



GPS Adjacent Band Compatibility Assessment

Munich Satellite Summit

March 2017

Objective

- ❑ Collect the necessary data to determine adjacent band transmit power levels that can be tolerated by existing GNSS receivers for civil applications
 - Excludes certified aviation applications that are considered in a parallel effort conducted by the FAA

- ❑ Data collected and discussed in this brief:
 - Radiated test data: collected in an anechoic chamber
 - Conducted test data: collected in a laboratory environment
 - Antenna characterization data
 - Integrated antennas: collected in an open sky environment
 - External antennas: collected in an anechoic chamber



Overview

- ❑ Developed GPS/GNSS receiver test plan and test procedures
 - Held many public workshops to obtain stakeholder input
- ❑ Coordinated government and manufacturer participation and executed Non Disclosure Agreements (NDAs)
- ❑ Developed/validated radiated RF test environment
- ❑ Carried out GPS/GNSS receiver testing and antenna characterization
 - Radiated receiver testing - White Sands Missile Range, NM
 - Wired (conducted) receiver testing - Zeta Associates , VA
 - 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)



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
 - Air Force/GPS Directorate conducted testing week of April 18th

- ❑ 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) – Focus of this briefing**
 - Intermodulation (effects of 3rd order intermodulation)



Categories of GPS/GNSS Receivers Tested

- 80 receivers were tested representing six categories of GPS/GNSS receivers:
 - General Aviation (non certified)
 - General Location/Navigation
 - High Precision & Networks
 - Timing
 - Space Based
 - Cellular



Participation in Testing

- ❑ Participation included DOT's federal partners/agencies and GPS manufacturers
 - 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

