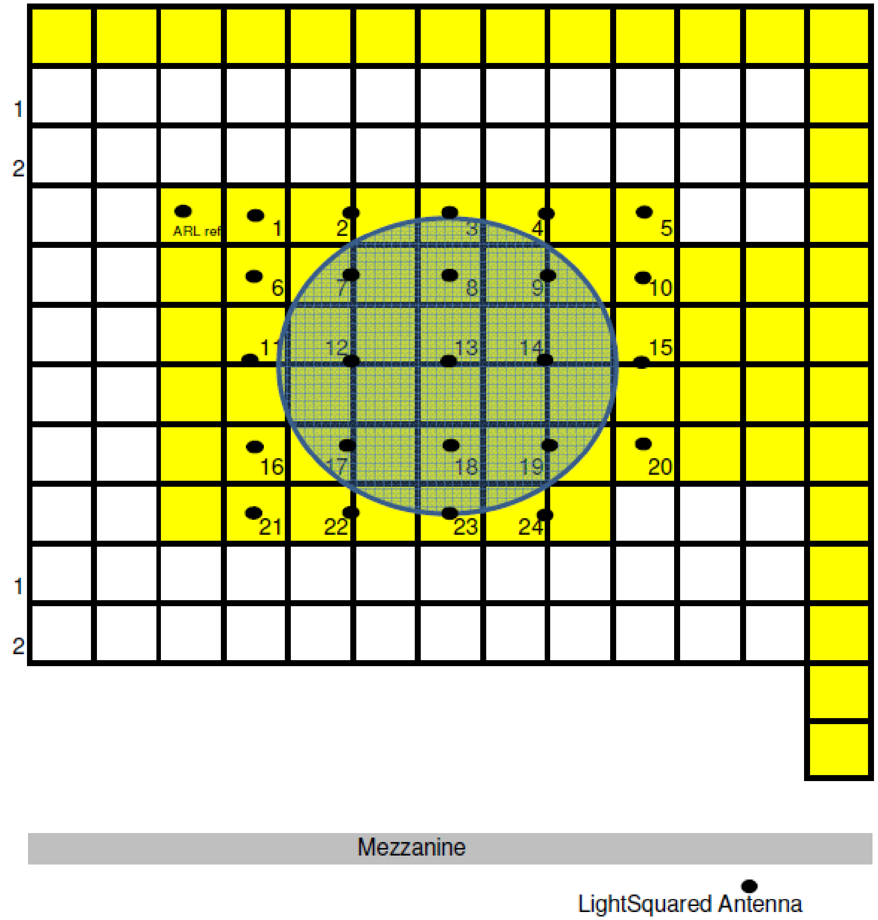
RAM Layout


1
2
ARL ref
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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16
17
18
19
20
21
22
23
24
1
2
Mezzanine
LightSquared Antenna

E.2 GPS SIMULATION CALIBRATION

GPS SIMULATION

GPS Simulation was provided by the SPAWAR Advanced Global Navigation Simulator (AGNS). SPAWAR downloaded the latest 31 Satellite almanac file covering the time period for the test week. Aerospace Corp. reduced the 31 satellite almanac to a 24 satellite almanac. The number of satellites was reduced to 24 by removing the satellites that did not occupy primary orbital slots. SPAWAR generated five simulations, one for each day of the week. All simulations were 24 hours in length. All simulation start times were set to 0800 MST daily. The simulator was started each day within a few minutes of actual 0800 MST. The simulator was transmitting continuously until all tests were completed each day.

GPS Calibration

The AGNS simulator calibration was performed using the following technique. The AGNS software was configured to transmit a CW tone on both L1 and L2 at maximum composite power of 140 dBW. The AGNS RF attenuators for each frequency were set to zero to achieve maximum transmit signal strength. A FRPA antenna connected to a spectrum analyzer was located directly under the GPS transmit antenna in the chamber (receiver grid location C4.5). The following power measurements were made at this location:

- L1: -68 dBm
- L2: - 62 dBm

The AGNS was configured to transmit P-code signals on L1 and L2 for the same power setting above. The measurements were made at this location, but with the spectrum analyzer configured for a 20 MHz integrated bandwidth. The following power measurements were taken:

- L1: -68 dBm
- L2: -62 dBm

The AGNS attenuator settings were calculated to calibrate the RF to the AGNS transmitted composite power of -140 dBW (-110 dBm). The settings were:

- L1: (-68 dBm) – (-110 dBm) = 42 dB attenuator setting
- L2: (-63 dBm) – (-110 dBm) = 47 dB attenuator setting

An AGNS calibration scenario was configured in accordance with ICD-GPS-200C code power settings for C/A and P-code on L1 and L2. These were:

- C/A code: -158.5 dBW
- P code: -161.5 dBW

Calculate the theoretical C/N_o using -200 dBW-Hz for N_o. This yields:

- $C/N_o = -161.5 – (-200) = 38.5$ dB-Hz

The receiver rack reference antenna was placed at Location C4.5. The AGNS calibration scenario was turned on and tracked at location C4.5 by the following receivers:

- DAGR

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- Rockwell 3S

The measured C/N_o for each receiver at location C4.5 was:

- C/A code: C/N_o = 39-40 dB
- L1 P(Y) code: C/N_o = 36-37 dB
- L2 P(Y) code: C/N_o = 36-37 dB

Adjust the AGNS RF attenuators for a measured C/N_o equal to 39 dB-Hz. This yields:

- L1: 40 dB RF attenuator setting
- L2: 45 dB RF attenuator setting

The receiver rack reference antenna was then placed on every point of the 25 point grid system for C/N_o measurements. The measured C/N_o range across the 25 point grid was:

- L1 range (P-code): 34-39 dB
- L2 range (P-code): 32-39 dB

The L1 and L2 power measurements were not equal across the 25 point grid with L2 P-code C/N_o less than L1 P-code C/N_o by no more than 2 dB. The AGNS RF attenuators for L1 and L2 were equally adjusted to bring the L1 C/N_o to 39 dB-Hz at the weakest point, receiver location A8. The final RF attenuator settings were:

- L1: 35 dB
- L2: 40 dB

The final AGNS calibration values for receiver location A8 were:

- L1 C/A–code C/N_o: 42 dB
- L1 P-code C/N_o: 39 dB
- L2 P-code C/N_o: 37 dB

The final AGNS calibration values for receiver location C4.5 were:

- L1 C/A–code C/N_o: 47 dB
- L1 P-code C/N_o: 44 dB
- L2 P-code C/N_o: 44 dB

Appendix F. PROPAGATION MODELS

F.1 INTRODUCTION

Two main propagation models were used during data analysis, Free Space Propagation Model and Irregular Terrain Model (ITM). The LightSquared ATC Follow-on Test Plan outlined data analysis using 13 separate propagation models. These models were Free Space Propagation and 12 Irregular Terrain Models provided by NTIA. Details of these models are provided in this appendix. To simplify analysis the team analyzed data using Free Space, Maximum-Power ITM and Minimum-Power ITM.

F.2 FREE SPACE PROPAGATION (62 DBM EIRP)

IT (dBm)	XFSPL (m)	IT (dBm)	XFSPL (m)	IT (dBm)	XFSPL (m)	IT (dBm)	XFSPL (m)
-85.0	348430	-66.0	39094	-47.0	4386	-28.0	492
-84.0	310539	-65.0	34843	-46.0	3909	-27.0	439
-83.0	276768	-64.0	31054	-45.0	3484	-26.0	391
-82.0	246670	-63.0	27677	-44.0	3105	-25.0	348
-81.0	219844	-62.0	24667	-43.0	2768	-24.0	311
-80.0	195937	-61.0	21984	-42.0	2467	-23.0	277
-79.0	174629	-60.0	19594	-41.0	2198	-22.0	247
-78.0	155638	-59.0	17463	-40.0	1959	-21.0	220
-77.0	138712	-58.0	15564	-39.0	1746	-20.0	196
-76.0	123628	-57.0	13871	-38.0	1556	-19.0	175
-75.0	110183	-56.0	12363	-37.0	1387	-18.0	156
-74.0	98201	-55.0	11018	-36.0	1236	-17.0	139
-73.0	87522	-54.0	9820	-35.0	1102	-16.0	124
-72.0	78004	-53.0	8752	-34.0	982	-15.0	110
-71.0	69521	-52.0	7800	-33.0	875	-14.0	98
-70.0	61961	-51.0	6952	-32.0	780	-13.0	88
-69.0	55222	-50.0	6196	-31.0	695	-12.0	78
-68.0	49217	-49.0	5522	-30.0	620	-11.0	70
-67.0	43865	-48.0	4922	-29.0	552	-10.0	62

F.3 IRREGULAR TERRAIN MODEL

The received power at the input of a GPS receiver is computed using Equation 1.

$$P_R = EIRP_{BS} - G_{Off-Axis} + G_R - L_P$$ **Equation 1**

Where:

$EIRP_{BS}$ is the main-beam effective isotropically-radiated power level of the MSS ATC base station transmitter (dBm);
$G_{Off\text{-}Axis}$ is the elevation off-axis gain reduction of the MSS ATC base station antenna (dB);
G_R is the gain of the GPS receive antenna (dBi); and
L_P is the propagation loss (dB).

The received power will be compared to the measured interference thresholds for the different GPS receivers to determine the required separation distance to preclude potential interference.

The maximum main-beam base station antenna gain is 16.74 dBi. The antenna patterns used to determine the off-axis antenna gain of the MSS ATC base station is shown in Figure 1 (2 degree down-tilt), Figure 2 (4 degree down-tilt), and Figure 3 (6 degree down-tilt).[14]

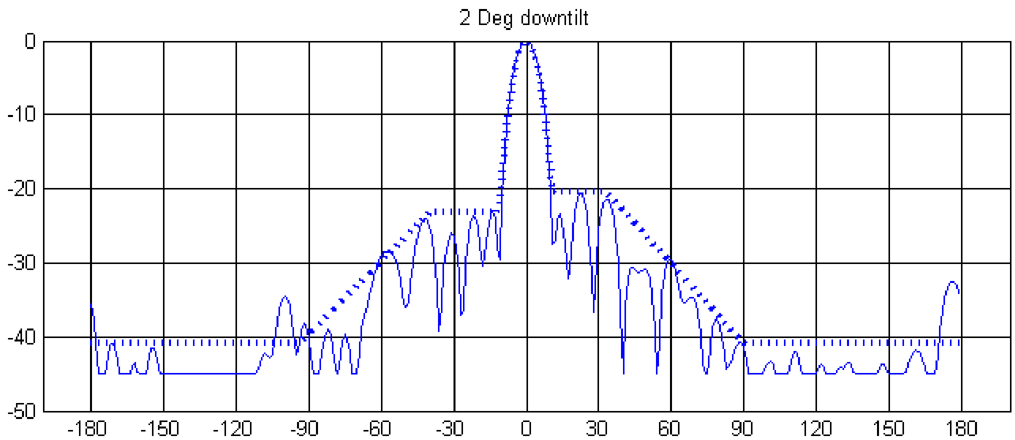
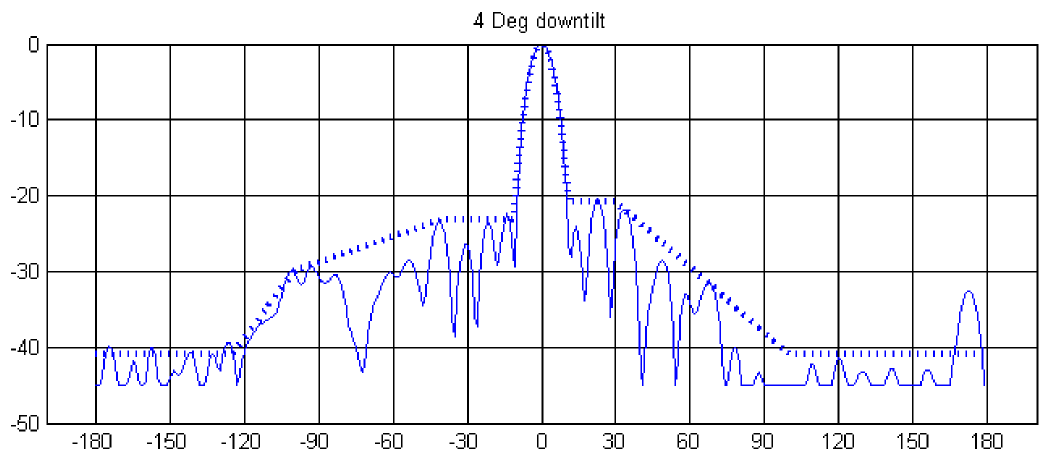


Figure 1.



