GPS Adjacent Band Compatibility Assessment

56th Meeting of the CGSIC
at the ION GNSS+ 2016 Conference
Portland, Oregon
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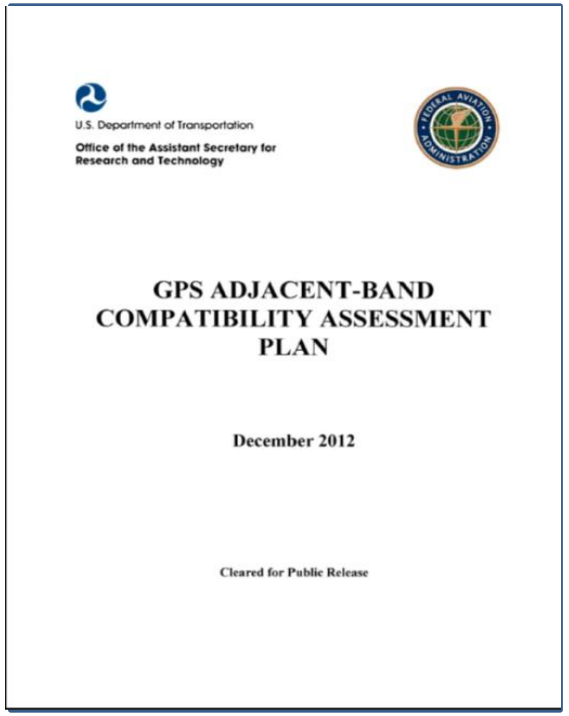
GPS Adjacent Band Compatibility Assessment

- EXCOM co-chair letter to NTIA (Jan. 2012)

Proposed development of GPS Spectrum interference criteria: "…that will help inform future proposals for non-space, commercial uses in the bands adjacent to GPS signals and ensure 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."


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

- DOT study to evaluate:
  - Phase 1: Adjacent-band power levels, as a function of offset frequency, necessary to ensure continued operation of all applications of GPS services
  - Phase 2: 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

