# GPS Adjacent Band Compatibility Assessment

## Space-Based PNT Advisory Board Meeting

May 18, 2016

# EXCOM Co-Chair Letter to NTIA

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

JAN 13 2012

UNITED STATES OF AMERICA

The Honorable Lawrence E. Strickling
Assistant Secretary for Communications and Information
U.S. Department of Commerce
Washington, DC 20230

Dear Assistant Secretary Strickling:

At the request of the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), the nine federal departments and agencies comprising the National Space-Based Positioning, Navigation and Timing (PNT) Executive Committee (EXCOM) have tested and analyzed LightSquared's proposals to repurpose the Mobile Satellite Services (MSS) frequency band adjacent to Global Positioning System (GPS) frequencies to permit another nationwide terrestrial broadband service. Over the past year we have closely worked with LightSquared to evaluate its original deployment plan, and subsequent modifications, to address interference concerns. This cooperative effort included extensive testing and analysis of GPS receivers. Substantial federal resources have been expended and diverted from other programs in testing and analyzing LightSquared's proposals.

It is the unanimous conclusion of the test findings by the National Space-Based PNT EXCOM Agencies that both LightSquared's original and modified plans for its proposed mobile network would cause harmful interference to many GPS receivers. Additionally, an analysis by the Federal Aviation Administration (FAA) has concluded that the LightSquared proposals are not compatible with several GPS-dependent aircraft safety-of-flight systems. Based upon this testing and analysis, there appear to be no practical solutions or mitigations that would permit the LightSquared broadband service, as proposed, to operate in the next few months or years without significantly interfering with GPS. As a result, no additional testing is warranted at this time.

The EXCOM Agencies continue to strongly support the President's June 28, 2010 Memorandum to make available a total of 500 MHz of spectrum over the next 10 years, suitable for broadband use. We propose to draft new GPS Spectrum interference standards that will help inform future proposals for non-space, commercial uses in the bands adjacent to the GPS signals and ensure that any such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs.

ASHTON B. CARTER
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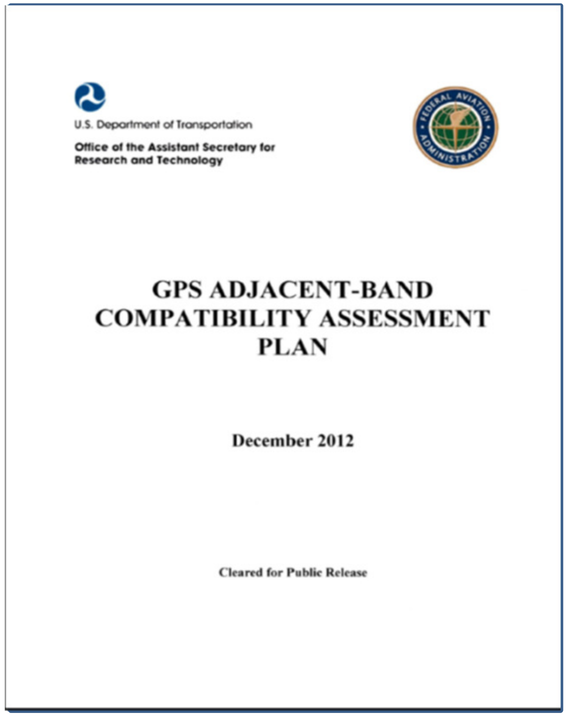
**"... without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs."**

# GPS Adjacent Band Compatibility Assessment

- DOT Study to Evaluate:
  - Adjacent-band power levels, as a function of offset frequency, necessary to ensure continued operation of all applications of GPS services
  - Adjacent-band power levels to ensure continued operation of all applications of GPS services by future GPS receivers utilizing modernized GPS and interoperable Global Navigation Satellite System (GNSS) signals