[14] Positive off-axis angles are directed toward the ground.

Figure 2.

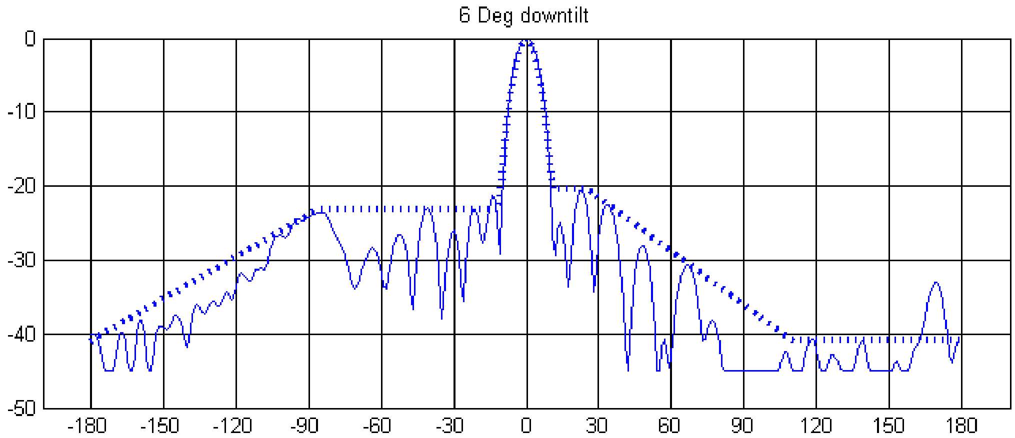


Figure 3.

A value of 0 dBi is used for GPS receive antenna gain.

For separation distances below 1 kilometer the free-space propagation model in Equation 2 is used to compute the propagation loss:[15]

$$L_P = 20 \log F + 20 \log D - 27.55 \qquad (2)$$

Where

F is the frequency (MHz)

D is the separation distance (meters)

For separation distances greater than 1 kilometer the Irregular Terrain Model (ITM) in the Area Prediction Mode is used to compute the propagation loss.[16] Different values of Δh are used to represent variations in terrain as a GPS receiver moves away from a MSS ATC base station transmitter. The ITM estimates radio propagation losses for frequencies between 20 MHz and 20 GHz as a function of distance and the variability of the signal in time and space. ITM is an improved version of the Longley-Rice Model, which gives an algorithm developed for computer applications. The ITM is based on electromagnetic theory and signal loss variability expressions derived from extensive sets of measurements. In the ITM Area Prediction Mode, the “area” is described by the terrain roughness factor Δh, which is defined as the interdecile value computed from the range of all terrain elevations for the area. Suggested values of Δh are available for different types of terrain. Using the Δh value and the antenna heights, the algorithm predicts the signal attenuation as a function of distance. The loss predicted by ITM in the Area Prediction Mode consists of the median attenuation of a radio signal as a function of distance for paths over irregular terrain as well as the variability of the signal in time and space. The computed values attempt to give a statistical description of received radio fields, which can be used for system

[15] The separation distance is computed based on the slant range.

[16] National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982), *available at* http://www.its.bldrdoc.gov/pub/ntia-rpt/82-100/index.php.

design or interference analysis. The statistics used are the time variability, the location variability, the situation variability, and the hourly median value. Table 1 provides the parameters used for ITM in the Area Prediction Mode.

Table 1. ITM Area Prediction Mode Parameters

Parameter	Value
Surface Refractivity	301 N-units
Conductivity of Ground	0.005 S/M
Dielectric Constant of Ground	15
Delta h	Linearly interpolated from 0 to 90 meters (separation distances of 1 to 5 kilometers) 90 meters (separation distances greater than 5000 kilometers)
Polarization	Vertical
Mode of Variability	Single Message Mode
Percent Confidence (Time/Situation/Location Variability)	50 percent
Frequency	1530 MHz
Transmitter Antenna Height	15 meters, 30 meters, 60 meters, and 80 meters
Receiver Antenna Height	2 meters
Site Criteria Transmitter	Very Careful
Site Criteria Receiver	Random
Radio Climate	Continental Temperate

Base Station EIRP of 62 dBm

Figures 4 through 14 show received power as a function of distance separation for various antenna heights and down-tilts. Tabular data supporting these figures are found in an embedded spreadsheet below each figure.

The received power as a function of distance separation is shown in Figures 4 through 7 for antenna base station antenna heights of 15 meters, 30 meters, 60 meters, and 80 meters and a 2 degree antenna down-tilt.

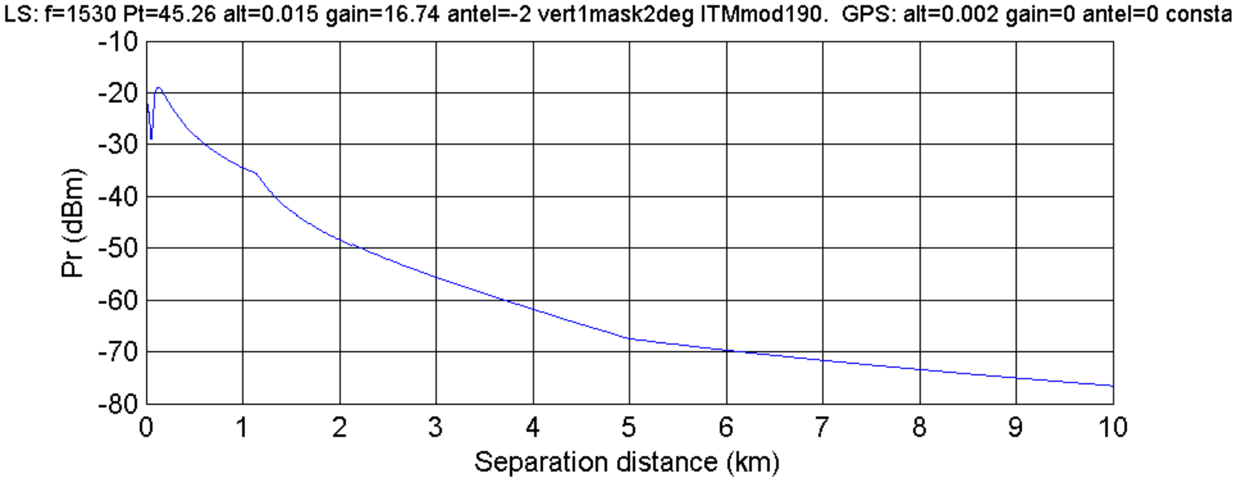
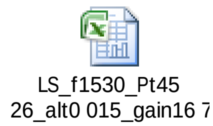


Figure 4.



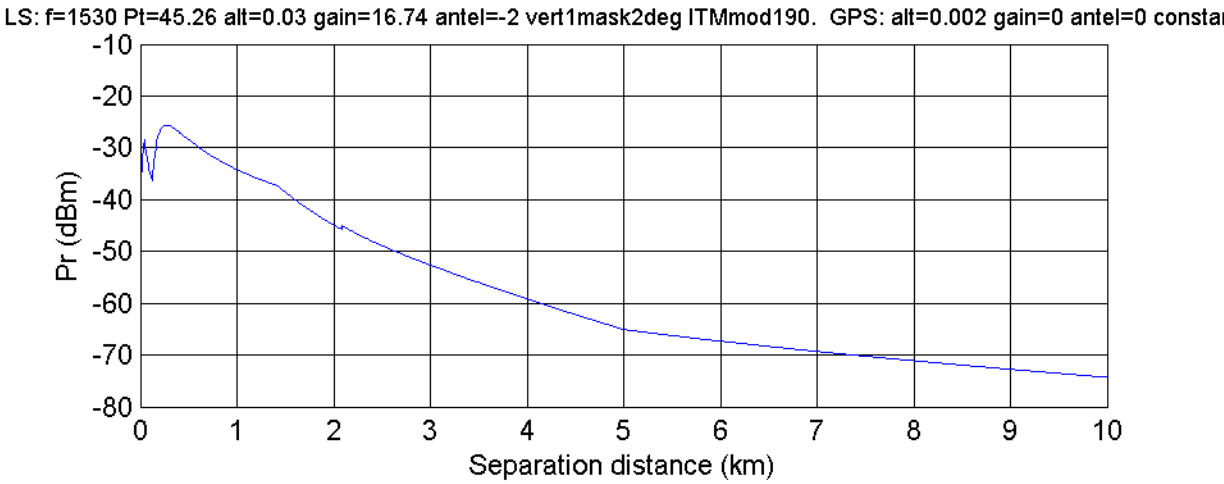
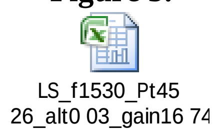


Figure 5.



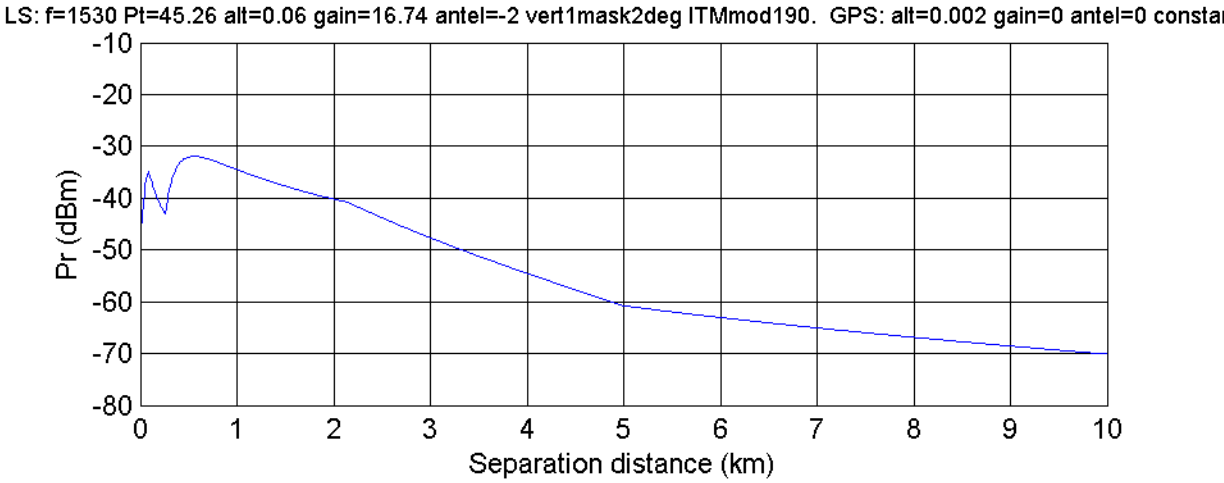


Figure 6.

