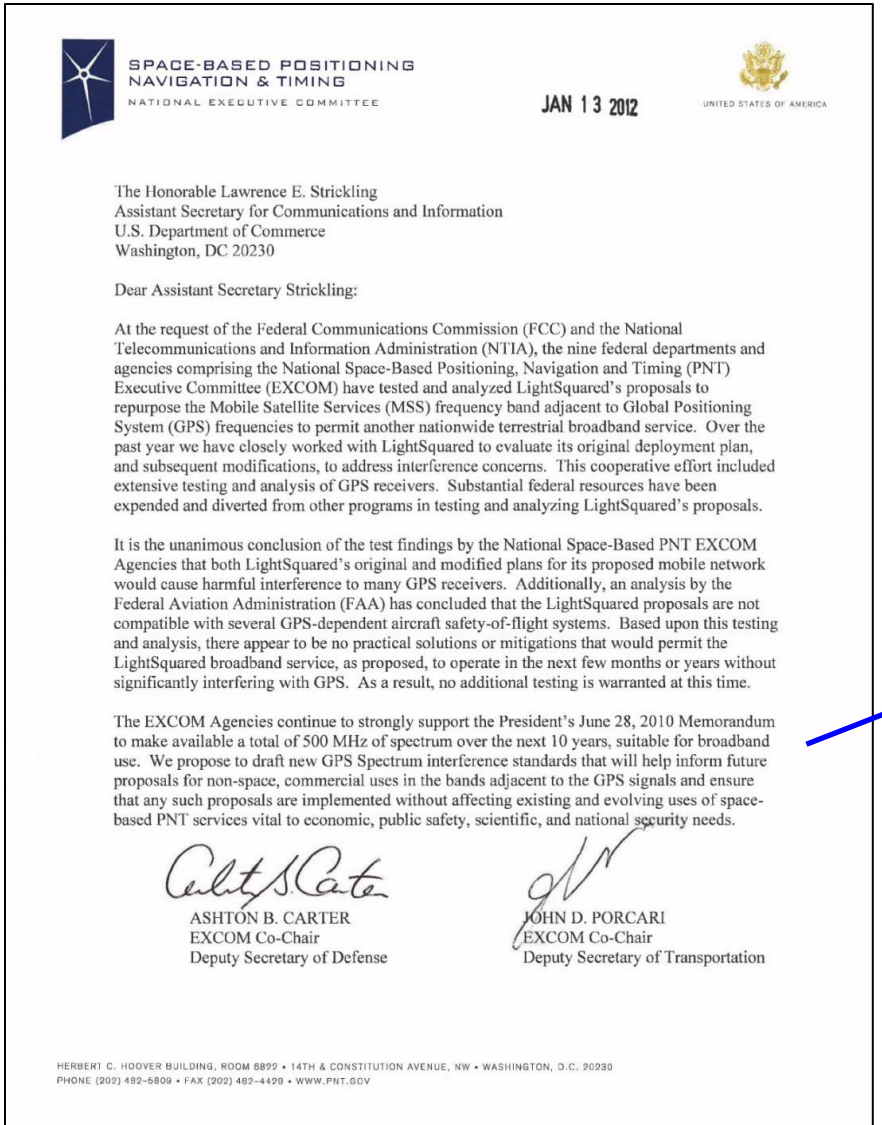
GPS Adjacent Band Compatibility Assessment

Space-Based PNT Advisory Board

December 7, 2016

GPS Adjacent Radiofrequency Band Compatibility Assessment



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
EXCOM Co-Chair
Deputy Secretary of Defense

JOHN D. PORCARI
EXCOM Co-Chair
Deputy Secretary of Transportation

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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."

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

Approach to DOT GPS Adjacent Band Compatibility Assessment

- Certified aviation portion of effort led by FAA
- The assessment for other civil applications (including non certified aviation) 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 five public workshops
  - Federal Register Notice for comments/input on draft test plan
  - One-on-one discussions with industry
  - Open and transparent approach as possible

Milestones

- Carried out GPS/GNSS receiver testing
  - Radiated receiver testing - White Sands Missile Range (WSMR), NM
    - Air Force/GPS Directorate conducted testing of military receivers week prior
  - Wired (conducted) receiver testing - Zeta Associates
  - Antenna Characterization – MITRE Corporation
- Produced Initial 1 dB Interference Tolerance Mask (ITM) results
  - ITM = Interference power (IP) resulting in 1 dB degradation to carrier-to-noise-ratio (CNR)
- Provided WSMR data to those Federal Partners who requested data (NTIA, NASA, and Air Force)

Test Participants

- United States Coast Guard (USCG)
- National Aeronautics and Space Administration (NASA)
- National Oceanic and Atmospheric Administration (NOAA)
- United States Geological Survey (USGS)
- Federal Aviation Administration (FAA)
- United States Department of Transportation (USDOT)
- General Motors (GM)
- u-blox
- NovAtel
- Trimble
- John Deere
- UNAVCO

Receiver Test List (1/2)

No.	Receiver
1	Trimble SPS461
2	Furuno GP-33
3	TriG
4	TriG V2
5	Septentrio PolaRx4TR Pro
6	Ashtech Z-12
7	Javad Delta-3
8	Ashtech uZ-CGRS
9	Javad EGGDT-160
10	Novatel OEM628V-G1S-B0G-TTN-H
11	Javad Delta II
12	Septentrio PolaRx4Pro
13	Trimble NETR5
14	Trimble NETR5
15	Trimble NETR9
16	Leica GRX1200GGPRO
17	Trimble 5700
18	Leica GRX1200GGPRO
19	Trimble NETRS
20	Trimble NETRS

No.	Receiver
21	Trimble NETRS
22	Topcon Net-G3A Sigma
23	Garmin GPSMap 295
24	Garmin - GPSMap 696
25	Garmin - Area 560
26	Garmin - GLOGPS (GPS & GLONASS)
27	Dual Electronics - SkyPro XGPS 150
28	EVA-7M EVK-7EVA-0
29	MAX-7C EVK-7C-0
30	MAX-7Q EVK-7N-0
31	EVA-M8M EVK-M8EVA-0
32	LEA-M8F EVK-M8F-0
33	MAX-M8Q EVK-M8N-0
34	LEA-M8S EVK-M8N-0
35	uBlox EVU-6P-0-001
36	SiRF III
37	Trimble NETR5
38	Symmetricom Xli
39	Symmetricom-GPS
40	Trimble SMT360 GPS receiver