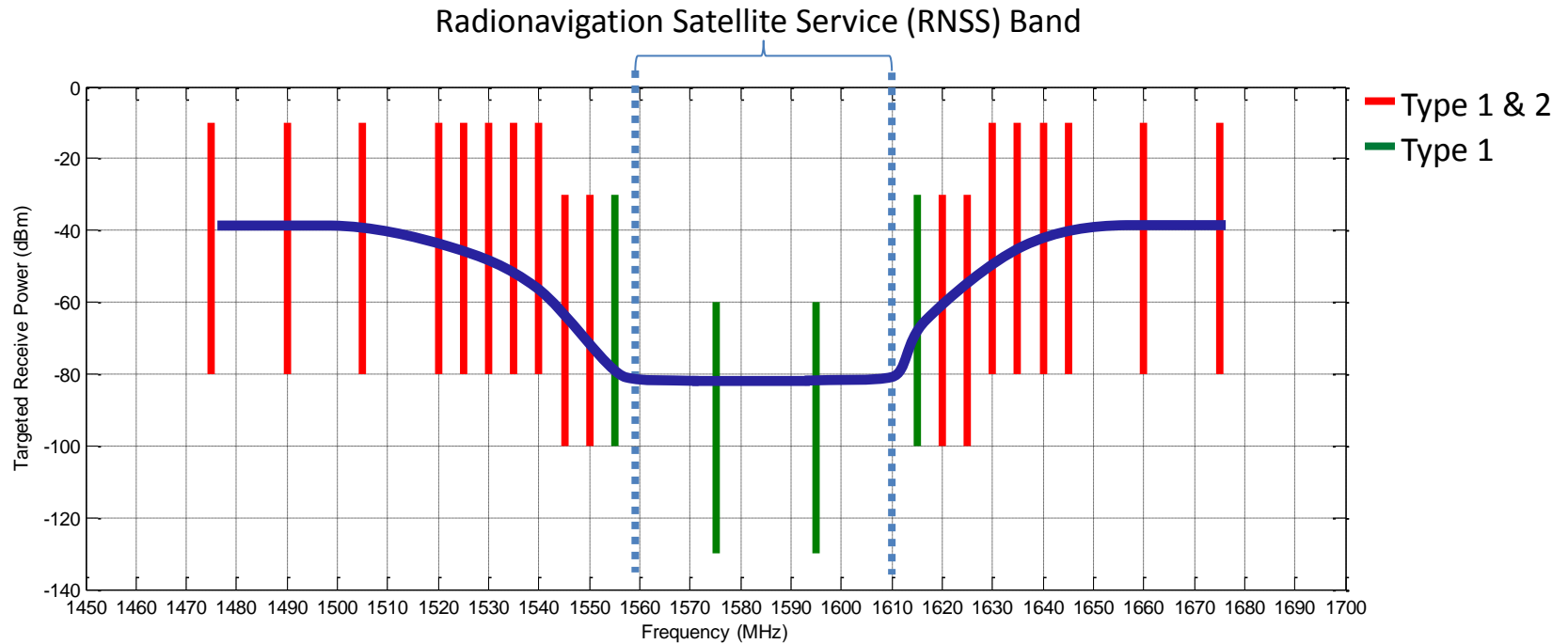


GNSS Signals Used in Testing

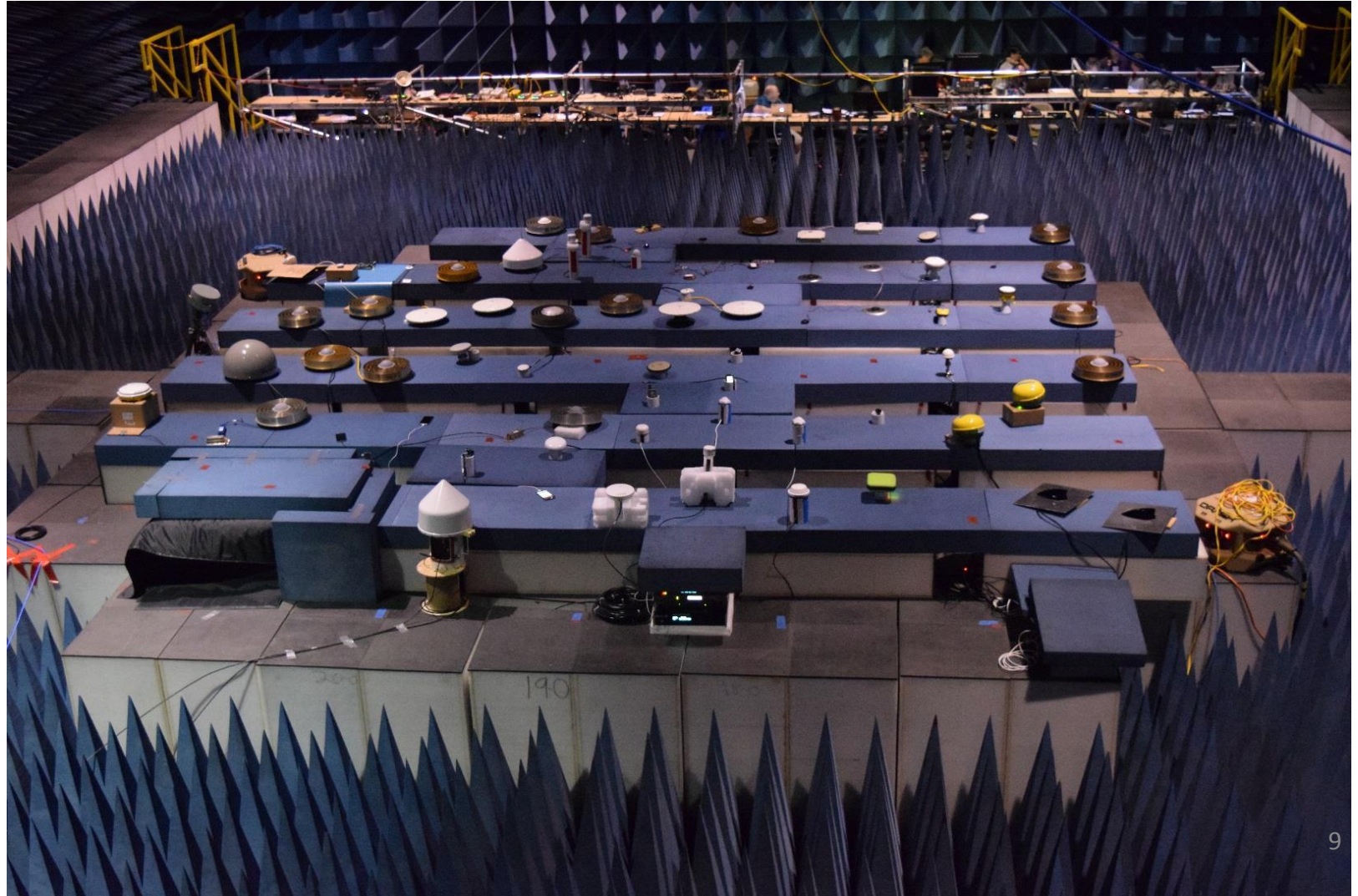
Signal
GPS L1 C/A-code
GPS L1 P-code
GPS L1C
GPS L1 M-code
GPS L2 P-code
SBAS L1
GLONASS L1 C
GLONASS L1 P
BeiDou B1I
Galileo E1 B/C