LS_f1530_Pt45
26_alt0 06_gain16 74

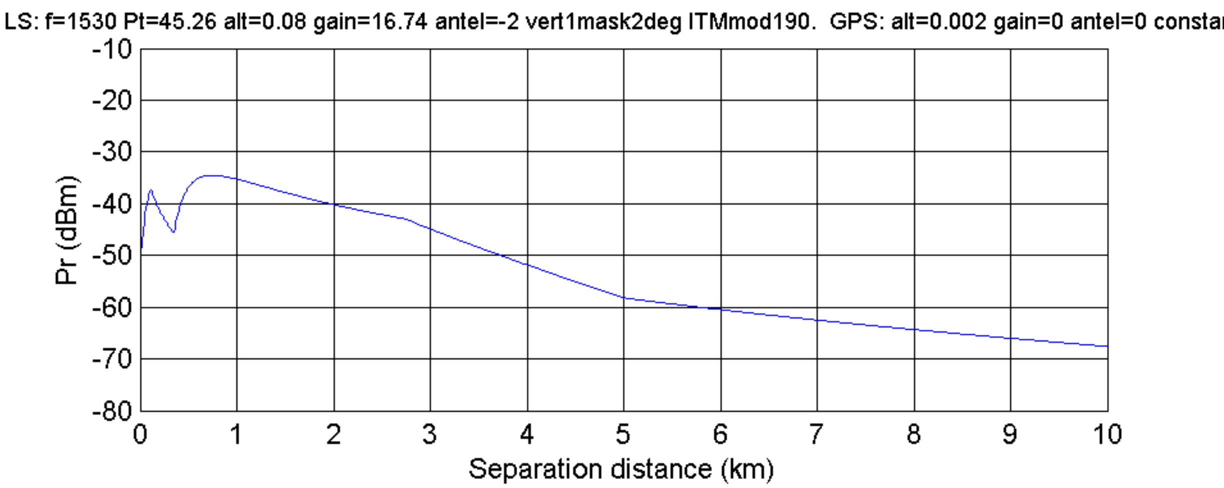


Figure 7.

LS_f1530_Pt45
26_alt0 08_gain16 74

The received power as a function of distance separation is shown in figures 8 through 11 for antenna base station antenna heights of 15 meters, 30 meters, 60 meters, and 80 meters and a 4 degree antenna down-tilt.

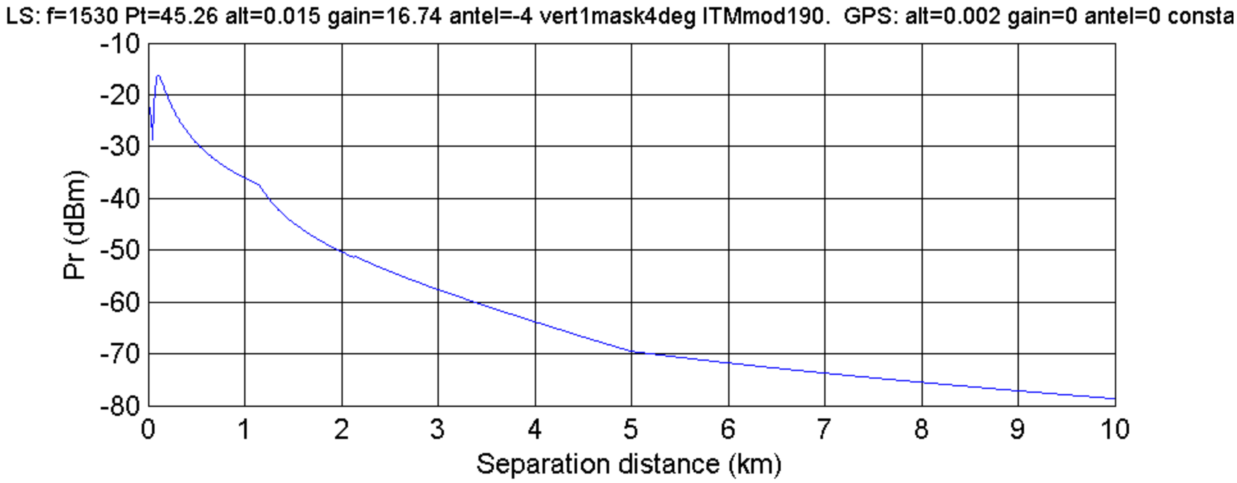


Figure 8.

LS_f1530_Pt45
26_alt0 015_gain16 7

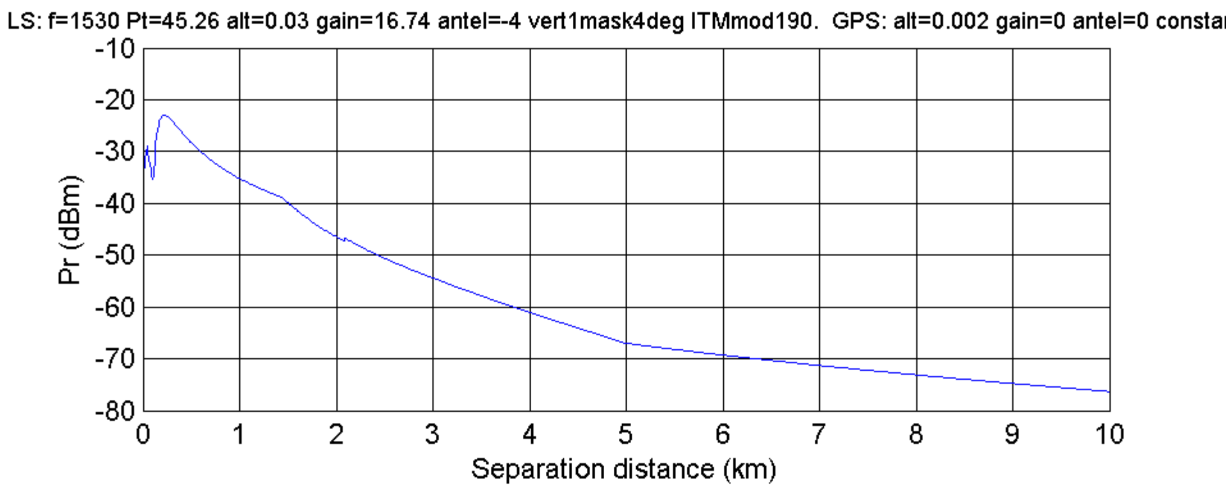


Figure 9.

LS_f1530_Pt45
26_alt0 03_gain16 74

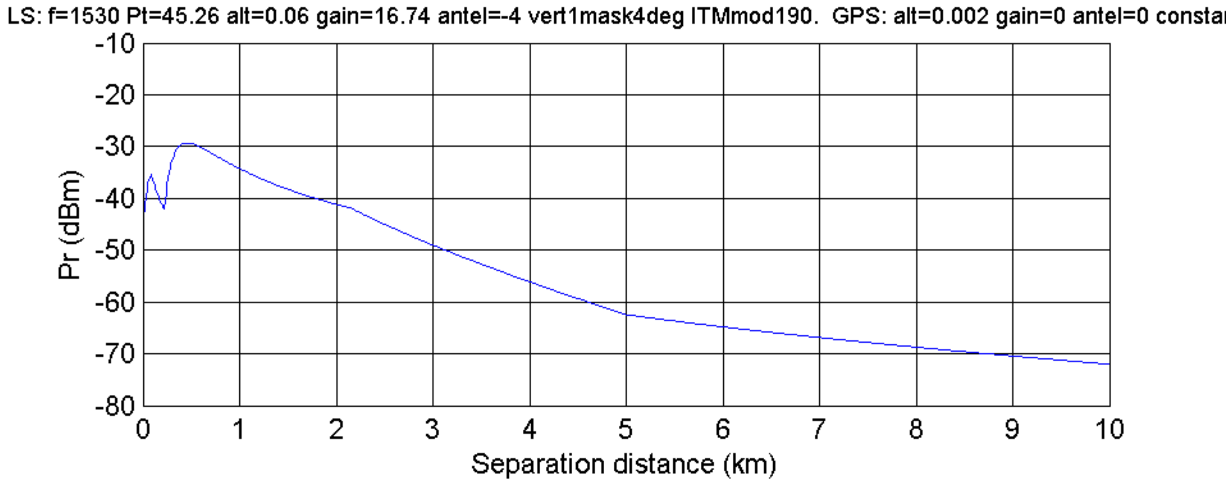


Figure 10.

LS_f1530_Pt45
26_alt0 06_gain16 74

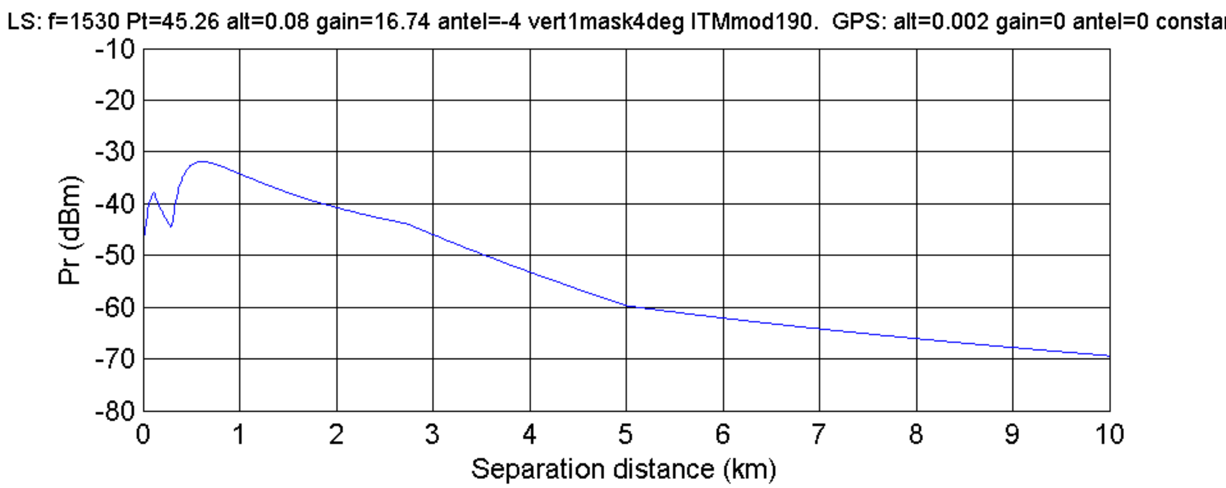


Figure 11.

LS_f1530_Pt45
26_alt0 08_gain16 74

The received power as a function of distance separation is shown in figures 12 through 15 for antenna base station antenna heights of 15 meters, 30 meters, 60 meters, and 80 meters and a 6 degree antenna down-tilt.

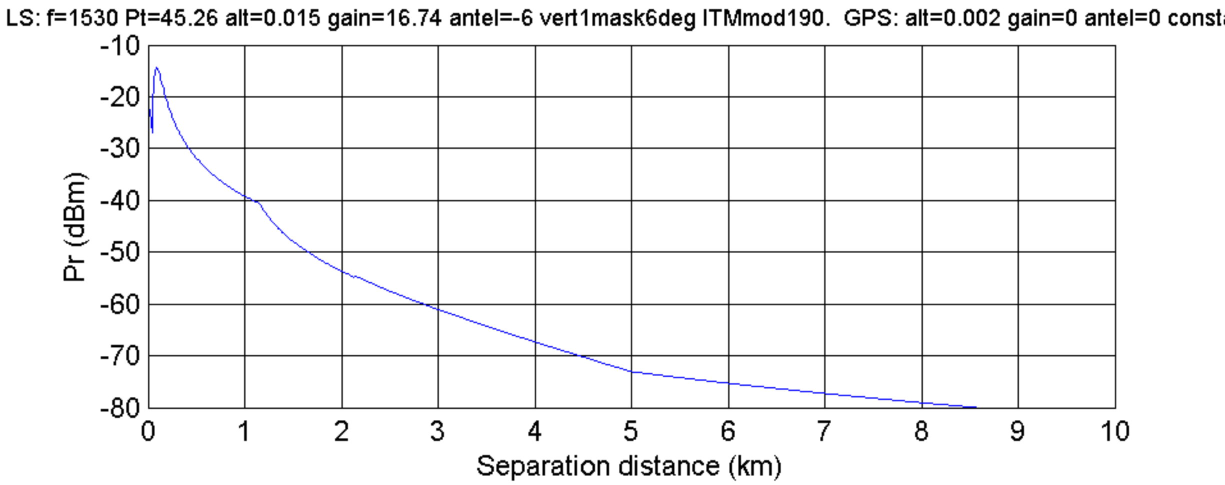


Figure 12.