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 as possible

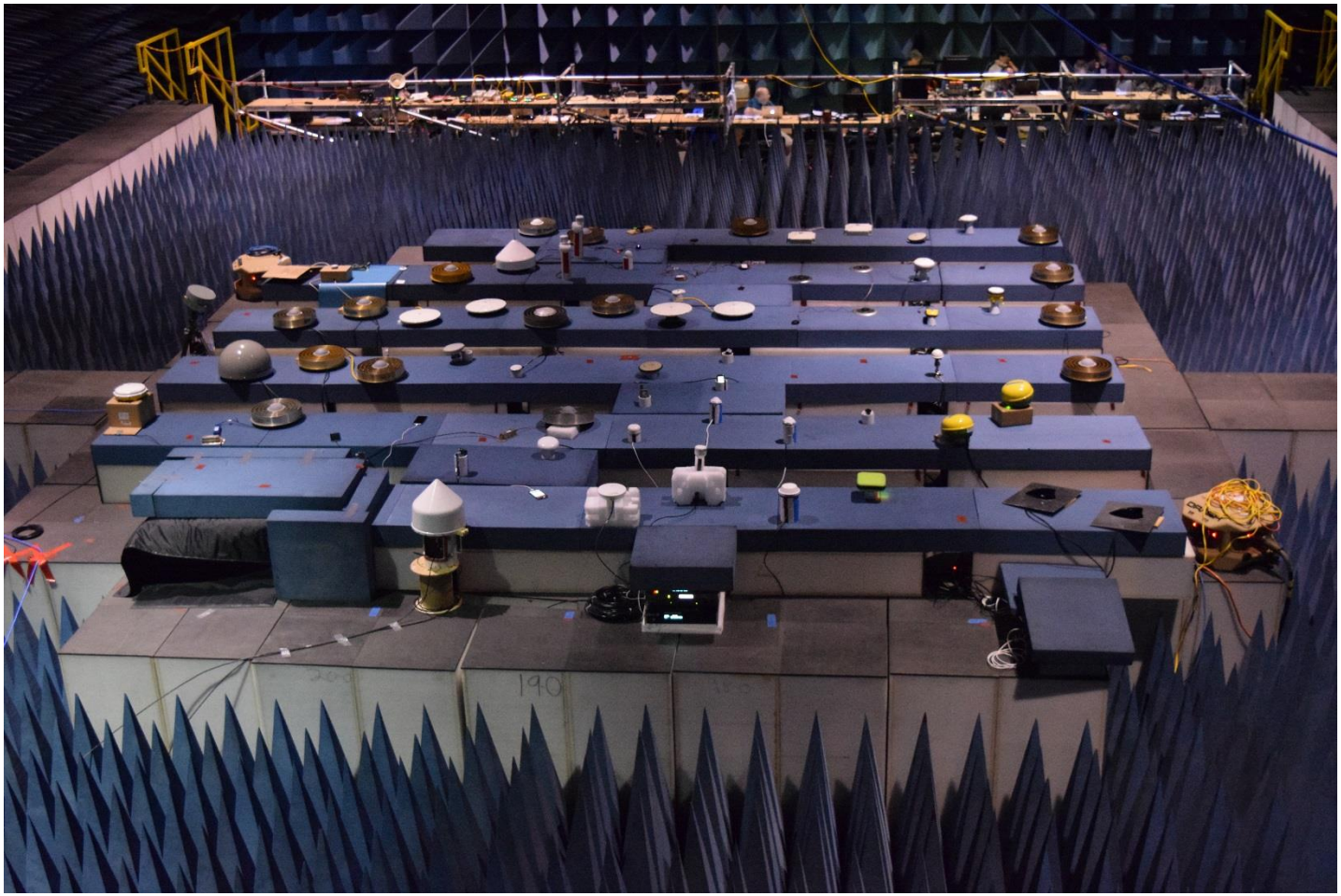
Milestones

- Finalized GPS/GNSS receiver test plan
- Coordinated government and manufacturer participation and executed Non Disclosure Agreements (NDAs)
- Developed test procedures
- Developed/validated radiated RF test environment
- Carried out GPS/GNSS receiver testing
  - Radiated receiver testing - White Sands Missile Range, NM
  - Wired (conducted) receiver testing - Zeta Associates

Radiated Testing Overview

- GPS receiver testing was carried out 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 performed in the anechoic chamber:
  - Linearity (receivers CNR estimators are operating in the linear region)
  - 1 MHz Bandpass Noise (Type 1)
  - 10 MHz LTE (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

Chamber Setup



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

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"

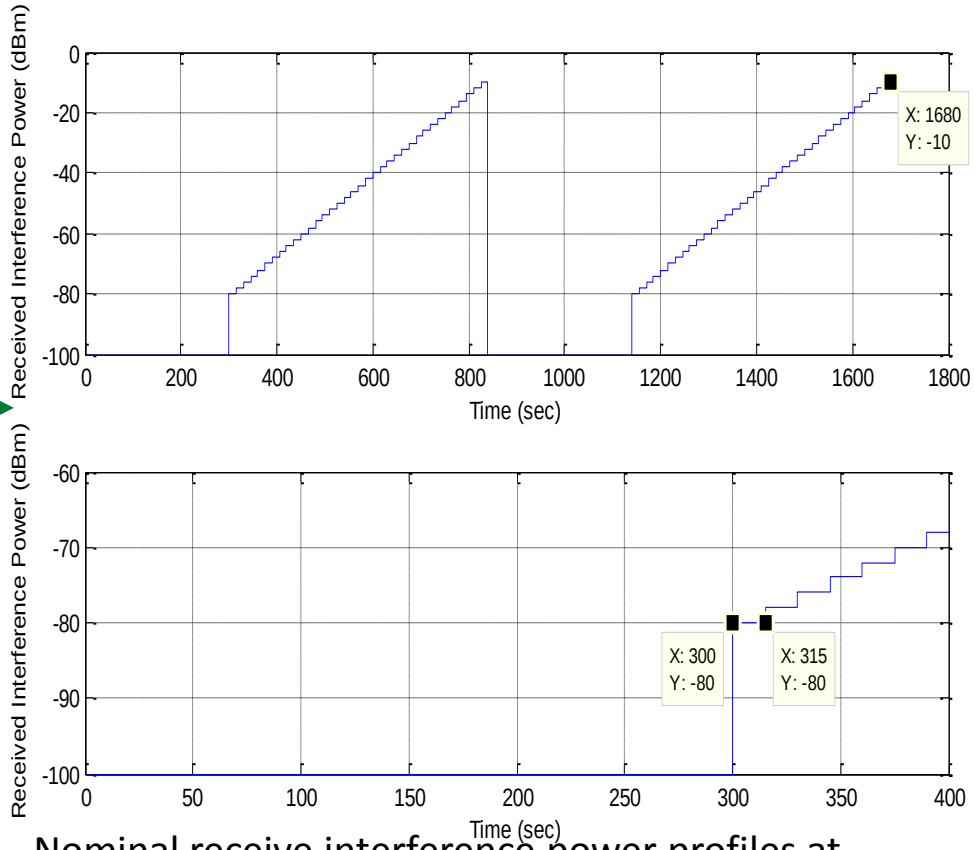
No.	Receiver
61	EVK-M8N
62	EVK-M8T
63	MAX-M8Q
64	EVK-7P
65	EVK-6n
66	NovAtel 628 Card w/ Flex pack
67	Trimble Ag-382
68	Trimble Geo 7X
69	Trimble Bison III
70	Trimble R8
71	Trimble SPS985
72	Trimble SPS855
73	Trimble Acutime 360
74	Trimble Ag-382
75	SF3000
76	SF3000
77	Septentrio PolaRx5TR Pro
78	Septentrio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