Receivers included in the wired/conducted test

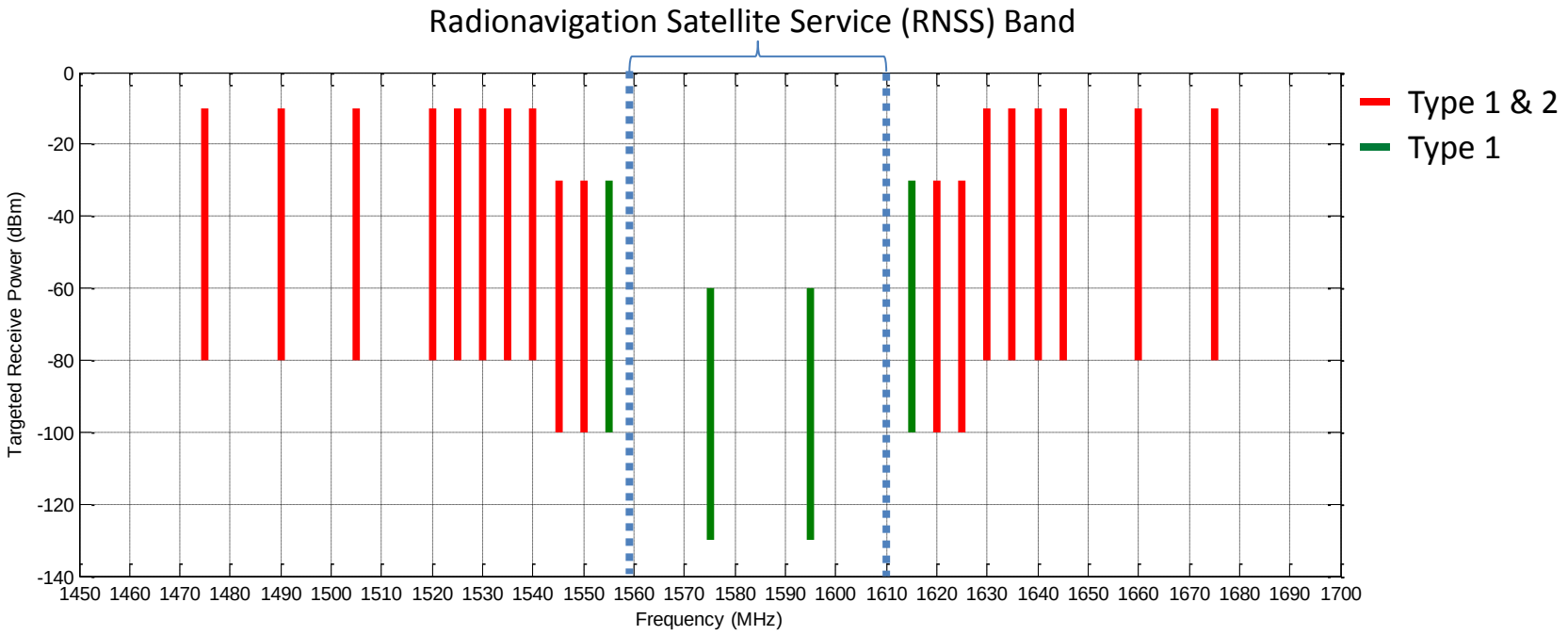
Receiver Test List (2/2)

No.	Receiver
41	Dynon 250
42	Dynon 2020
43	Garmin EDGE 1000
44	Garmin GPSMAP 64
45	Garmin ETREX 20x
46	Garmin FORERUNNER 230
47	Garmin GPSMAP 741
48	Symmetricom Xli
49	JAVAD Triumph-1
50	Hemisphere R330
51	NAVCOM SF3050
52	Symmetricom SyncServer S350
53	Arbiter Systems 1088B
54	Arbiter Systems 1094B
55	Schweitzer Eng. Labs SEL-2401
56	Android S5
57	Android S6
58	Android S7
59	Supercruise "VCP"
60	Supercruise "VCP"

No.	Receiver
61	EVK-M8N
62	EVK-M8T
63	MAX-M8Q
64	EVK-7P
65	EVK-6n
66	NovAtel 628 Card w/ Flex pack
67	Trimble Ag-382
68	Trimble Geo 7X
69	Trimble Bison III
70	Trimble R8
71	Trimble SPS985
72	Trimble SPS855
73	Trimble Acutime 360
74	Trimble Ag-382
75	SF3000
76	SF3000
77	Septentrio PolaRx5TR Pro
78	Septentrio PolaRx5TR Pro
79	Trimble NetRS
80	Trimble NETR9

Receivers included in the wired/conducted test

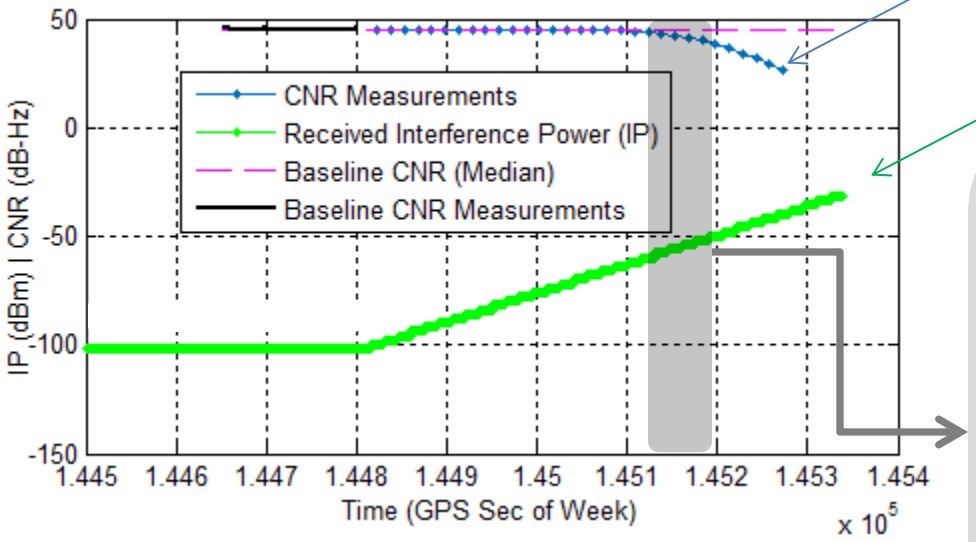
Interference Test Signal Frequencies and Power Profiles



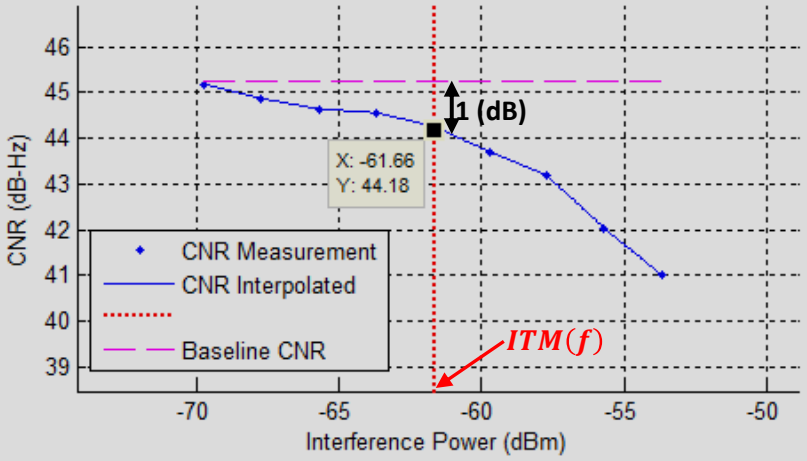
Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

- Example for determining ITM for 1 frequency (1545 MHz) for PRN 31 for one of the Devices Under Test (DUT)