U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

GPS ADJACENT-BAND COMPATIBILITY ASSESSMENT PLAN

December 2012

Cleared for Public Release

# Approach to DOT GPS Adjacent Band Compatibility Assessment

- Certified Aviation Portion of Effort Led by FAA
- Non Aviation Certified effort (all other applications) led by DOT/OST-R Volpe Center
- DOT Extended Pos/Nav Working Group (Civil Departments and Agencies)
  - GPS Directorate, Aerospace, Mitre, Zeta Associates, and Stansell Consulting
- Conduct public outreach to ensure the plan, on going work, and assumptions are vetted and an opportunity to gain feedback
  - Held Many Public Workshops
  - Federal Register Notice for Comments/Input on Draft Test Plan
  - One-on-One Discussions with Industry
  - Open and Transparent Approach

# Activity Since October 2015 Advisory Board Meeting

- Finalized GPS/GNSS Receiver Test Plan
- Contracted for Use of WSMR Anechoic Chamber
- Coordinated Government and Manufacturer Participation and executed Non Disclosure Agreements (NDAs)
- Developed Test Procedures
- Developed/Validated Radiated RF Test Environment
- Conducted GPS/GNSS Receiver Testing

# Testing Overview

- GPS Receiver Testing Conducted April 25-29, 2016 at the Army Research Laboratory's (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF), White Sands Missile Range (WSMR), NM
  - EMVAF – 100' x 70' x 40' Anechoic Chamber
- Participation included DOT's federal partners/agencies and GPS manufacturers
- 80 receivers were tested representing six categories of GPS/GNSS receivers: General Aviation (non certified), General Location/Navigation, High Precision & Networks, Timing, Space Based, and Cellular
- Tests Conducted:
  - Linearity (receivers CNR's estimators are operating in the linear region)
  - 1 MHz Bandpass Noise (Type 1)
  - 10 MHz LTE (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

# Signal Generation Equipment

- GNSS Generation and Playback
  - Spirent GSS8000 GNSS signal simulators synchronously generate signals for the GPS+WAAS, Beidou, GLONASS, and Galileo systems
  - Constellations recorded using three National Instruments (NI) Vector Signal Analyzers
  - Playback through three NI Vector Signal Generators (VSGs)