GNSS Signals Used in Testing

Signal
GPS 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

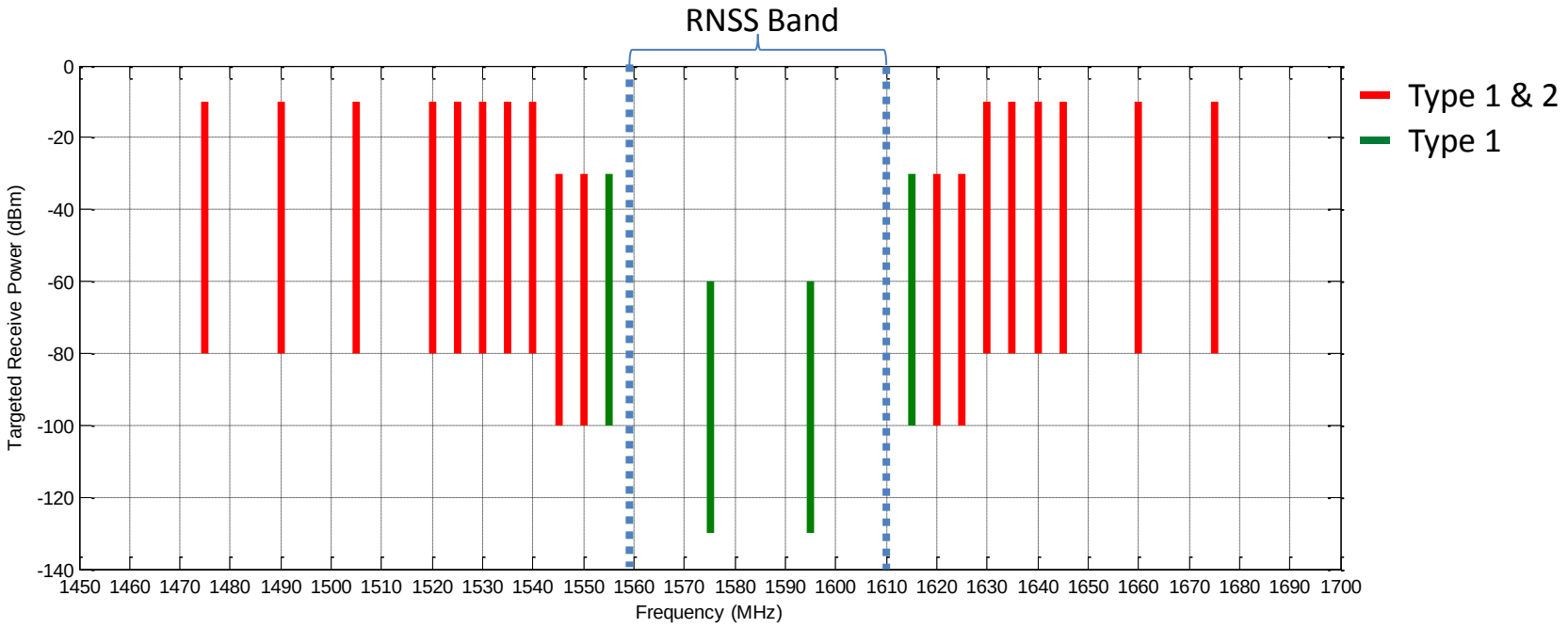
Interference Test Signal Frequencies and Power Profiles (1/2)

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
Δf_1(1475 to 1520 MHz)	15	MHz
Δf_2(1520 to 1555 MHz)	5	MHz
Δf_3(1575 and 1595 MHz)	N/A	MHz
Δf_4(1615 to 1645 MHz)	5	MHz
Δf_5(1645 to 1675 MHz)	15	MHz
ΔP	2	dB
Startup Time	15	min
T_{BL}	5	min
T_{step}	15	s
N_{cycle}	2	N/A