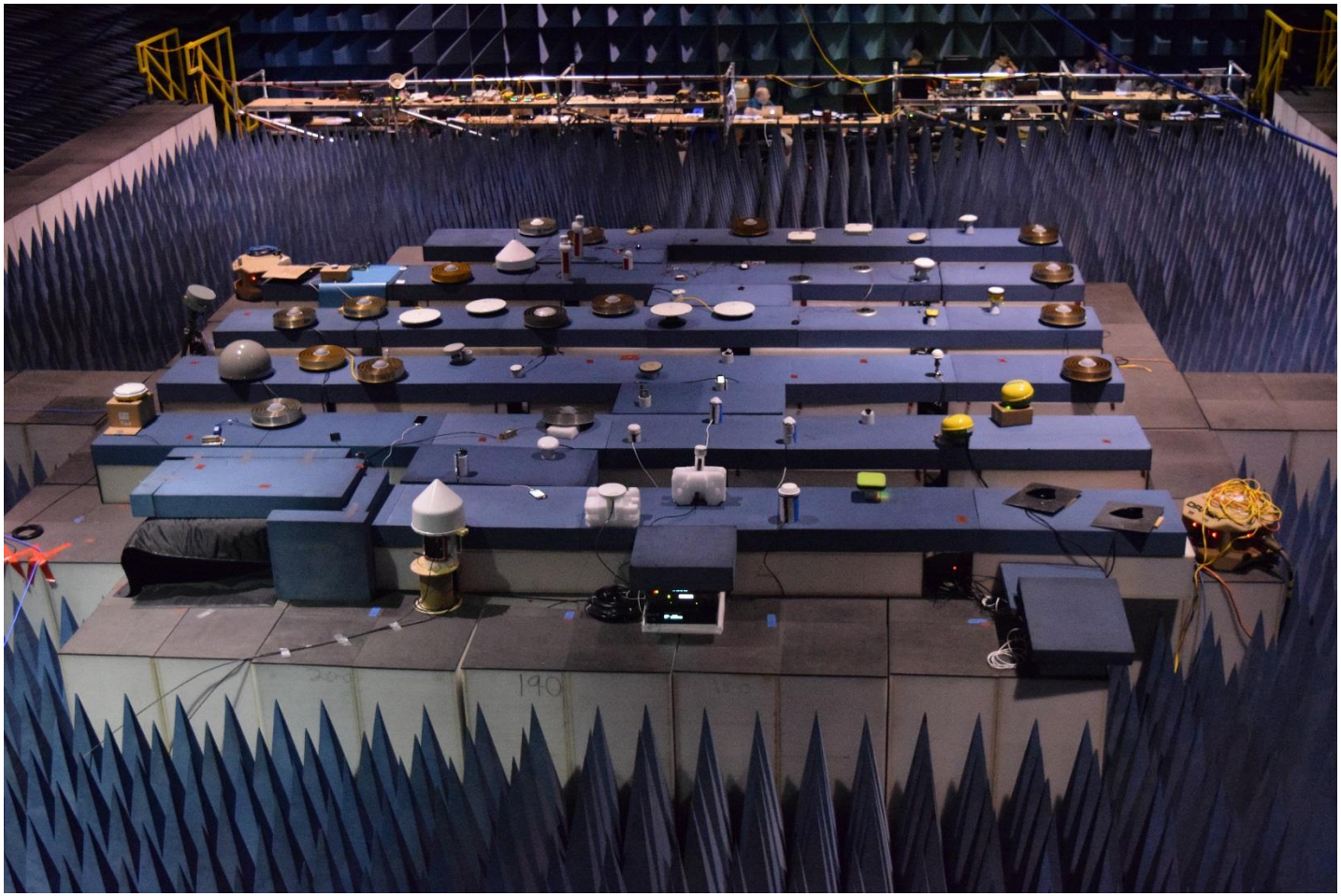
CNR vs. Time



IP vs. Time



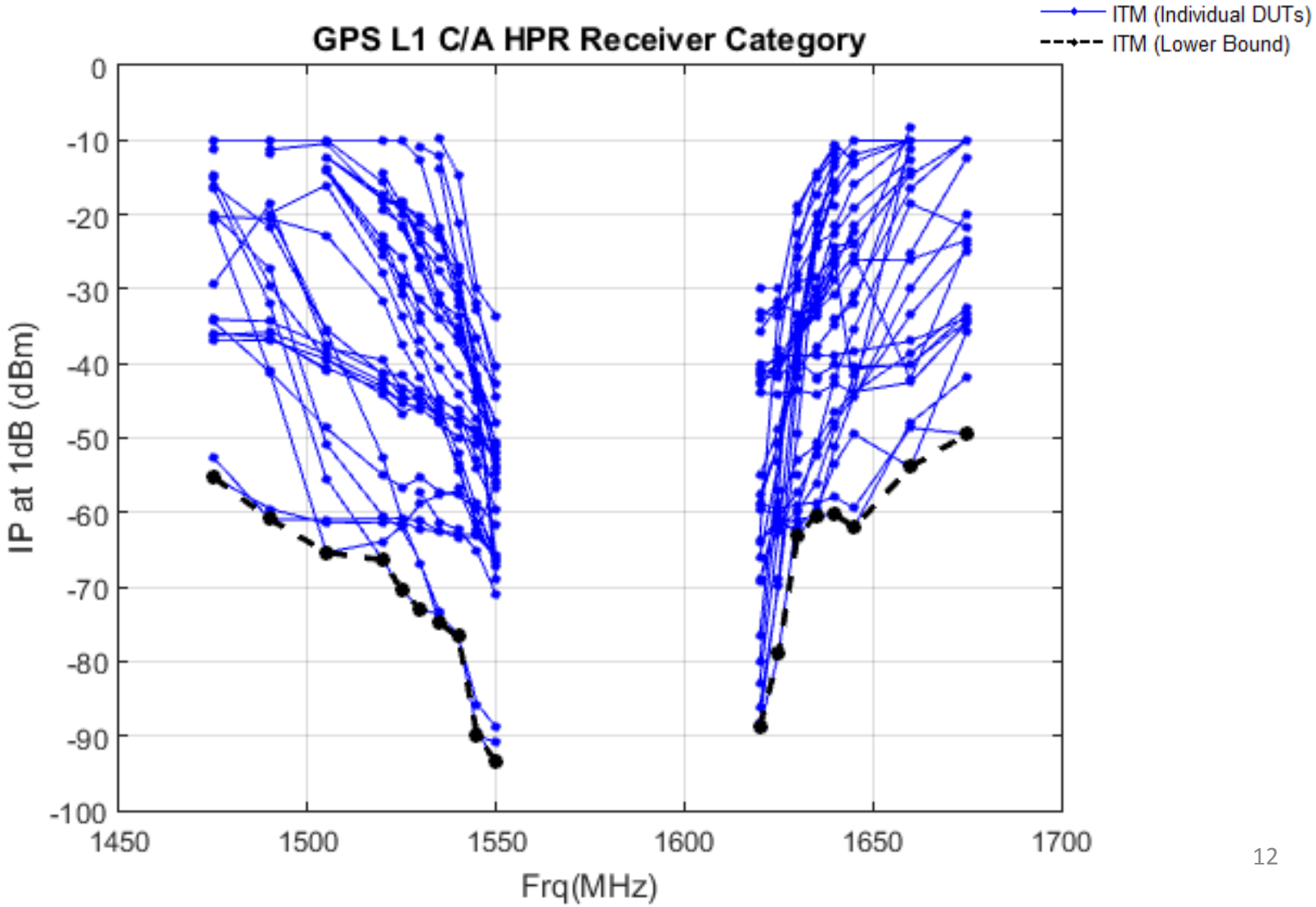
Chamber Setup



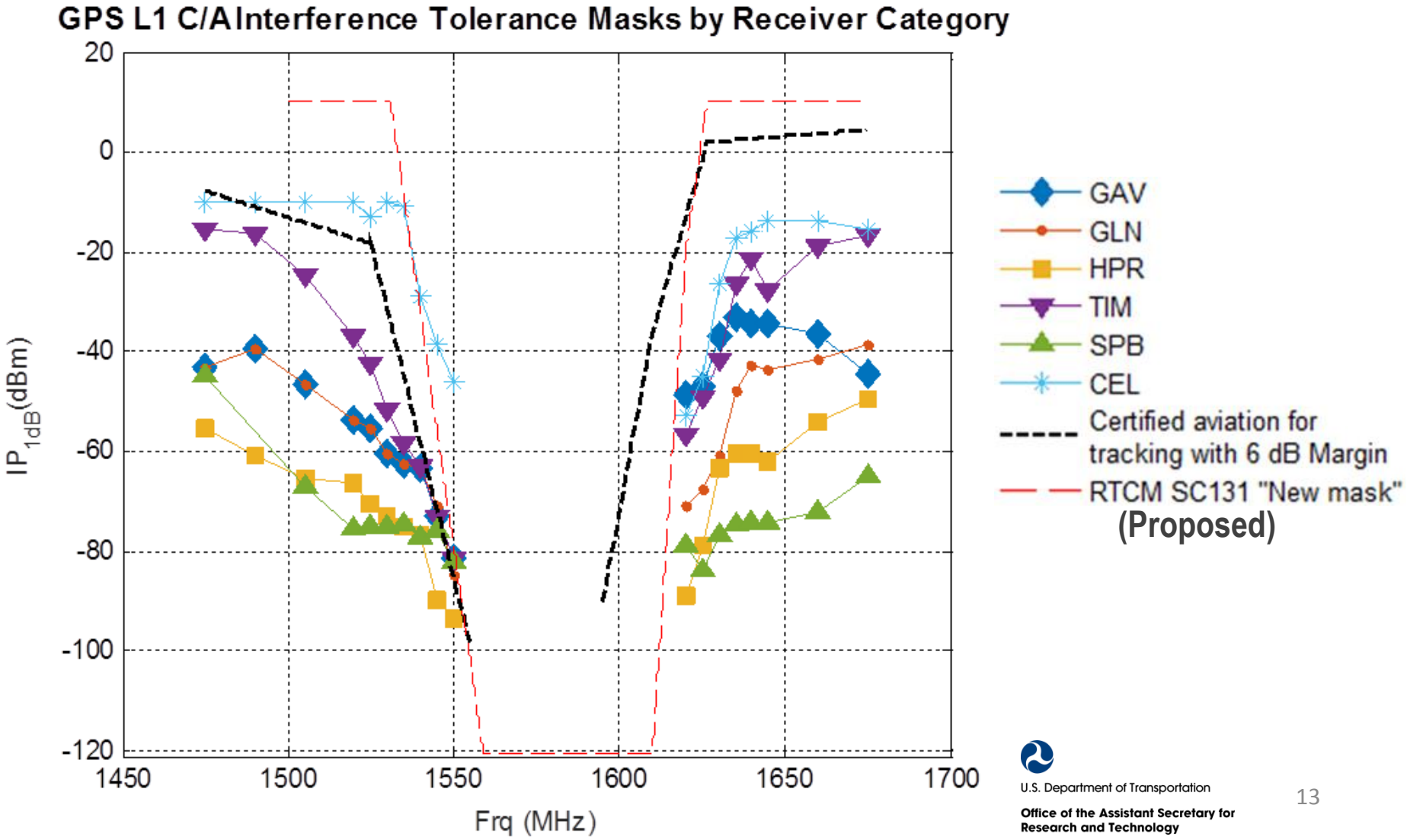
GNSS Signals Used in Testing

Signal