Interference Test Signal Frequencies and Power Profiles

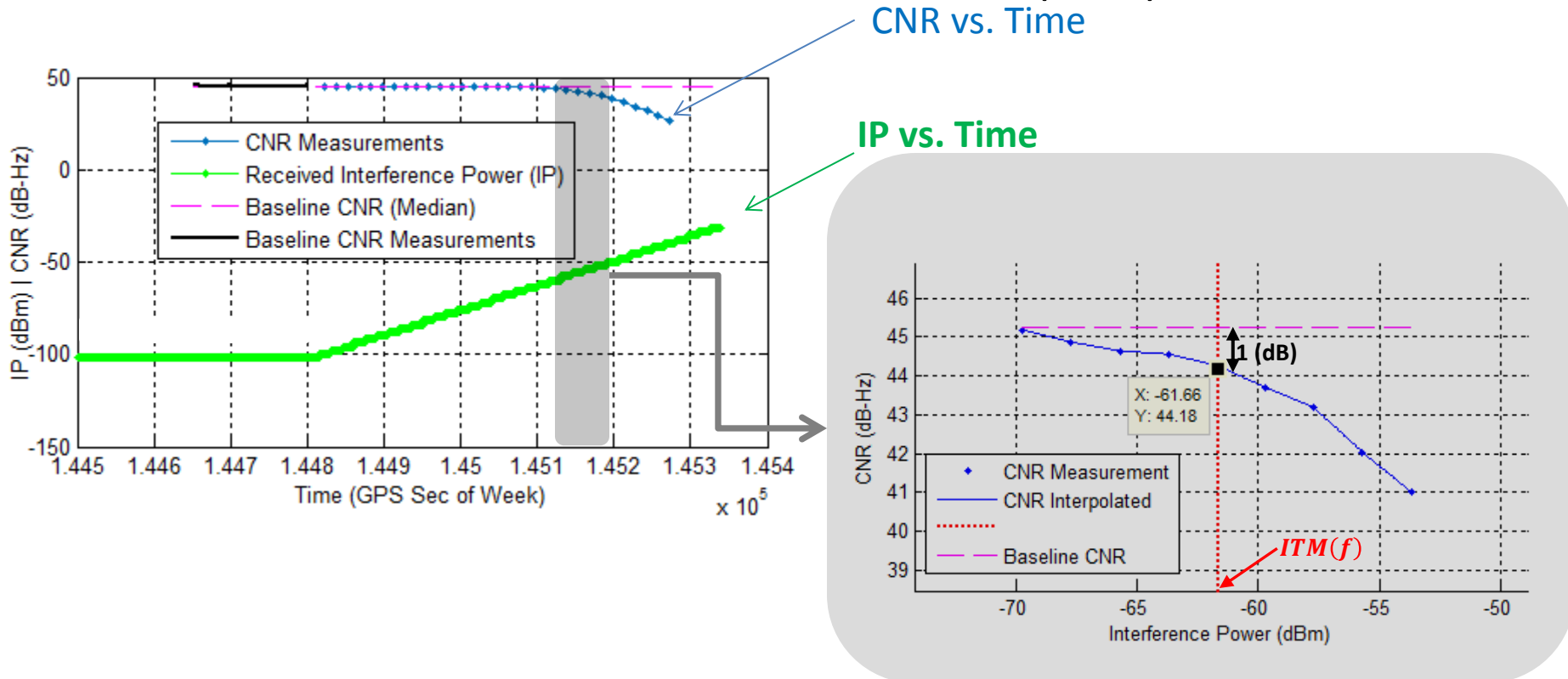


Chamber Setup

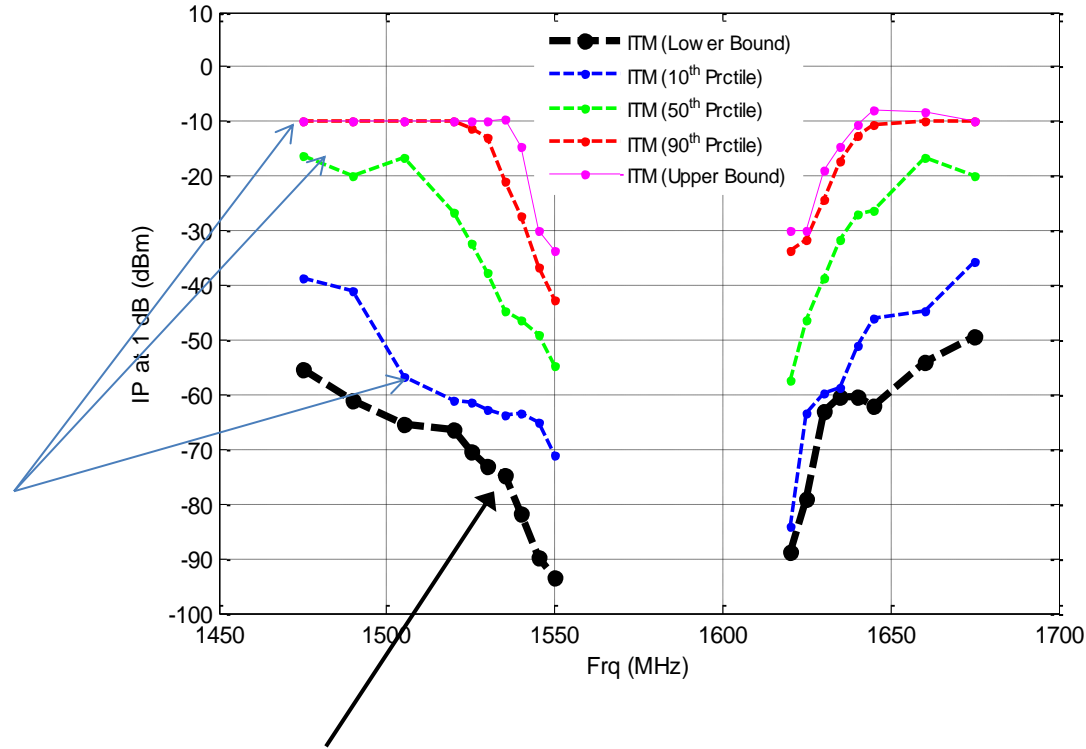


Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