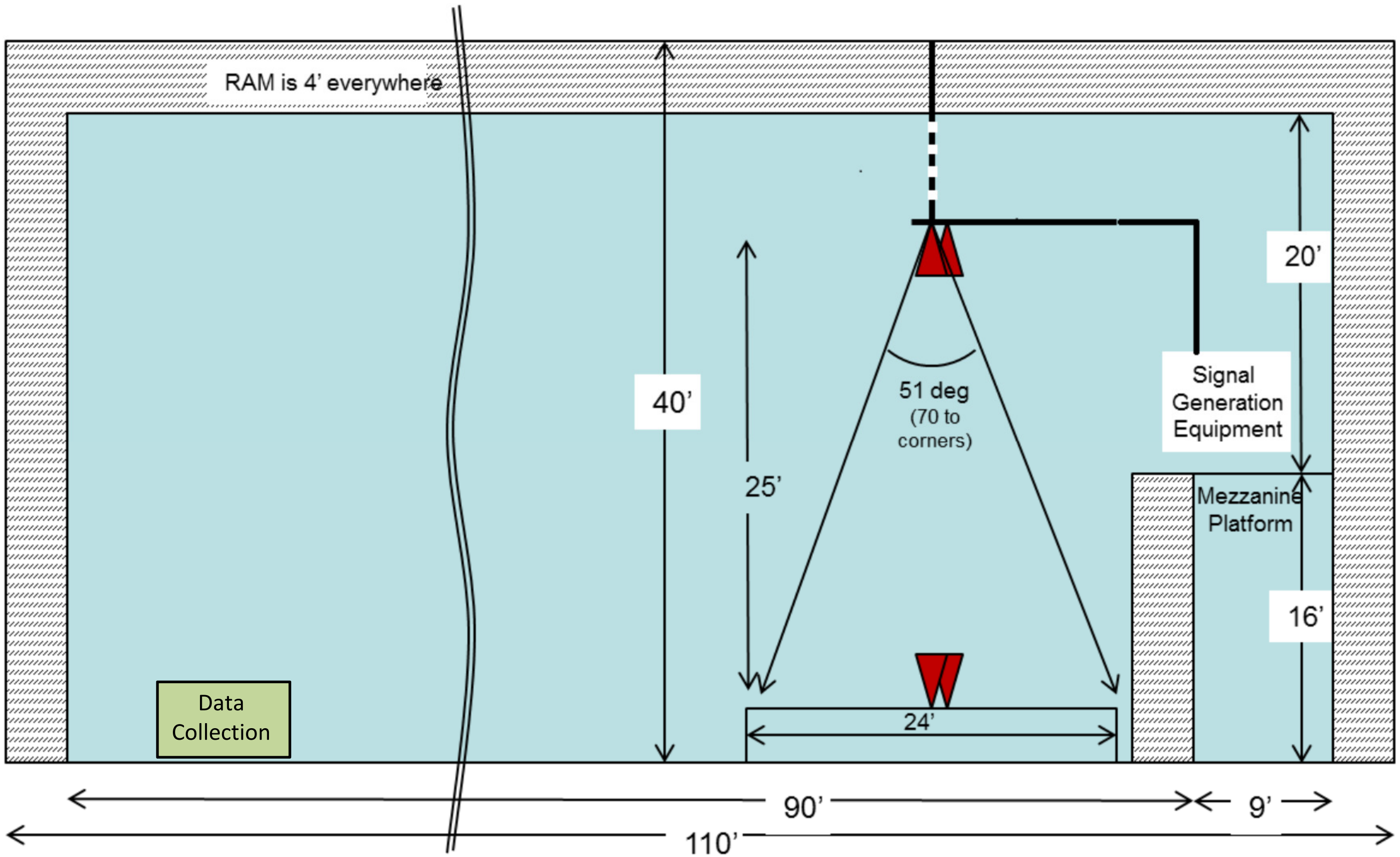
- Interference Signal Generation
  - Interference signal generation uses a VSG to generate the interference signal of either Type 1 or Type 2
  - 200 Watt High Power Amplifier used to boost the interference signal
  - 22 RF filters used to sufficiently attenuate the interference out-of-band emission (OOBE), to ensure that degradation measured is not due to OOBE

- Signal Antennas
  - GNSS Signals: Passive GNSS Patch Antenna
  - Interference Signals: Passive Horn Antenna

# GNSS Signals Used in Testing

| Signal |
| --- |
| GPS C/A-code |
| GPS L1 P(Y)-code |
| GPS L1C |
| GPS L2 P(Y)-code |
| SBAS L1 |
| GLONASS L1 C or P |
| BeiDou B1I |
| Galileo E1 B/C |