LS_f1530_Pt45
26_alt0 015_gain16 7

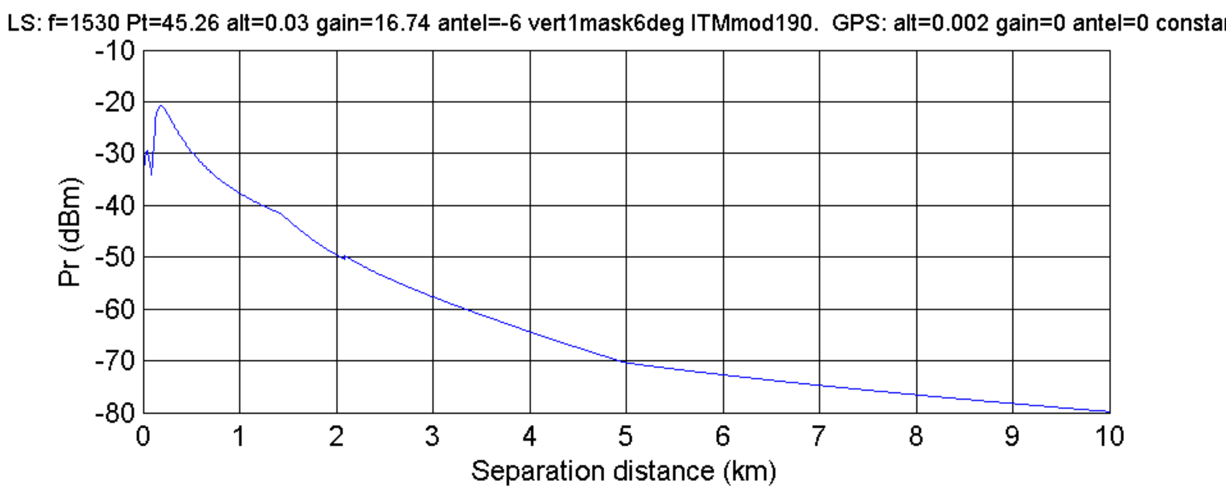


Figure 13.

LS_f1530_Pt45
26_alt0 03_gain16 74

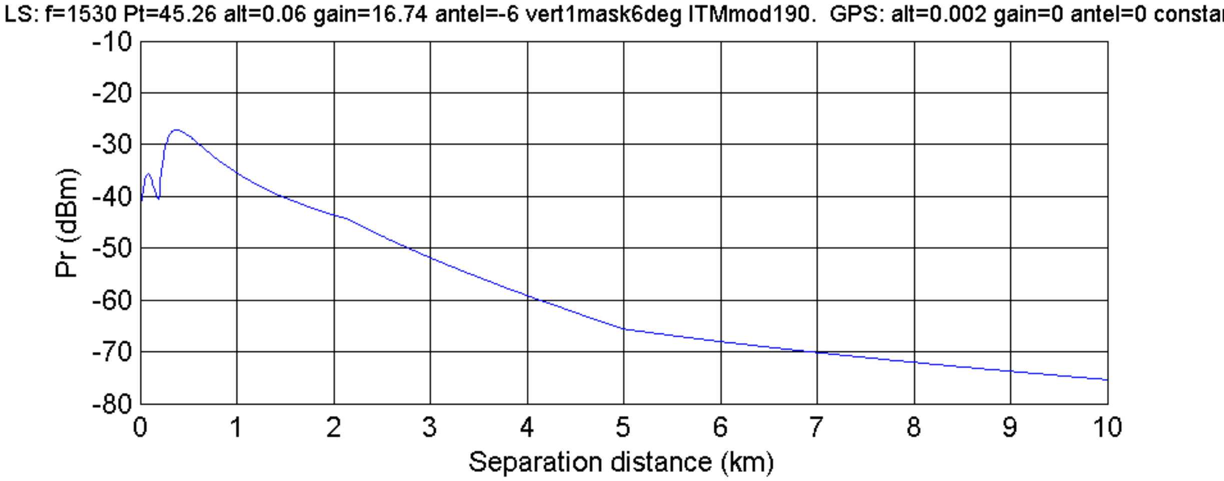


Figure 14.

LS_f1530_Pt45
26_alt0 06_gain16 74

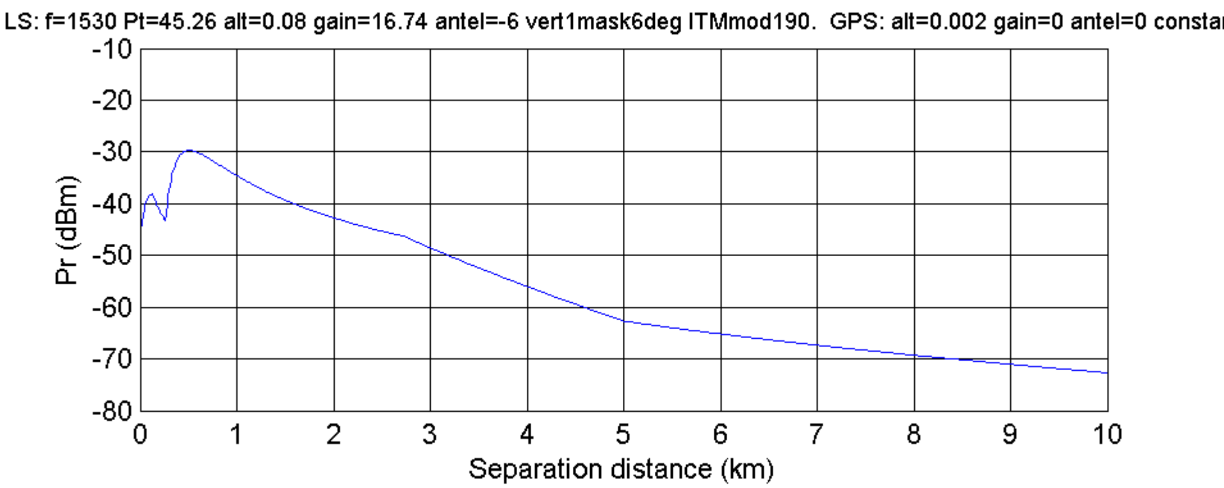


Figure 15.

LS_f1530_Pt45
26_alt0 08_gain16 74

The interference threshold (I_t) represents the measured power level that causes a constant 1 db reduction in the carrier-to-noise density ratio (C/N_O). The value of I_t is used to determine the required separation distance based on calculated received power curves shown in Figures 4 through 16.

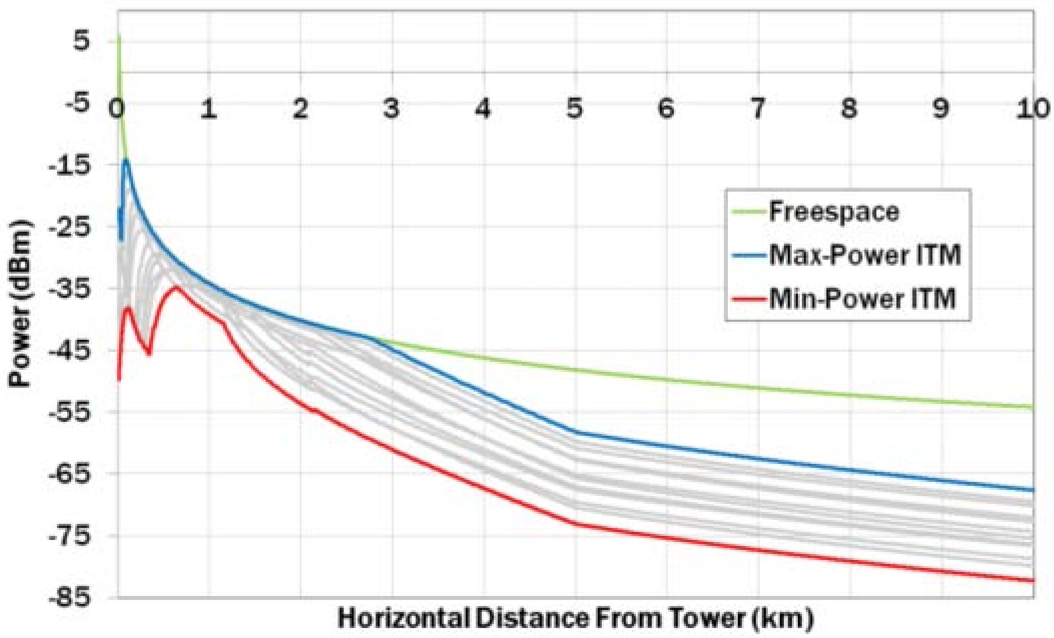


Figure 16.

Figure16 shows all 12 ITM models plotted in gray and the Max Power and Min Power ITM bounds in blue and red. The Min-Power ITM, Max-Power ITM and Free-Space models were used for data analysis.

Appendix G. LIGHTSQUARED SIGNAL SIMULATION

LightSquared signal simulation setup and calibration details were provided in the following report from MITRE

To:	Capt Justin Deifel, SMC/GPEV	Date:	29 November 2011
From:	Jeffry Ross	Letter No:	14402
Subject:	Setup and Calibration Report for the LightSquared Test Signals for the Second SMC/GPEV LightSquared Interference Test (24 Oct 2011 – 3 Nov 2011)		
Copies To:	Dan Williams (ARL), Avram Tetewsky (Draper Lab), Alfredo Perez (746th TS)		

The purpose of this report is to document the setup and calibration procedures used to generate the signals that were used to represent the LightSquared signals during the second SMC/GPEV Interference Test held at the WSMR EMVAF from 24 Oct 2011 – 3 Nov 2011. The work described herein was principally carried out by: Alfredo Perez (746th TS), Jeffry Ross (MITRE), Avram Tetewsky (Draper Lab), and Dan Williams (ARL). Many other people assisted in this work, include staff from the ARL EMVAF and SPAWAR San Diego.

RF Chain Setup

Figure 1 depicts the two RF chains used to generate the LightSquared Base Station signals. The antenna used during the test was an Argus HPX308R-J2. It was provided for the test by LightSquared. Each RF chain fed one port on the LightSquared base station antenna. The RF chain that fed the +45 degree port was referred to as the “A” chain. The RF chain that fed the -45 degree port was referred to as the “B” chain.