GPS L1 C/A-code
GPS L1 P-code
GPS L1C
GPS L1 M-code
GPS L2 P-code
SBAS L1
GLONASS L1 C
GLONASS L1 P
BeiDou B1I
Galileo E1 B/C

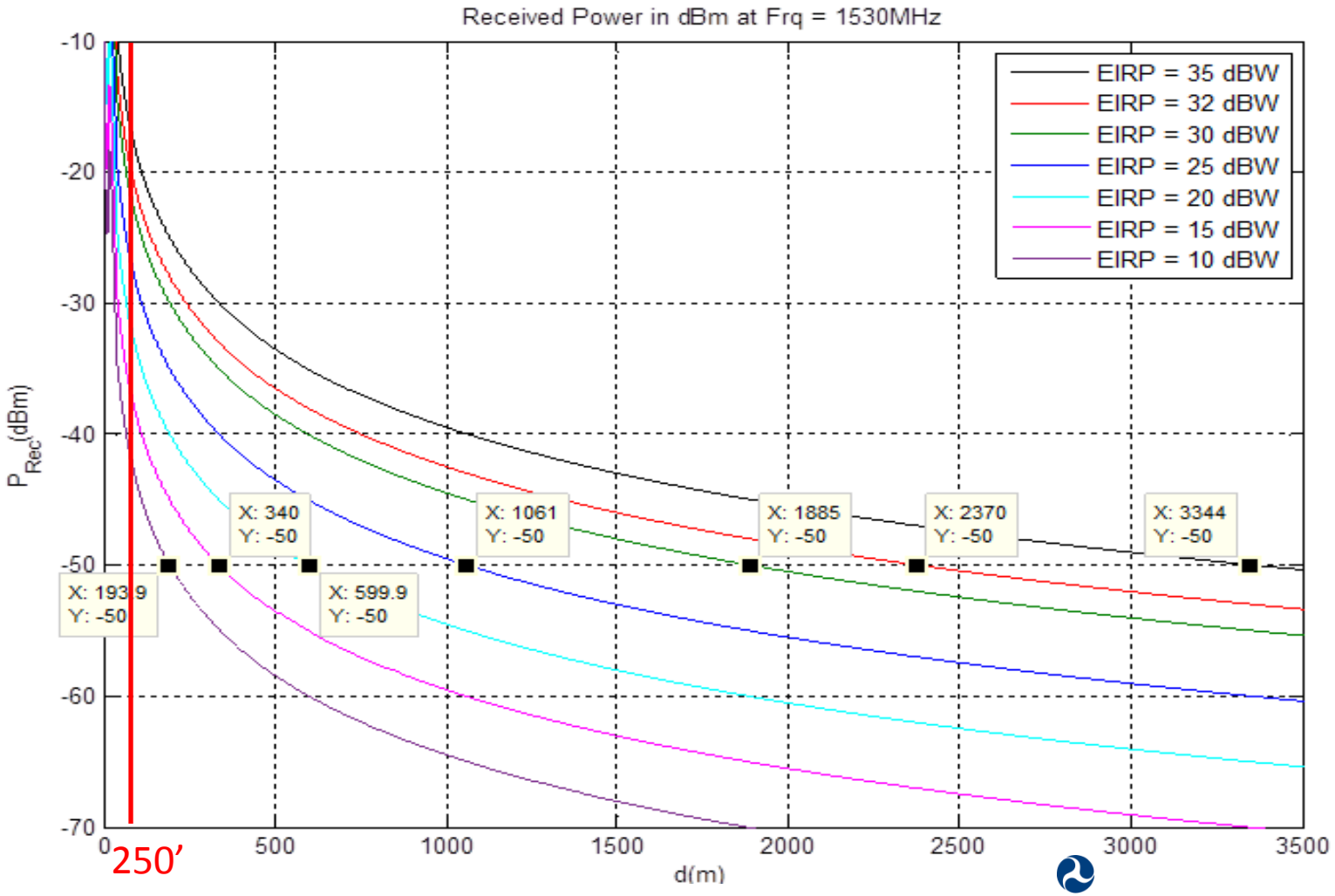
GPS L1 C/A
High Precision (35 DUTs)