# Chamber Diagram

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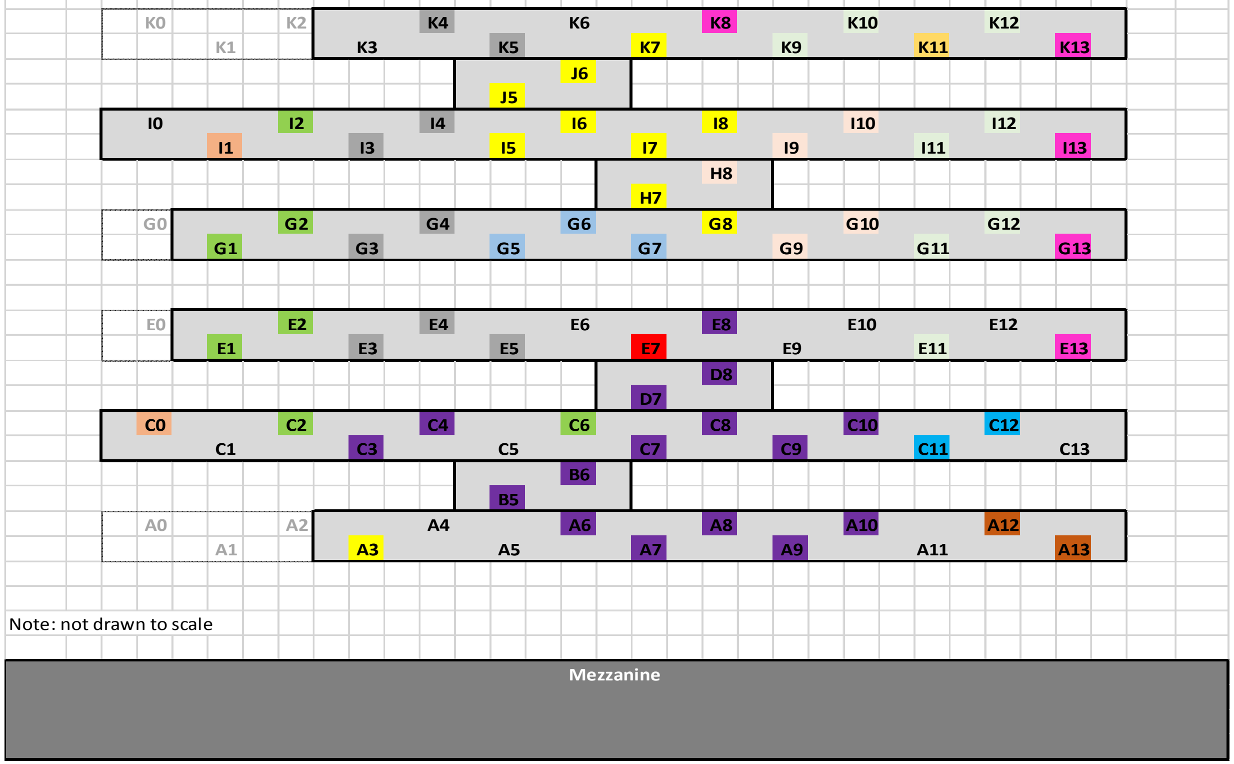
# Test Grid

←Exit

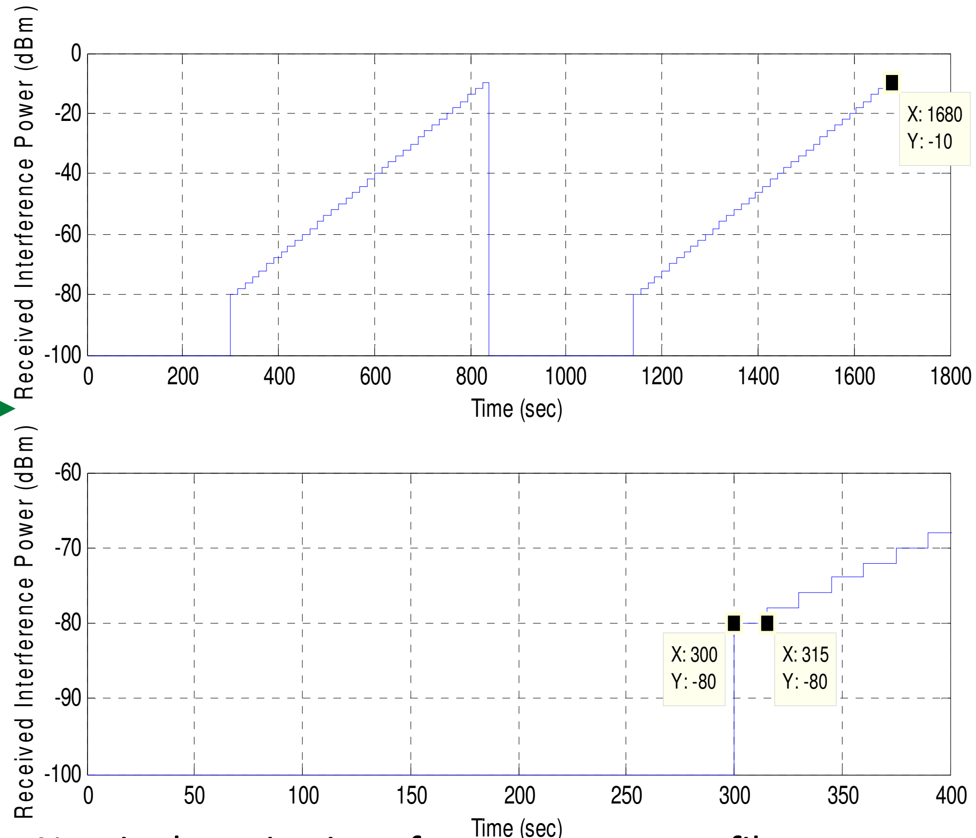
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USCG | NASA | NOAA | USGS | FAA | USDOT | GM | UBLOX | NOVATEL | TRIMBLE | DEERE | UNAVCO | Aero_Spec_A |
| 2 | 8 | 9 | 3 | 23 | 16 | 2 | 5 | 1 | 8 | 2 | 5 | 1 |