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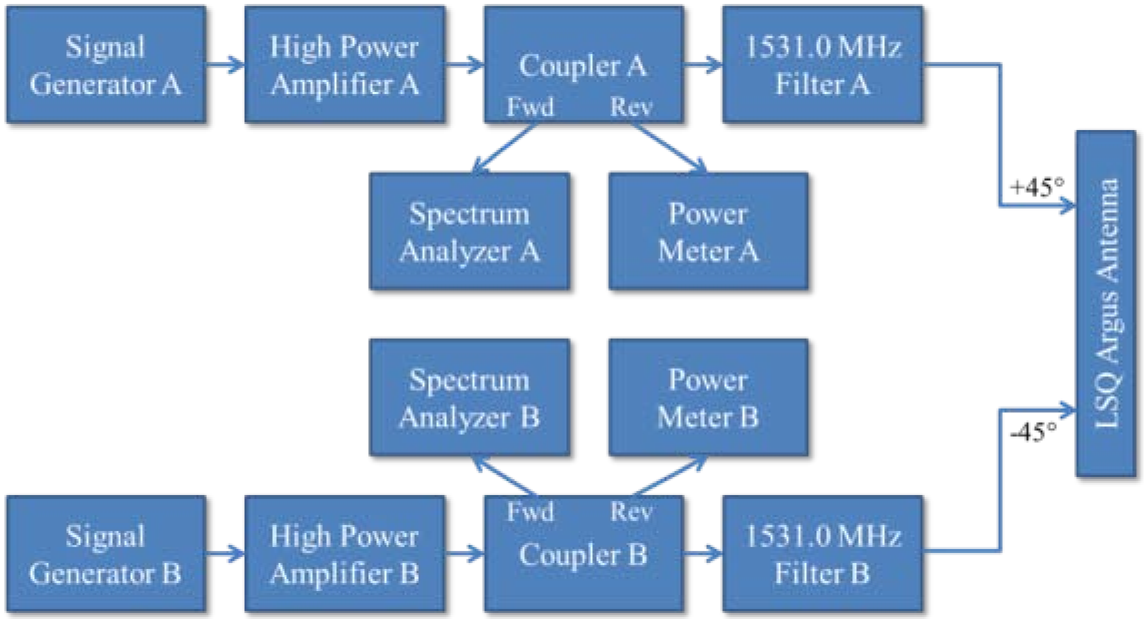

Figure 1 – LightSquared Base Station RF Chains

The base station antenna was placed on the mezzanine of the anechoic chamber. With the mezzanine at the North end of the chamber, the antenna was 40 feet North, 25 feet West, and 13.9 feet above the center of the test area. The mechanical boresight of the antenna was aimed at a point 5.7 feet East and 10.4 feet South of the center of the test area. The antenna had an additional electronic boresight adjustment of -2 degrees relative to the mechanical boresight.

Figure 2 depicts the RF chain used to generate the LightSquared handset signal. This signal was meant to be representative of one transmitted from a LightSquared handset. The RF chain fed a dual ridge horn. The RF chain that fed the antenna port was referred to as the “C” chain. The chain had to be configured for each experiment for either 1632.5 or 1651.7 MHz. This was accomplished by changing the signals center frequency and swapping out the RF filter.

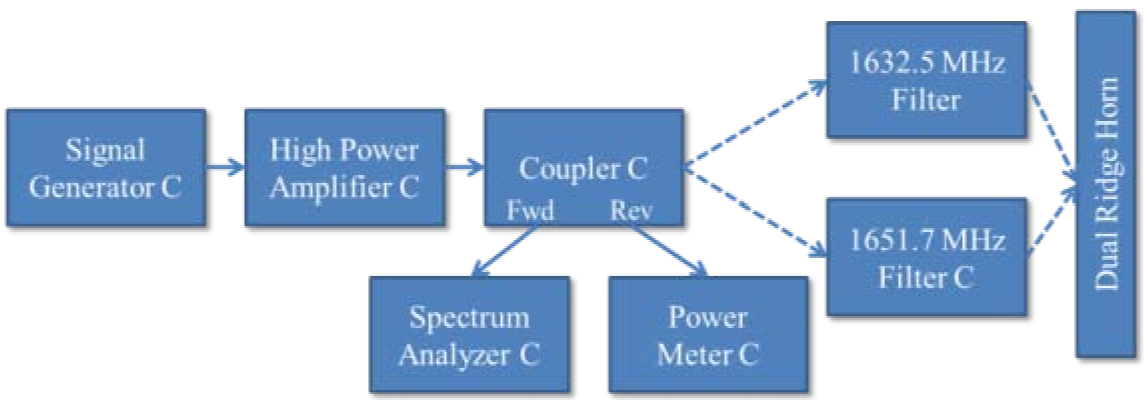

Figure 2 – LightSquared Handset RF Chain

The handset antenna was suspended 25.7 feet above the test area. The mechanical boresight of the antenna was aimed straight down at a point 4 feet South of the center of the test area.

For both the base station and the handset chains, the coupler was placed between the High-Power Amplifier (HPA) and the filter in order to control any reflections that could occur if the wrong signal was sent into the filters. This was for the protection of the HPA. An additional isolator could have been used. However, during the first SMC/GPEV lead LightSquared test, maximum power was needed into the antenna. It was decided then to not use the additional isolator. In the interest of consistency between the tests, the same signal chain was used for this test. The only drawback, of not having the coupler and hence the monitoring spectrum analyzer (SA) after the filter, was that the signal into the antenna was not directly observed. However, the filter was previously characterized with a network analyzer. This allowed for the pre-filter spectrum to be translated to a post-filter spectrum. Additionally, due to the dynamic range of the LightSquared signal and the limited dynamic range of the SA, the post-filtered signal would not have been observable in both the MSS and GPS bands simultaneously. Finally, the power meter on the reverse reflection port of the coupler was used to make sure only an acceptable amount of power did reflect off of the filter. If the power meter reading spiked, it was an indication there was a fault in the RF chain.

After the RF chains were connected, power calibration and linearity measurements were made. During the power calibration measurements, all three SAs were used to make common measurements with power meter “A”. The calibrated power meter was used as truth. This allowed the measurements later made on each SA to be compensated for SA to SA variation. During the linearity testing, each RF chain was run from low power to a high power greater than was to be used during the main test. At each power level, simultaneous measurements were made with that chain’s monitor port SA and both the power meter and a second SA on the RF output port. These results established that over the power range used during the main test, a predictable amount of power could be delivered to the antenna.

<u>Signal Validation</u>

In order to ensure accurate test results, it was critical that the signal used to represent the LightSquared signals were spectrally equivalent and contained within the mandated FCC spectral mask. To this end, the waveform parameters were provided by LightSquared and used to generate waveform files for the Agilent Vector Signal Generators (VSG). This work was performed by SPAWAR and the 746th TS and is outside the scope of this document. Given the generated waveform, it was the job of this team to validate that at maximum effective isotropically-radiated power (EIRP) of the signals did not exceed the FCC spectral mask within the GPS band.

Due to the setup schedule for the test, collection of the data needed to validate the LightSquared test signal occurred before the final drive levels for the VSGs was determined. In order to account for the worst case situation, power spectrums were collected at power levels exceeding those used during the test. This resulted in distortion and spectral regrowth worse than during the test. Additionally, the distortion observed appeared to be mostly in the SA and not from the VSG. As long and the signal spectrum in this over driven condition satisfied the FCC emission mask within the GPS band, the signal was deemed valid.

As depicted in Figure 1 & 2, the SA used to capture the spectrum of the signals use for this validation was located after the HPA but before the LightSquared filter. The noise Figure of the SA limits its measurements to a power level well above that which must be measured to validate the signal with respect to the FCC mask. A technique was adopted to combine SA measurements from before the LightSquared filters with the filter's magnitude response as measured with a network analyzer. Scaling this combined spectrum by the measured power difference between the monitor SA port and the RF output port provided an estimate of the signal that would be fed into the LightSquared antenna. Scaling that estimate for the measured gain of the antenna resulted in the estimated transmitted signal. Reducing the power for the estimated free space path loss to P13 (a test point near the center of the test area), resulted in the estimated received power at P13. The comparison of these signals with the FCC mask is shown in Figure 3, 4, 5, and 6.