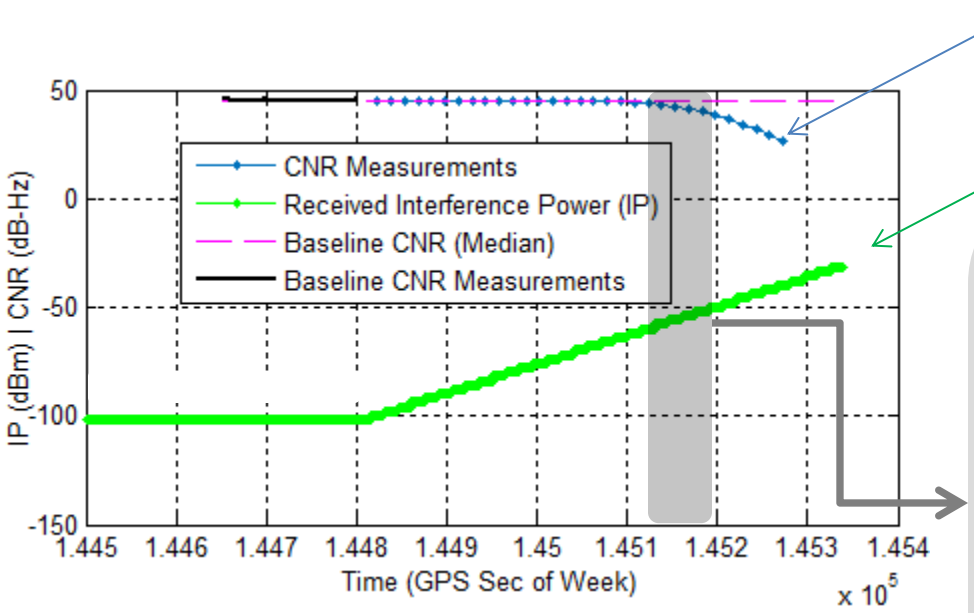
Nominal receive interference power profiles at GNSS antenna location for the (1475 to 1540 MHz) and (1630 to 1675 MHz) frequency ranges.

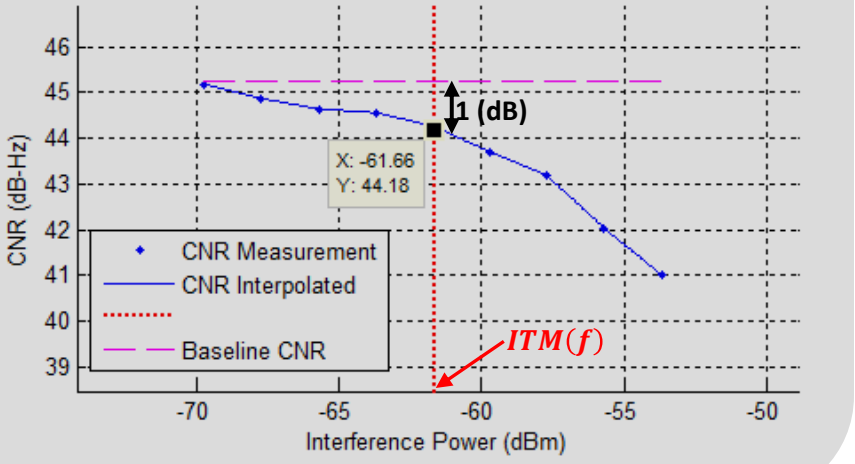
Interference Test Signal Frequencies and Power Profiles (2/2)