Note: not drawn to scale

# Interference Test Signal Frequencies and Power Profiles (1/2)

| Name | Value | Unit |
|---|---|---|
| $f_{start}$ | 1475 | MHz |
| $f_{end}$ | 1675 | MHz |
| $[p_{min_1}, p_{max_1}]$ (1475 to 1540 MHz) | [-80,-10] | dBm |
| $[p_{min_2}, p_{max_2}]$ (1545 to 1555 MHz) | [-100,-30] | dBm |
| $[p_{min_3}, p_{max_3}]$ (1575 and 1595 MHz) | [-130,-60] | dBm |
| $[p_{min_4}, p_{max_4}]$ (1615 to 1625 MHz) | [-100,-30] | dBm |
| $[p_{min_5}, p_{max_5}]$ (1630 to 1675 MHz) | [-80,-10] | dBm |
| $\Delta f_1$(1475 to 1520 MHz) | 15 | MHz |
| $\Delta f_2$(1520 to 1555 MHz) | 5 | MHz |
| $\Delta f_3$(1575 and 1595 MHz) | N/A | MHz |
| $\Delta f_4$(1615 to 1645 MHz) | 5 | MHz |
| $\Delta f_5$(1645 to 1675 MHz) | 15 | MHz |
| $\Delta P$ | 2 | dB |
| Startup Time | 15 | min |
| $T_{BL}$ | 5 | min |
| $T_{step}$ | 15 | s |
| $N_{cycle}$ | 2 | N/A |




Nominal receive interference power profiles at GNSS antenna location for the (1475 to 1540 MHz) and (1630 to 1675 MHz) frequency ranges.