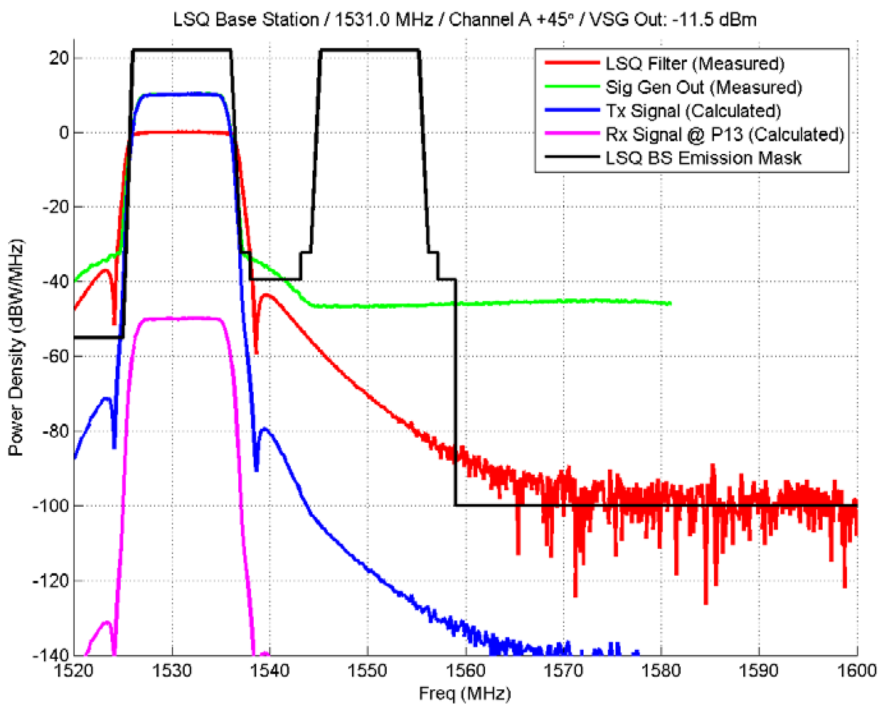

Figure 3 – LightSquared Base Station Spectral Validation +45 Degree Antenna Port

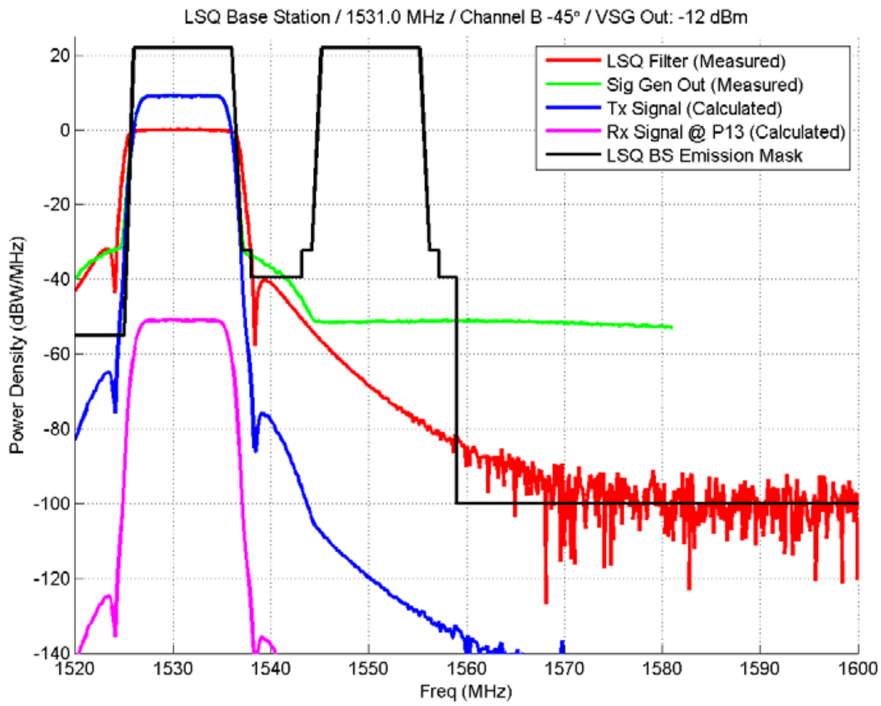

Figure 4 – LightSquared Base Station Spectral Validation -45 Degree Antenna Port

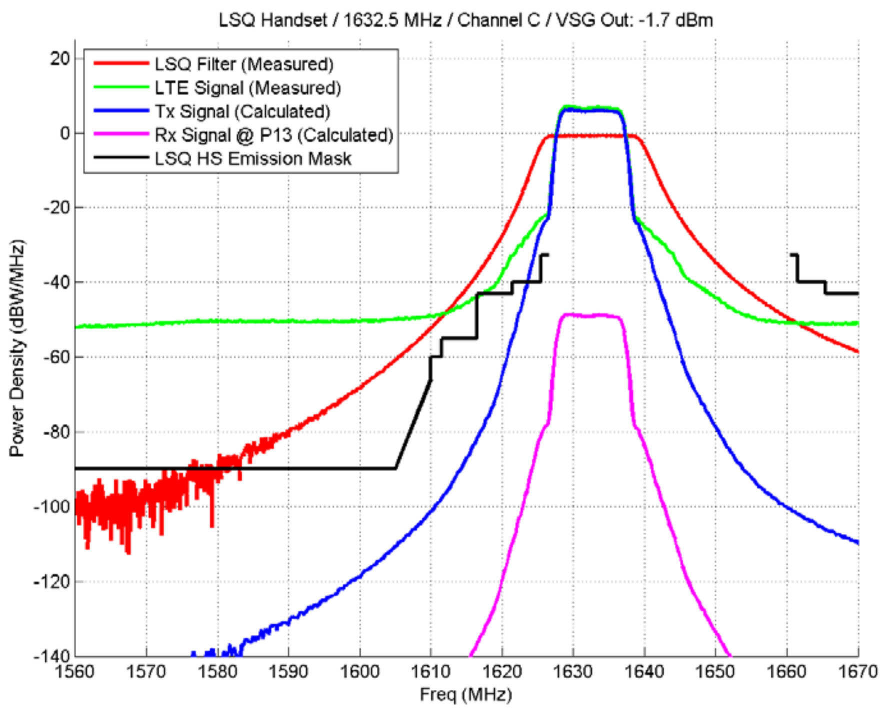

Figure 5 – LightSquared Handset Spectral Validation @ 1632.5 MHz

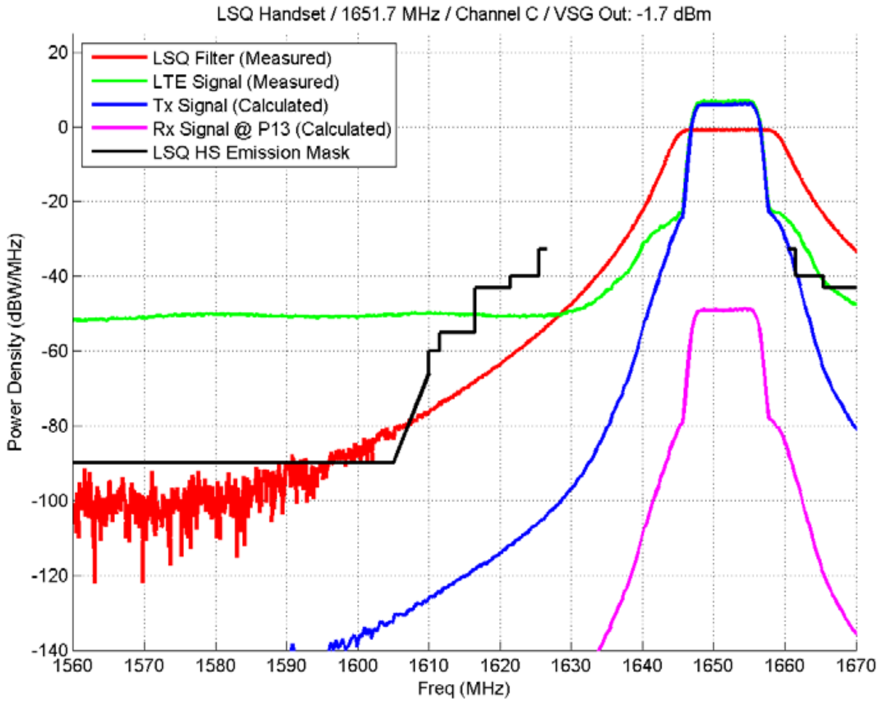

Figure 6 – LightSquared Handset Spectral Validation @ 1651.7 MHz

As can be seen in each plot, within the GPS band, the transmitted LightSquared signals are all well below the FCC mask.

Antenna Modeling

Determination of the final power levels delivered to the GPS receivers under test was determined by ARL by using a reference antenna to map the power profile in the test area from each transmit antenna. The details of that work are beyond the scope of this report. However, for planning purposes and initial selection of VSG maximum power levels, antenna radiation pattern modeling was performed prior to testing.

For each antenna, principal plane cuts were provided. The horizontal and vertical cuts were used to interpolate the pattern at any azimuth and elevation angle. This approach is less optimal than having a full 4π steradian pattern. However, this approach is sufficient within the main beam of the antenna. One caveat is that the dual ridge horn used as a proxy for the handset antenna was only measured at 1630 MHz. In terms of fractional frequency, this frequency is very close to both 1632.5 MHz and 1651.7 MHz. Figures 7, 8, 9, and 10 show the resulting patterns assuming free space path loss and the antenna geometry described in the first section of this report. The "X" denotes the transmit antenna location. The "+" denotes the mechanical aim point of the antenna. The "◊" denote the ARL mapping locations P1 – P25 with P13 in the center of the grid.

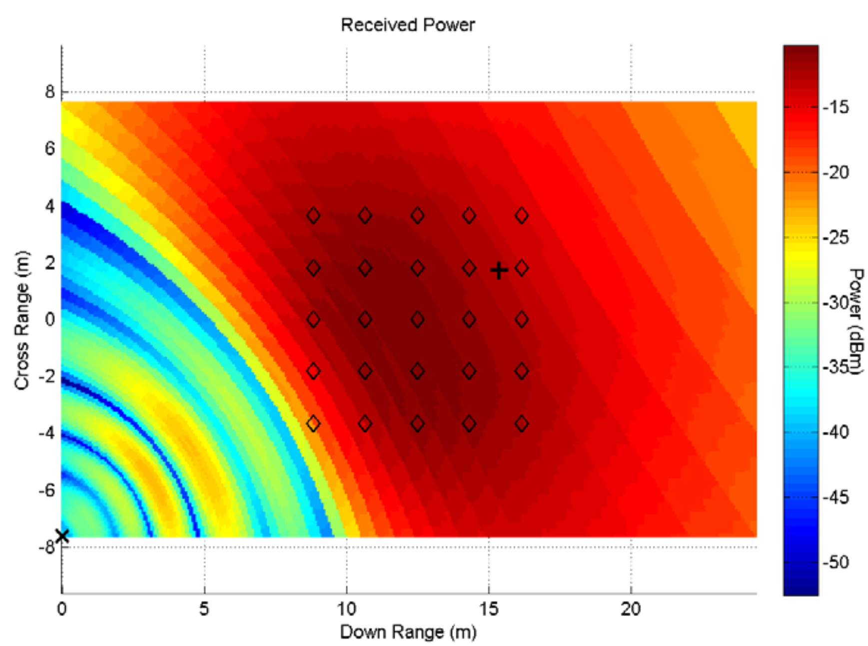

Figure 7 – LightSquared Base Station Radiation Profile +45 Degree Port @ 1531.0 MHz

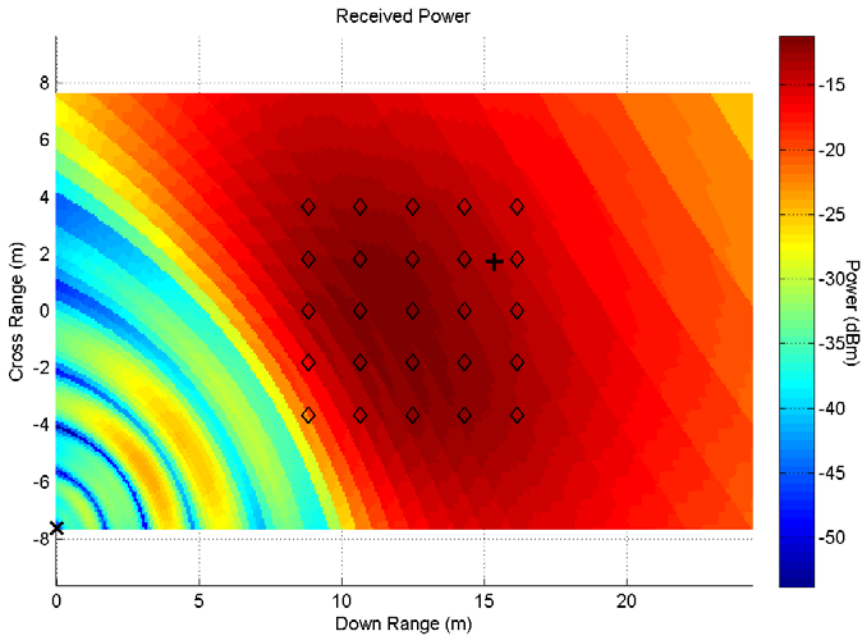

Figure 8 – LightSquared Base Station Radiation Profile -45 Degree Port @ 1531.0 MHz

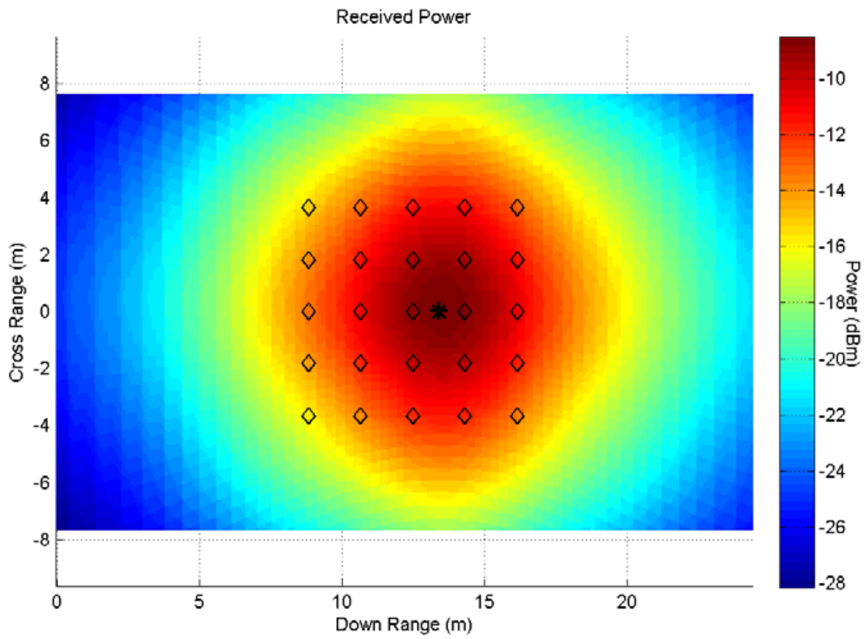

Figure 9 – LightSquared Handset Radiation Profile @ 1632.5 MHz

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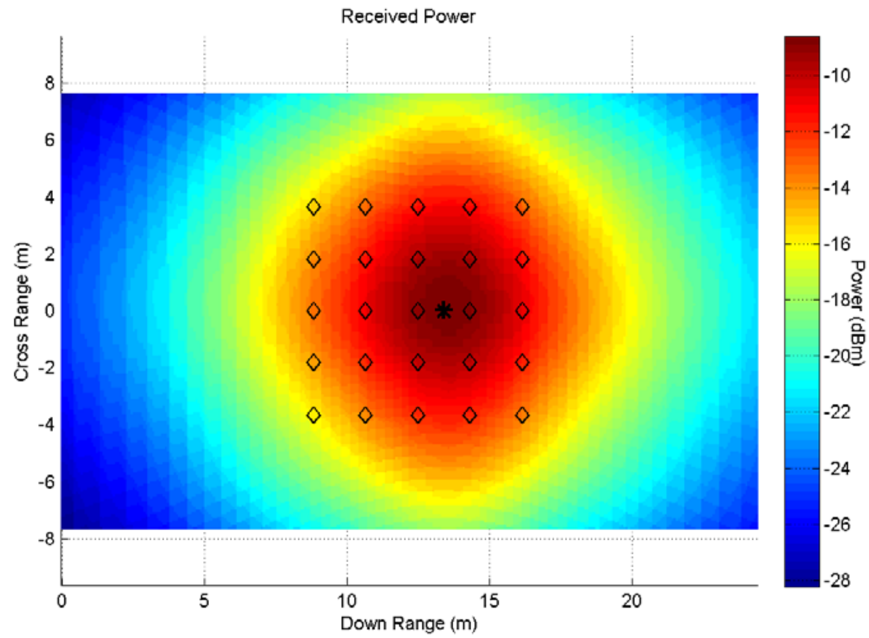