L1 C/A Bounding Masks Compared
With Certified Aviation Mask and Proposed RTCM Multi-GNSS Mask



Example Min. Separation Distance vs. Received Power Single Transmitter with Free Space Path Loss



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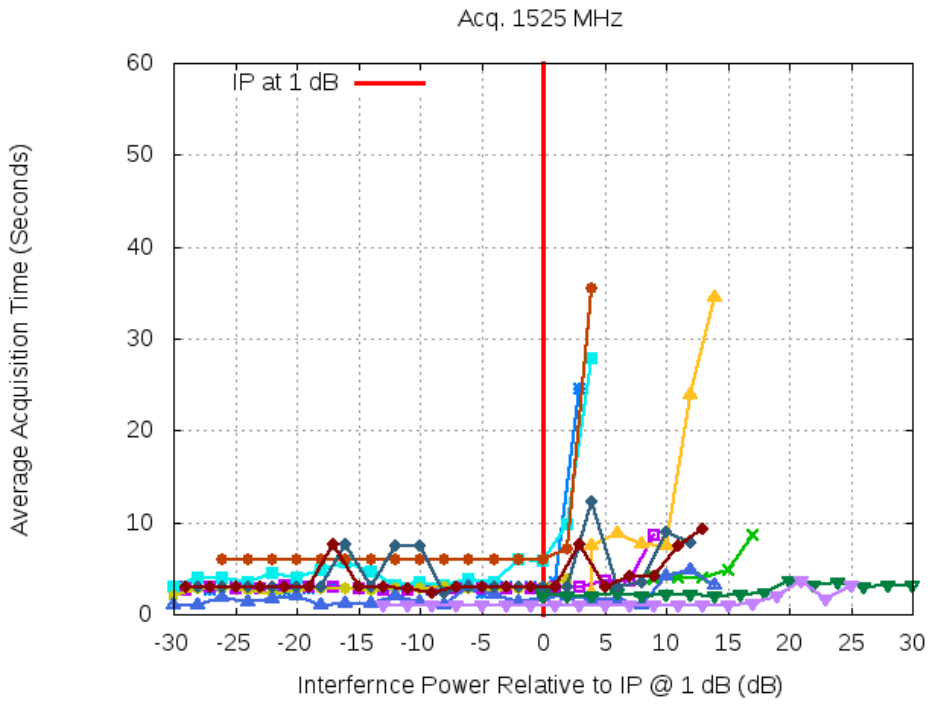
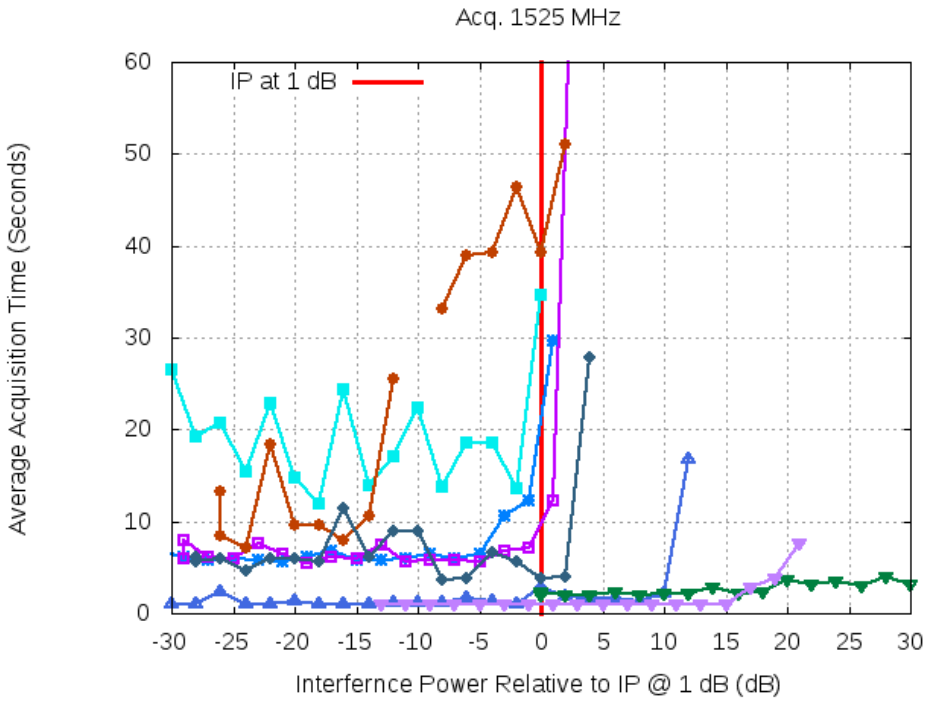
Acquisition Performance -1525 MHz



ICD Min. Power



Low Elevation

Summary of Results

- ITMs have been produced as a function of interference center frequency for all emulated GNSS signals
- Results show good consistency between repeated tests
- Certified aviation receiver mask does not bound the masks of the 6 civil receiver categories
- Satellite acquisition time observed to degrade at interference level similar to IP @ 1 dB
  - In some instances receivers failed to acquire satellite emulating low elevation conditions at this interference level
- Suggests exceeding the 1 dB interference level can adversely affect receiver performance by slowing satellite acquisition times
  - Effectively raises elevation angle that satellites are acquired at and reduces satellite availability

Next Steps

- Use Case Development
  - Developing representative use cases for receivers
  - Defining parameters for transmit application for uplink and down link
- Defining and finalize propagation models to be used
- Additional Antenna Characterization
- Refining the inverse modeling frame work to determine tolerable EIRP levels

(www.gps.gov/spectrum/ABC)

FAA Addressing Protection of Certified Avionics

- Utilizes identical methodology to that being used in the DOT GPS Adjacent Band effort
- Unlike other receivers, testing is not required. The interference protection mask is defined in Minimum Operational Performance Standards (MOPS) and ICAO Standards and Recommended Practices (SARPS)
  - Receivers must meet all of their performance requirements in the presence of interference at the specified levels
- Study approach vetted by RTCA, Inc in March 2015
  - Key effort is development of model to determine aggregate effects when receiver is airborne
- One critical item still not settled
  - "Keep Out Area" defining minimum separation between an aircraft and interference source
  - Integral to calculation of allowed transmit power

"FAA Deference"

- Ligado proposal is to reduce their tower transmit power to a level that ensures protection of certified avionics
  - FAA has held informal discussions with Ligado to try to understand their proposal
  - Ligado documents explaining their approach sent to RTCA for vetting 20 Oct, 2016
    - Some simplifying assumptions wrt FAA 2011 study approach
  - Assumes "keep out area" lateral distance of 250 ft.
- Review by RTCA ongoing – expected to complete Dec. 2016

Questions?