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

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

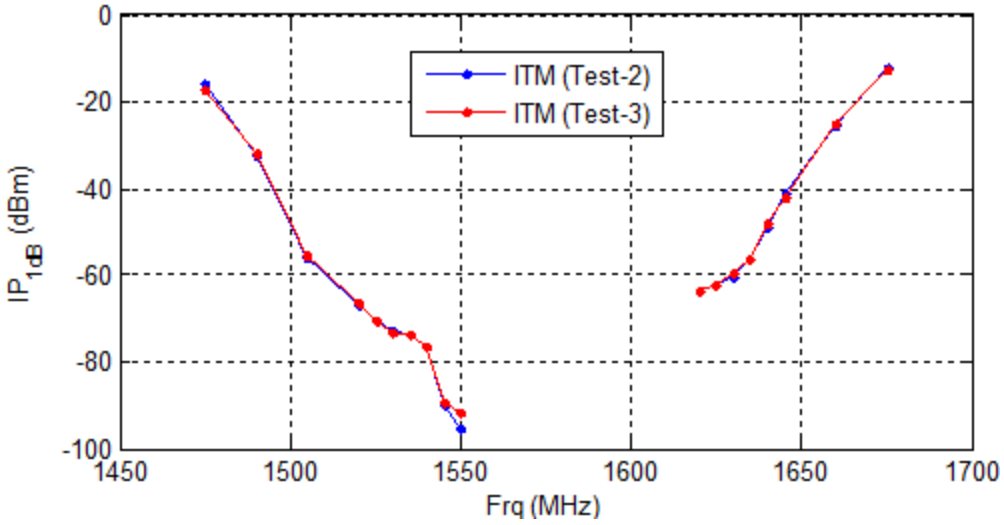




ITM 10 MHz - Test Averaging

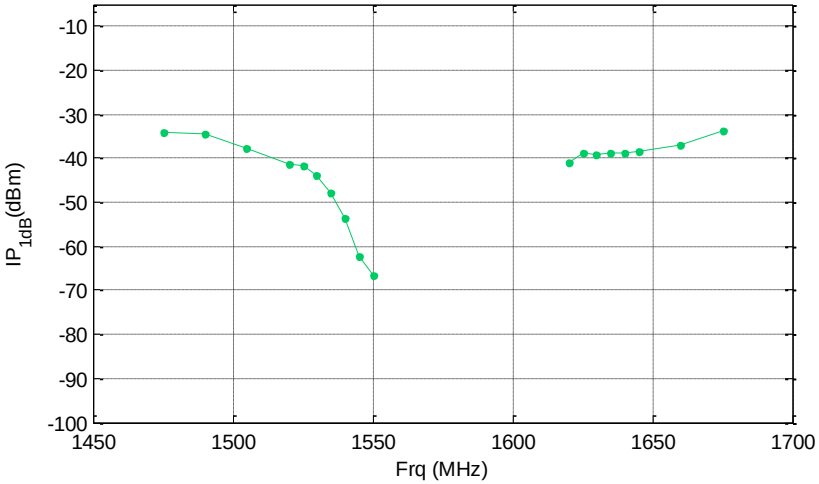
- Since the LTE 10 MHz test was repeated on two consecutive days (tests 2 and 3), the results were averaged when possible to produce a final masks for each receiver/RNSS service interference signal type combination.

- Results showed good consistency between tests. An example overlaying ITMs from tests 2 and 3 for one of the DUTs listed on slide-8 is shown below:

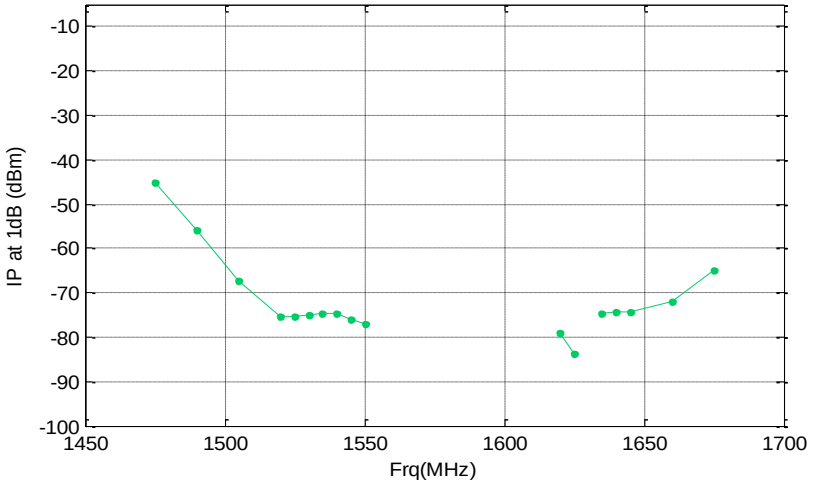


Example Masks Resulting from Averaging Tests 2 and 3 ITMs (Emulating LTE Interference Signals)

Example 1



Example 2



Summary and Next Steps

- Significant testing completed and mask generation underway
- Preliminary ITM bounds have been produced for 10 MHz LTE interference as a function of interference center frequency.
- Results showed good consistency between repeated tests.
- The results will be presented in the next **GPS Adjacent Band workshop planned for October 14, 2016 at RTCA Washington DC**
- Next steps:
  - Finalize bounding ITM results
  - Evaluate and vet use case scenarios
  - Use inverse modeling to transform the bounding masks to allowable transmit power levels for each category.
  - Analysis continuing on other tests including the 1 MHz (Type-1) interference masks, in-band, linearity, and intermodulation.

Questions?