Figure 10 – LightSquared Handset Radiation Profile @ 1651.7 MHz

From these preliminary power profiles, we expected a peak power of -11 to -12 dBm from each 45 degree polarization at P13 for the LightSquared Base Station scenarios and -8 to -9 dBm at P13 for the LightSquared handset scenarios. Note these results do not include any measurements for the ARL mapping of actual received power levels.

<u>Power Delivery</u>

The final task was to review the peak ramp powers delivered during each of the test events. The goal was to ensure that the proper power was seen by the receivers under test. To this end, ARL used an SA connected to a standard gain horn reference antenna to monitor the received power in the chamber during the test. The reference antenna was located at a reference location South and East of the test area. The ARL chamber mapping derived a power translation factor from the reference location to P13. By applying that factor to the post-processed SA data a receiver power profile for each test vent was produced. Figure 11 show such a power profile for the first ramp of Test Event (TE) 1.

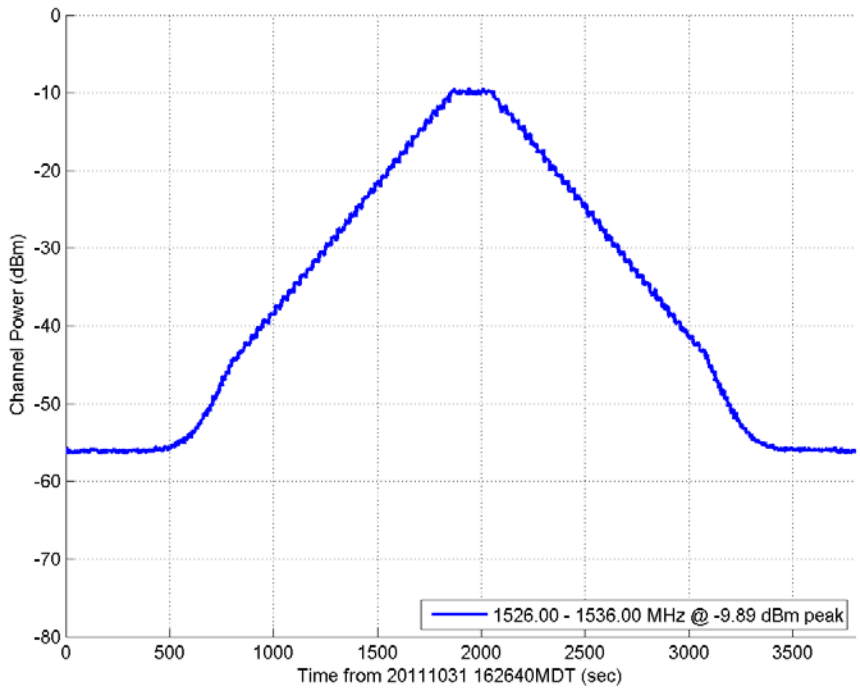

Figure 11 – Power Profile for Ramp 1 TE 1

The power profiles for each TE were then aggregated into a final summery plot that shows the peak power achieved as mapped to P13. As can be seen in Figure 12, all the LightSquared Base Station TEs consistently saw a peak power of approximately -10 dBm. Additionally, all the LightSquared handset TEs consistently saw a peak power of approximately -4 dBm. The expected power levels are shown by the dash lines. These were derived from direct measurements made with the same reference antenna placed at P13 during the ARL mapping. Within good measurement accuracy, all the TEs agree with the mapping results.

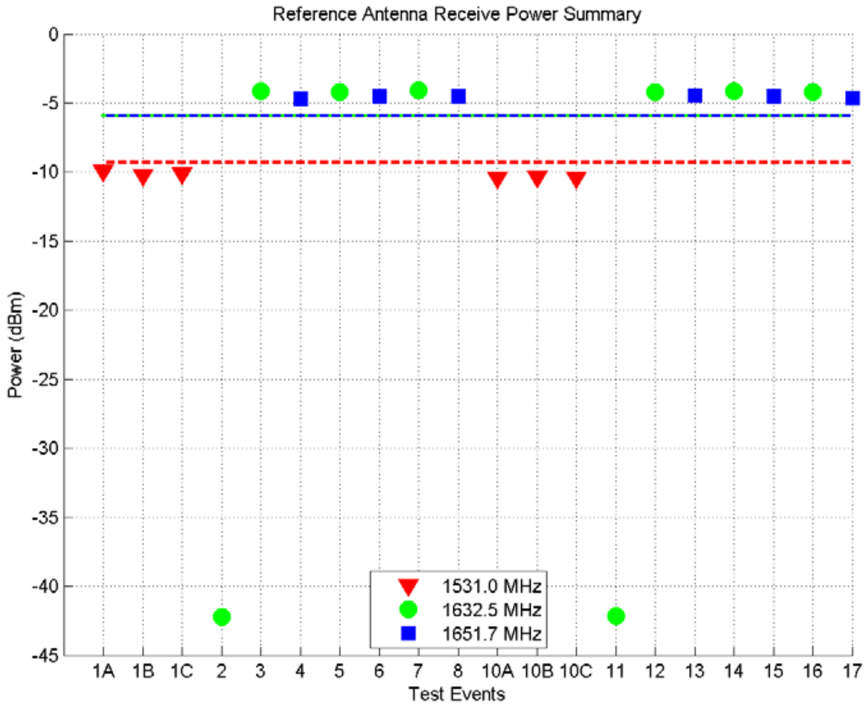

Figure 12 – Test Event Peak Power Summery @ P13

One last comment is in order for Figure 12. TE 2 and 11 are far from the expected levels. These two TEs were added to the test plan to look at a low duty cycle handset signal. The averaging of the SA was not able to accurately measure the power in these signals. The instantaneous power level of these signals was confirmed to be correct with a real-time spectrum analyzer provided by ARL.

RF Chain Equipment Details

RF Chain A

Item	Model	S/N	Details
Vector Signal Generator	Agilent N5182A	47071022	
High-Power Amplifier	Ophir 5063	1047	200W 0.8-2 GHz
Spectrum Analyzer	Anritsu 2034A	AF75244	

RF Chain B

Item	Model	S/N	Details
Vector Signal Generator	Agilent N5182A	47071021	
High-Power Amplifier	Ophir 5063	1048	200W 0.8-2 GHz
Spectrum Analyzer	Anritsu 2034A	AF76737	

RF Chain C

Item	Model	S/N	Details
Vector Signal Generator	Agilent E4438C	45090149	
High-Power Amplifier	Empower 2030	BBS3Q7EK0	100W
Spectrum Analyzer	Anritsu 2034A	DL5616	

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Appendix H. AGILENT SETTINGS FOR LTE SIMULATION

Table H-1. Agilent LTE Setup (LightSquared 10 MHz Low)

PARAMETER	SETTING	COMMENT
Center frequencies	10 MHz Downlink channels LTE Carriers centered @ 1531 MHz, BW: 10 MHz	According to Test
Release	3GPP R8	
Duplexing	FDD	
Modulation	OFDM/OFDMA	
Frame Duration	10 ms	
Sub-frame Duration	1.0 ms	
Subcarrier Modulation	QPSK	For PCH, PDCCH, PDSCH
Subcarrier Size	15 KHz	
Channel Bandwidth	5/10 MHz	According to test
PRB	0.180 MHz	
Sampling Rate	15.36 MHz	
FFT Size	1024	
Dummy Data	PN9	

Table H-2 Agilent LTE Setup (LightSquared Handset)

PARAMETER	SETTING	COMMENT
Center frequencies	1632.5 MHz and 1651.7 MHz	
Release	3GPP R8	
Duplexing	FDD	
Modulation	OFDM/OFDMA	
Allocation	1 Lower-most RB Freq = 1628 -1628.180 MHz	
RB Bandwidth	180 kHz	
UE Power	+23 dBm	
Subcarrier Modulation	QPSK	
Dummy Data	PN9	

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Appendix I. ALMANAC DATA

******** Week 1660 almanac for PRN-01 ********

ID:	01
Health:	000
Eccentricity:	0.4177093506E-003
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9605500072
Rate of Right Ascen(r/s):	-0.7840326581E-008
SQRT(A) (m 1/2):	5153.616211
Right Ascen at Week(rad):	0.2772166937E+001
Argument of Perigee(rad):	1.424048369
Mean Anom(rad):	0.1780235837E+001
Af0(s):	0.4386901855E-004
Af1(s/s):	0.2546585165E-010
week:	1660

******** Week 1660 almanac for PRN-02 ********

ID:	02
Health:	000
Eccentricity:	0.1055669785E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9391341973
Rate of Right Ascen(r/s):	-0.8034620388E-008
SQRT(A) (m 1/2):	5153.532715
Right Ascen at Week(rad):	0.2763174648E+001
Argument of Perigee(rad):	-2.922130037
Mean Anom(rad):	-0.2497453673E+001
Af0(s):	0.3614425659E-003
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-03 ********

ID:	03
Health:	000
Eccentricity:	0.1489830017E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9293251092
Rate of Right Ascen(r/s):	-0.8286059433E-008
SQRT(A) (m 1/2):	5153.623047
Right Ascen at Week(rad):	0.1602660134E+001
Argument of Perigee(rad):	1.148279745
Mean Anom(rad):	-0.2331936921E+001
Af0(s):	0.7848739624E-003
Af1(s/s):	0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-04 ********

ID:	04
Health:	000
Eccentricity:	0.9920120239E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9382174041
Rate of Right Ascen(r/s):	-0.8046049436E-008
SQRT(A) (m 1/2):	5153.670898
Right Ascen at Week(rad):	0.2780344672E+001
Argument of Perigee(rad):	0.783457842
Mean Anom(rad):	0.6994147203E+000
Af0(s):	0.2670288086E-003
Af1(s/s):	0.1091393642E-010
week:	1660

******** Week 1660 almanac for PRN-05 ********

ID:	05
Health:	000
Eccentricity:	0.2537250519E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9530299061
Rate of Right Ascen(r/s):	-0.8217485148E-008
SQRT(A) (m 1/2):	5153.718750
Right Ascen at Week(rad):	-0.2457969771E+001
Argument of Perigee(rad):	0.171529837
Mean Anom(rad):	-0.4854498668E+000
Af0(s):	-0.2346038818E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-07 ********