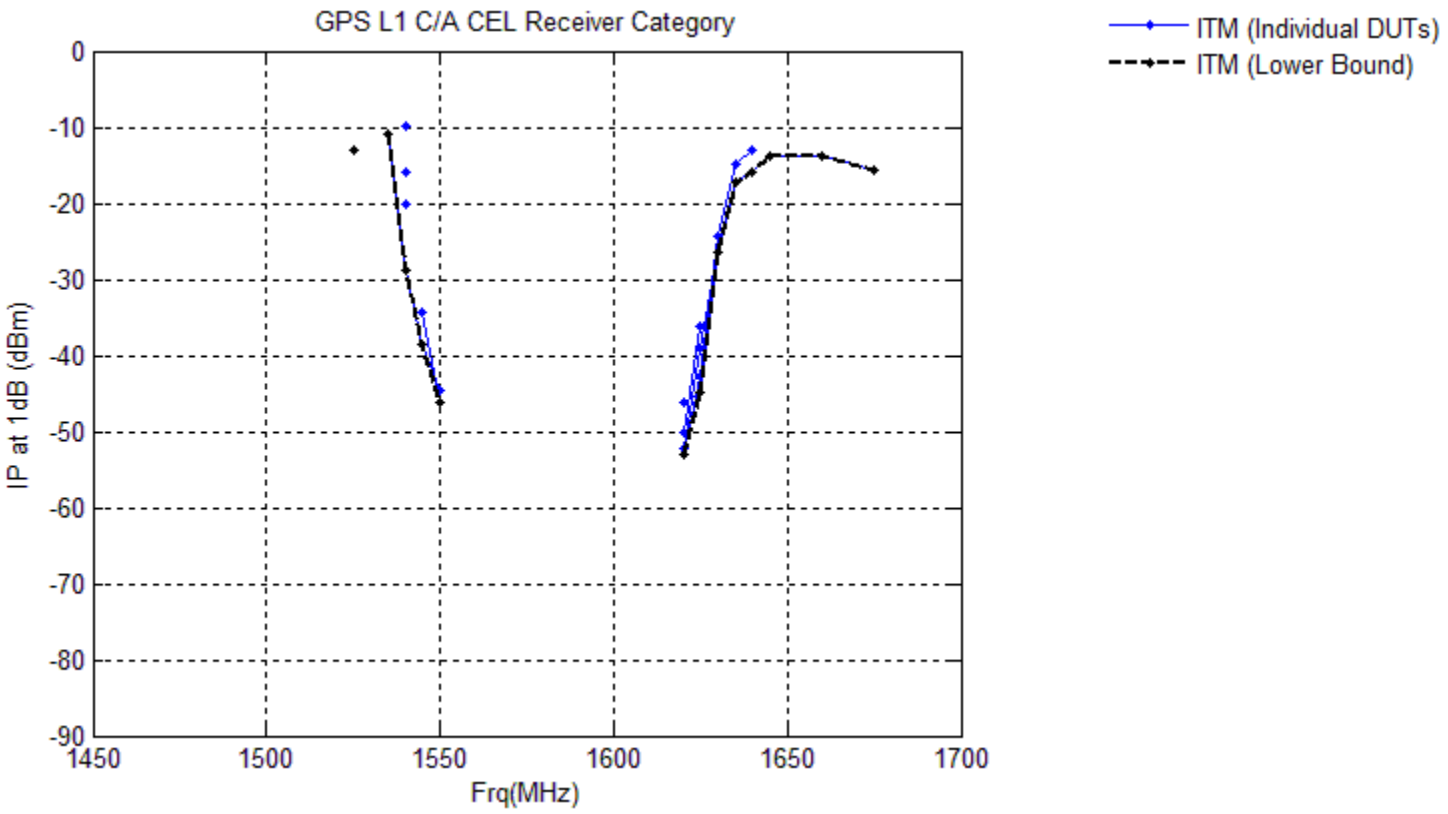
BACKUP SLIDES

Results on the Next Few Slides

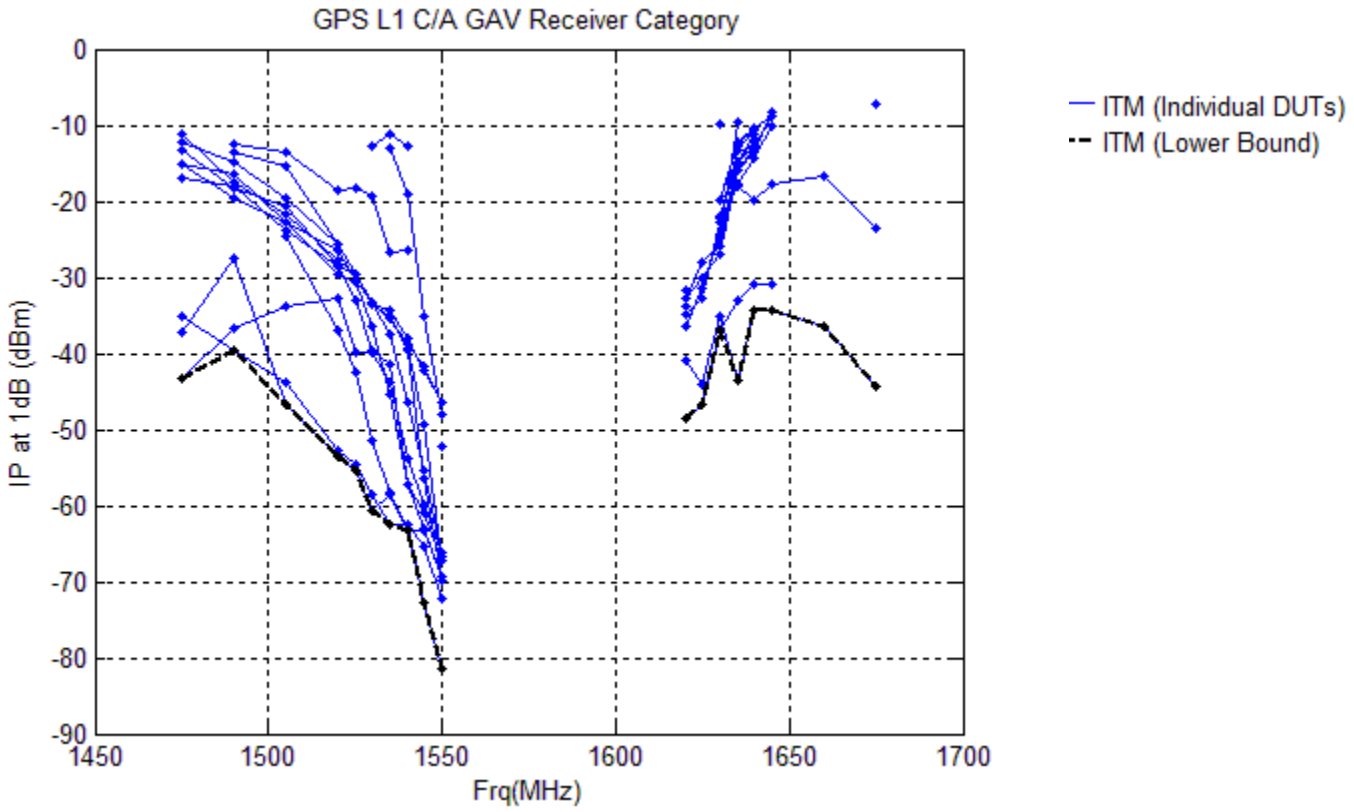
- ITMs for GPS L1 C/A RNSS signal in the presence of 10 MHz LTE interference vs. LTE center frequency

- Results shown for each receiver (blue) as well as the bounding mask per category (black)