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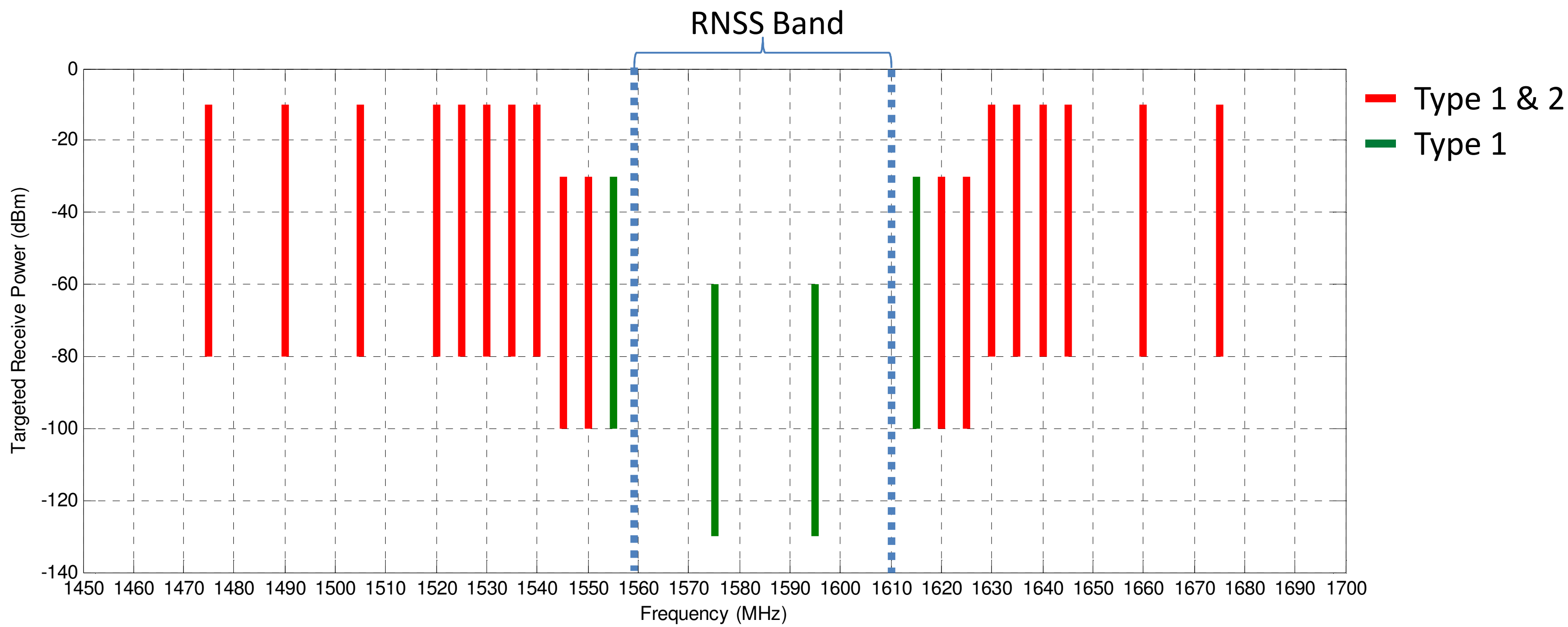
# Interference Test Signal Frequencies and Power Profiles (2/2)



# Data Collected

- Data Needed to Develop an ITM for each receiver:
  - $CNR(s, i, j.\Delta t)$ (here, *s* identifies the GNSS, *i* the SV, $\Delta t$ is the reporting time increment)

- To the extent possible, additional data to report the state of the receiver at each time step
  - Number of satellites tracked for each GNSS service: $N_{SV}(s, t_j)$
  - Location: $Lat_s(j.\Delta t)$, $Lon_s(j.\Delta t)$, $h_s(j.\Delta t)$ (relative to WGS84 or other Datum)
  - Pseudorange: $R_{s,i}(j.\Delta t)$
  - Carrier phase
  - Cycle slip or loss of carrier phase lock indicator (per satellite)
  - Loss of code and carrier tracking indicator, or inferred loss of tracking in the case when it is not reported by the receiver (per satellite)

# Next Steps

- Analyze test data and develop interference tolerance masks for all receivers tested based on 1 dB CNR degradation
- Conduct lab testing on a limited number of receivers to determine how well test results can be reproduced
- Conduct receiver acquisition testing on a limited number of receivers
- Evaluate correlation of 1-dB CNR degradation to other receiver data collected
- Develop use-case scenarios
- Evaluate appropriate propagation models for each use-case scenario
- Develop maximum tolerable transmitter power level as a function of frequency offset

# Questions?