ID:	07
Health:	000
Eccentricity:	0.5074977875E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9754583830
Rate of Right Ascen(r/s):	-0.7817468486E-008
SQRT(A) (m 1/2):	5153.589355
Right Ascen at Week(rad):	-0.3498753265E+000
Argument of Perigee(rad):	-3.045651443
Mean Anom(rad):	0.2274870289E+001
Af0(s):	0.3337860107E-004
Af1(s/s):	0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-08 ********

ID:	08
Health:	000
Eccentricity:	0.1215600967E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9973775304
Rate of Right Ascen(r/s):	-0.7588887536E-008
SQRT(A) (m 1/2):	5153.702637
Right Ascen at Week(rad):	-0.2712741659E+000
Argument of Perigee(rad):	-3.015781512
Mean Anom(rad):	0.1766910303E+001
Af0(s):	0.0000000000E+000
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-09 ********

ID:	09
Health:	000
Eccentricity:	0.1717805862E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9842907568
Rate of Right Ascen(r/s):	-0.7726036106E-008
SQRT(A) (m 1/2):	5153.613770
Right Ascen at Week(rad):	-0.3772117181E+000
Argument of Perigee(rad):	1.601498038
Mean Anom(rad):	0.1598948769E+001
Af0(s):	0.1134872437E-003
Af1(s/s):	0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-12 ********

ID:	12
Health:	000
Eccentricity:	0.3576755524E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9770343086
Rate of Right Ascen(r/s):	-0.8046049436E-008
SQRT(A) (m 1/2):	5153.589355
Right Ascen at Week(rad):	0.7050252101E+000
Argument of Perigee(rad):	-0.065972409
Mean Anom(rad):	0.2093583421E+001
Af0(s):	0.2956390381E-004
Af1(s/s):	0.3637978807E-011
week:	1660

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******** Week 1660 almanac for PRN-13 ********

ID:	13
Health:	000
Eccentricity:	0.4584312439E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9879040006
Rate of Right Ascen(r/s):	-0.7657461821E-008
SQRT(A) (m 1/2):	5153.723145
Right Ascen at Week(rad):	-0.1322800769E+001
Argument of Perigee(rad):	1.956820570
Mean Anom(rad):	-0.1563989287E+001
Af0(s):	0.2450942993E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-14 ********

ID:	14
Health:	000
Eccentricity:	0.6312847137E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9808572763
Rate of Right Ascen(r/s):	-0.7726036106E-008
SQRT(A) (m 1/2):	5153.684082
Right Ascen at Week(rad):	-0.1348009211E+001
Argument of Perigee(rad):	-2.077268022
Mean Anom(rad):	-0.1516653471E+001
Af0(s):	0.1773834229E-003
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-15 ********

ID:	15
Health:	000
Eccentricity:	0.3804683685E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9478766894
Rate of Right Ascen(r/s):	-0.8114623721E-008
SQRT(A) (m 1/2):	5153.648926
Right Ascen at Week(rad):	-0.1428682519E+001
Argument of Perigee(rad):	-0.074449376
Mean Anom(rad):	0.4712388980E+001
Af0(s):	-0.1020431519E-003
Af1(s/s):	0.0000000000E+000
week:	1660

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******** Week 1660 almanac for PRN-16 ********

ID:	16
Health:	000
Eccentricity:	0.6142139435E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9779630860
Rate of Right Ascen(r/s):	-0.8046049436E-008
SQRT(A) (m 1/2):	5153.488770
Right Ascen at Week(rad):	0.7230015474E+000
Argument of Perigee(rad):	-0.070590830
Mean Anom(rad):	0.0000000000E+000
Af0(s):	-0.2050399780E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-17 ********

ID:	17
Health:	000
Eccentricity:	0.6670951843E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9614967610
Rate of Right Ascen(r/s):	-0.7886042771E-008
SQRT(A) (m 1/2):	5153.541504
Right Ascen at Week(rad):	0.1765084581E+001
Argument of Perigee(rad):	-2.403758755
Mean Anom(rad):	-0.1157728931E+001
Af0(s):	0.1697540283E-003
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-18 ********

ID:	18
Health:	000
Eccentricity:	0.1275587082E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9317998517
Rate of Right Ascen(r/s):	-0.8411778956E-008
SQRT(A) (m 1/2):	5153.576172
Right Ascen at Week(rad):	-0.2442977131E+001
Argument of Perigee(rad):	-2.207994943
Mean Anom(rad):	0.2875903136E+000
Af0(s):	0.1630783081E-003
Af1(s/s):	0.0000000000E+000
week:	1660

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******** Week 1660 almanac for PRN-19 ********

ID:	19
Health:	000
Eccentricity:	0.7652759552E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9589740817
Rate of Right Ascen(r/s):	-0.7908900866E-008
SQRT(A) (m 1/2):	5153.661621
Right Ascen at Week(rad):	0.1818733462E+001
Argument of Perigee(rad):	0.122056709
Mean Anom(rad):	-0.1916087687E+001
Af0(s):	-0.1964569092E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-20 ********

ID:	20
Health:	000
Eccentricity:	0.4654407501E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9321174336
Rate of Right Ascen(r/s):	-0.8446066098E-008
SQRT(A) (m 1/2):	5153.507812
Right Ascen at Week(rad):	-0.2496830493E+001
Argument of Perigee(rad):	1.259343174
Mean Anom(rad):	0.7366081368E+000
Af0(s):	0.5435943604E-004
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-21 ********

ID:	21
Health:	000
Eccentricity:	0.1816701889E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9318657649
Rate of Right Ascen(r/s):	-0.8137481816E-008
SQRT(A) (m 1/2):	5153.645020
Right Ascen at Week(rad):	0.2787756541E+001
Argument of Perigee(rad):	-2.323370073
Mean Anom(rad):	0.1380399575E+001
Af0(s):	-0.1792907715E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-22 ********

ID:	22
Health:	000
Eccentricity:	0.5871772766E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9295048726
Rate of Right Ascen(r/s):	-0.8434637051E-008
SQRT(A) (m 1/2):	5153.637207
Right Ascen at Week(rad):	-0.2439144052E+001
Argument of Perigee(rad):	-1.969686384
Mean Anom(rad):	-0.5699532582E+000
Af0(s):	0.1440048218E-003
Af1(s/s):	0.0000000000E+000
week:	1660

******** Week 1660 almanac for PRN-23 ********

ID:	23
Health:	000
Eccentricity:	0.7570743561E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9624734753
Rate of Right Ascen(r/s):	-0.7943188009E-008
SQRT(A) (m 1/2):	5153.668945
Right Ascen at Week(rad):	-0.1396162201E+001
Argument of Perigee(rad):	-3.039842839
Mean Anom(rad):	-0.2395945415E+001
Af0(s):	0.2660751343E-003
Af1(s/s):	-0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-25 ********

ID:	25
Health:	000
Eccentricity:	0.1012802124E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9658710031
Rate of Right Ascen(r/s):	-0.8160339911E-008
SQRT(A) (m 1/2):	5153.523926
Right Ascen at Week(rad):	0.6734681243E+000
Argument of Perigee(rad):	0.943832613
Mean Anom(rad):	0.6127290765E+000
Af0(s):	0.2479553223E-004
Af1(s/s):	0.0000000000E+000
week:	1660

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******** Week 1660 almanac for PRN-28 ********

ID:	28
Health:	000
Eccentricity:	0.1732397079E-001
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9762733103
Rate of Right Ascen(r/s):	-0.8034620388E-008
SQRT(A) (m 1/2):	5153.652832
Right Ascen at Week(rad):	0.7300168131E+000
Argument of Perigee(rad):	-1.876996269
Mean Anom(rad):	-0.5185978584E+000
Af0(s):	0.7724761963E-004
Af1(s/s):	0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-29 ********

ID:	29
Health:	000
Eccentricity:	0.2130031586E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9619821221
Rate of Right Ascen(r/s):	-0.7874613724E-008
SQRT(A) (m 1/2):	5153.656250
Right Ascen at Week(rad):	0.1773544320E+001
Argument of Perigee(rad):	-1.165631030
Mean Anom(rad):	0.1582683554E+001
Af0(s):	0.2508163452E-003
Af1(s/s):	0.3637978807E-011
week:	1660

******** Week 1660 almanac for PRN-31 ********

ID:	31
Health:	000
Eccentricity:	0.7752895355E-002
Time of Applicability(s):	503808.0000
Orbital Inclination(rad):	0.9805756471
Rate of Right Ascen(r/s):	-0.7760323249E-008
SQRT(A) (m 1/2):	5153.715820
Right Ascen at Week(rad):	-0.3479421213E+000
Argument of Perigee(rad):	-0.951915223
Mean Anom(rad):	0.2273820171E+001
Af0(s):	0.1583099365E-003
Af1(s/s):	0.3637978807E-011
week:	1660

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Appendix J. IONOSPHERE AND TROPOSPHERE MODELS

1. IONOSPHERE PARAMETERS

ALPHA0: 5.58793544769E-009
ALPHA1: 1.49011611938E-008
ALPHA2: -5.96046447754E-008
ALPHA3: -1.19209289551E-007
BETA0: 83968
BETA1: 98304
BETA2: -65536
BETA3: -524288

2. TROPOSPHERE PARAMETERS

NOTE:
TROPOSPHERIC MODEL IN THE SIMULATORS MAY VARY, HOWEVER, THE NET SOLUTION WILL DIFFER MINIMALLY AND HAVE NO EFFECT ON THE OBJECTIVES OF THESE TESTS SINCE EACH TEST AGENCY WILL HAVE THEIR OWN BASELINE DATA.

ZENITH_DELAY: 2.4225
SCALE_HEIGHT: 7492.83

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Appendix K. REFERENCES

K1. *NAVSTAR GPS Space Segment/Navigation Interfaces*, IS-GPS-200E, 8 June 2010.

K2.* *NAVSTAR GPS Military-Unique Space Segment/User Segment Interfaces*, ICD-GPS-700, 24 August 2001; ICD-GPS-700A, 11 March 2004.

K3. *Navstar GPS Space Segment/User Segment L5 Interfaces*, IS-GPS-705, 9 August 2004.

K4.* *GPS Security Classification Guide*, 30 Sept 2008.

K5. DoD 5220.22-M, *National Industry Security Program Operating Manual (NISPOM)*, January 1995, (Change 2, May 1, 2000).

K6. FCC Order DA 11-133, in the matter of LightSquared Subsidiary LLC "Request for Modification of its Authority for an Ancillary Terrestrial Component," adopted and released January 26, 2011.

K7. *Test Report for the Assessment of LightSquared Ancillary Terrestrial Component Affects on GPS Receivers (Anechoic Chamber & Live Sky Tests)*, SMC/GP, 25 May 2011.

K8. *Navstar GPS Space Segment/User Segment L1C Interfaces*, IS-GPS-800, 19 April 2006.

K9. EXCOM Tasking letter to the NPEF, 12 October 2011

K10. LightSquared Responses to NTIA Questions, 2011-02-24

K11.* *Idaho National Laboratory Independent Assessment of the Follow-on Test of LightSquared Ancillary Terrestrial Component Effects on GPS Recievers* dated 5 December 2011

K12. *Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations*, RTCA, 3 Jun 2011.

K13. *Assessment of LightSquared Terrestrial Broadband System Effects on GPS Receivers and GPS-dependent Applications*, NPEF, 1 Jun 2011

K14. *Technical Working Group Final Report into LightSquared Interference with GPS*, 30 Jun 2011

K15.* *Test Plan for the LightSquared Ancillary Terrestrial Component Effects on GPS Receivers: Follow-on Test (Anechoic Chamber)*, NPEF, 23 Oct 2011

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