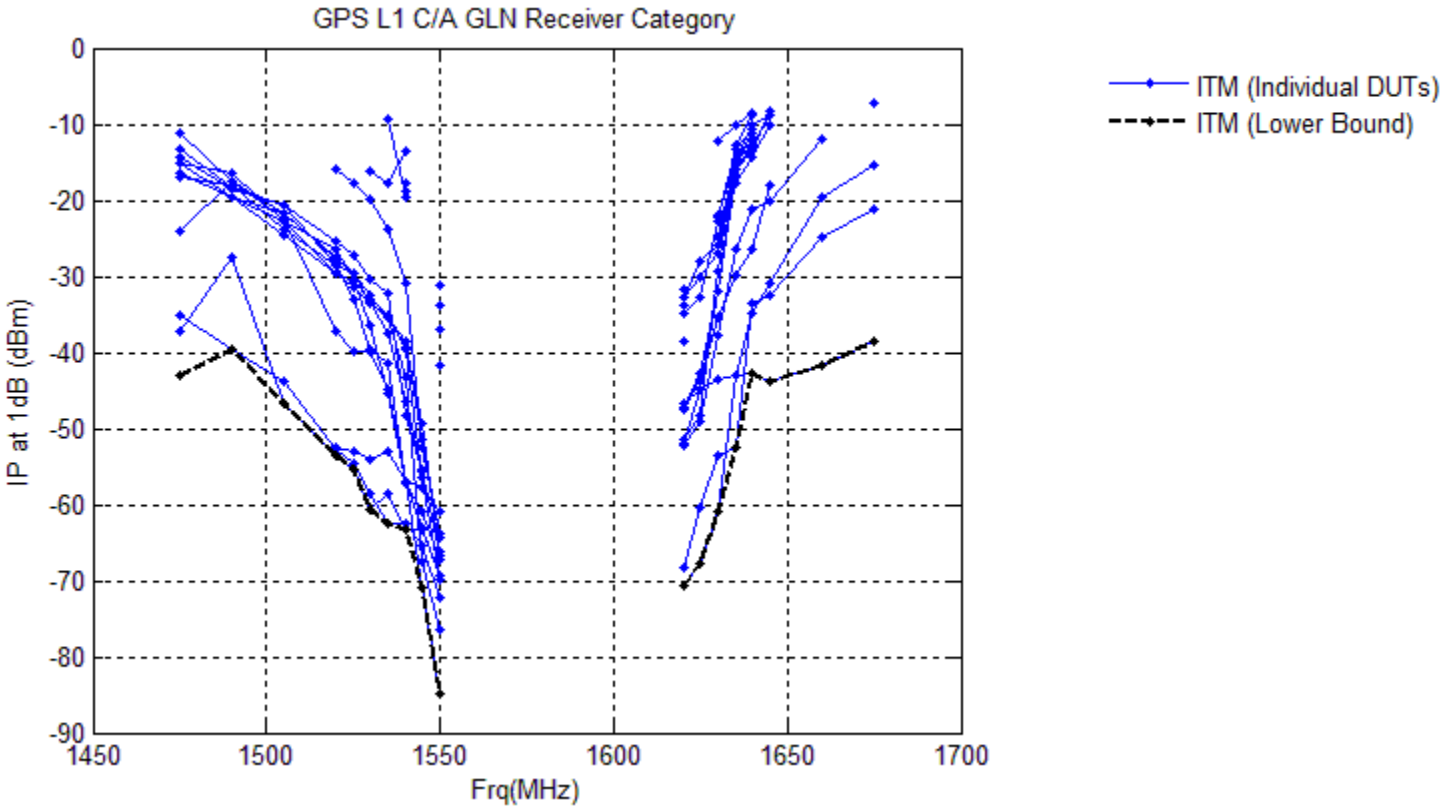
Cellular (5 DUTs)



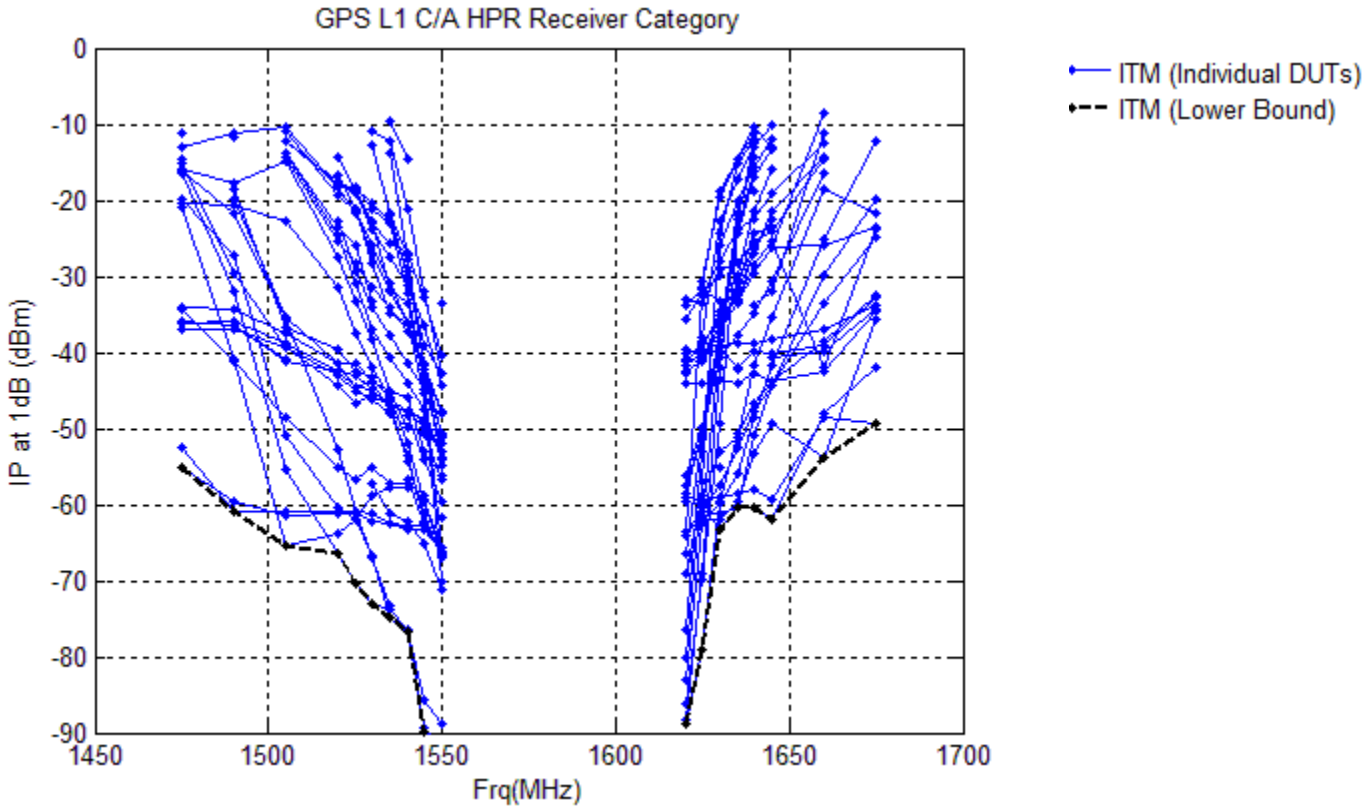
General Aviation (14 DUTs)



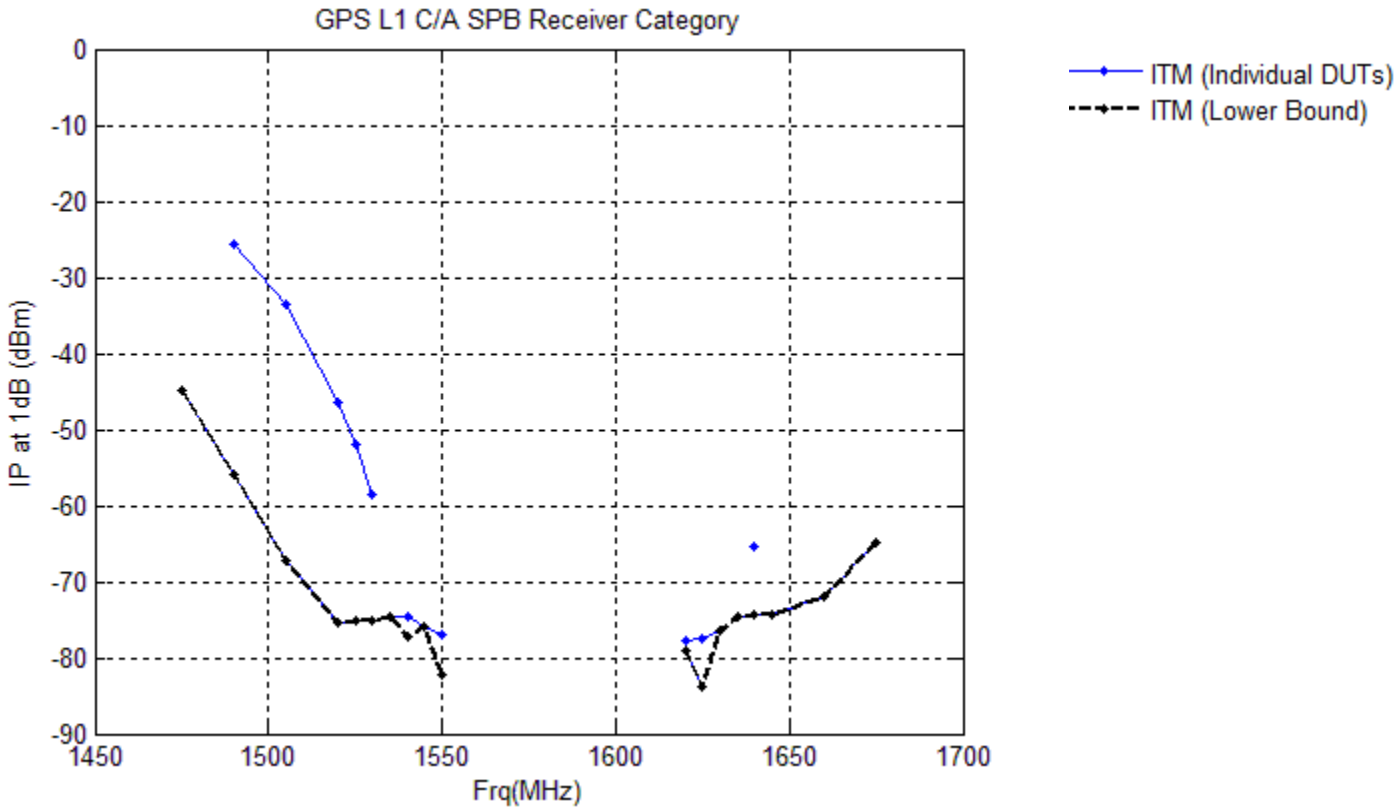
General Location Navigation (18 DUTs)



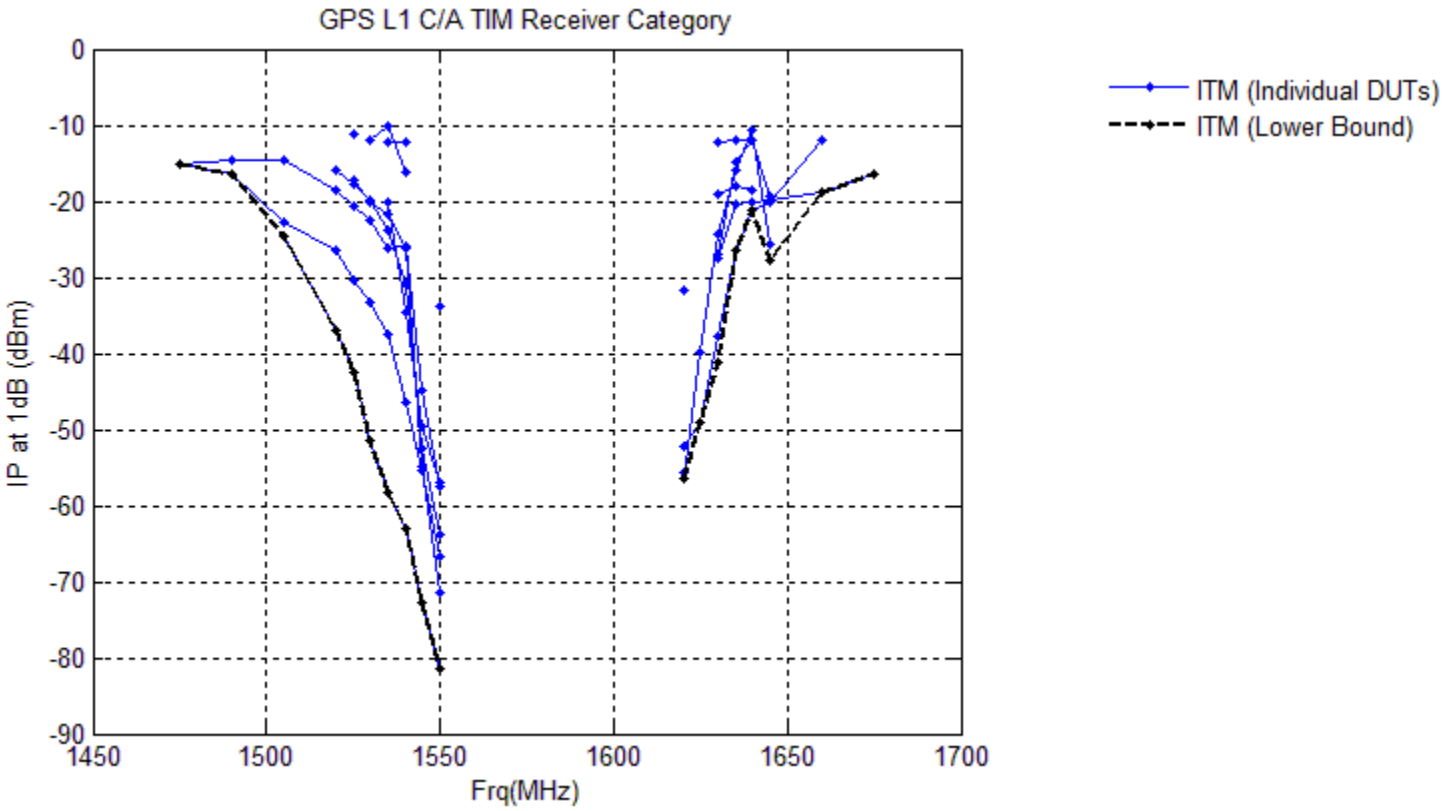
High Precision (35 DUTs)



Space Based (2 DUTs)



Timing (8 DUTs)



Wired (Conducted) Test Overview

- Test executed the week of 25 July at Zeta Associates - Fairfax, VA
- 14 GNSS receivers tested -subset of receivers tested at WSMR representing 5 categories (all except SPB).
- Completed test objectives as planned
  - Receiver characterizations for comparison with chamber results
    - This required a separate antenna characterization effort executed by MITRE
  - Inclusion of Out-of-Band (OOB) interference at prescribed and proposed levels w/LTE uplink & downlink signals
  - GNSS signal acquisition characterizations (Base station frequencies of 1525 and 1550 MHz & Hand-set frequencies of 1620 and 1645 MHz)