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



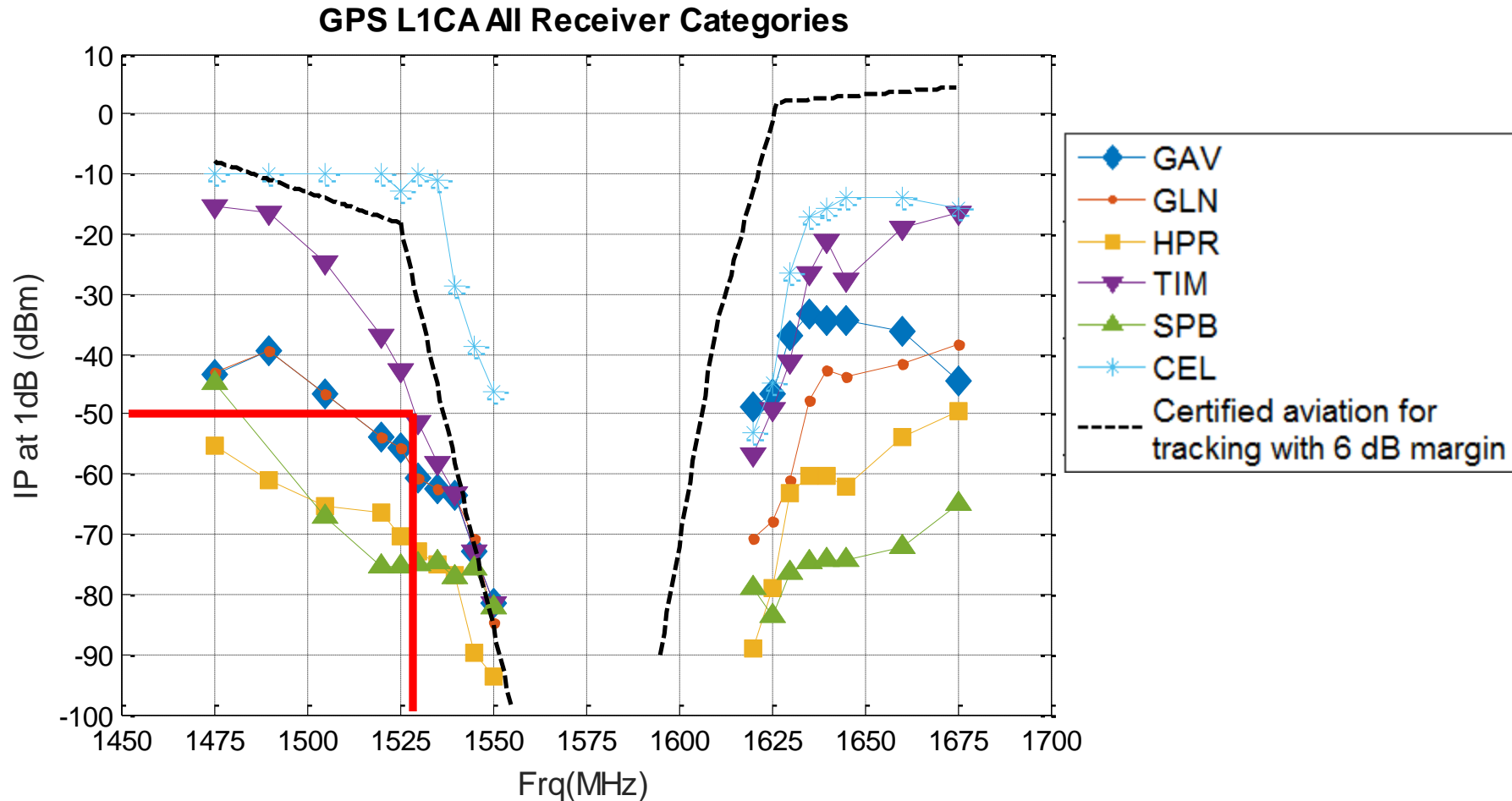
Aggregate Results for L1 C/A High Precision Category



GPS L1 C/A ITM lower bound and different percentiles corresponding to the HPR category.

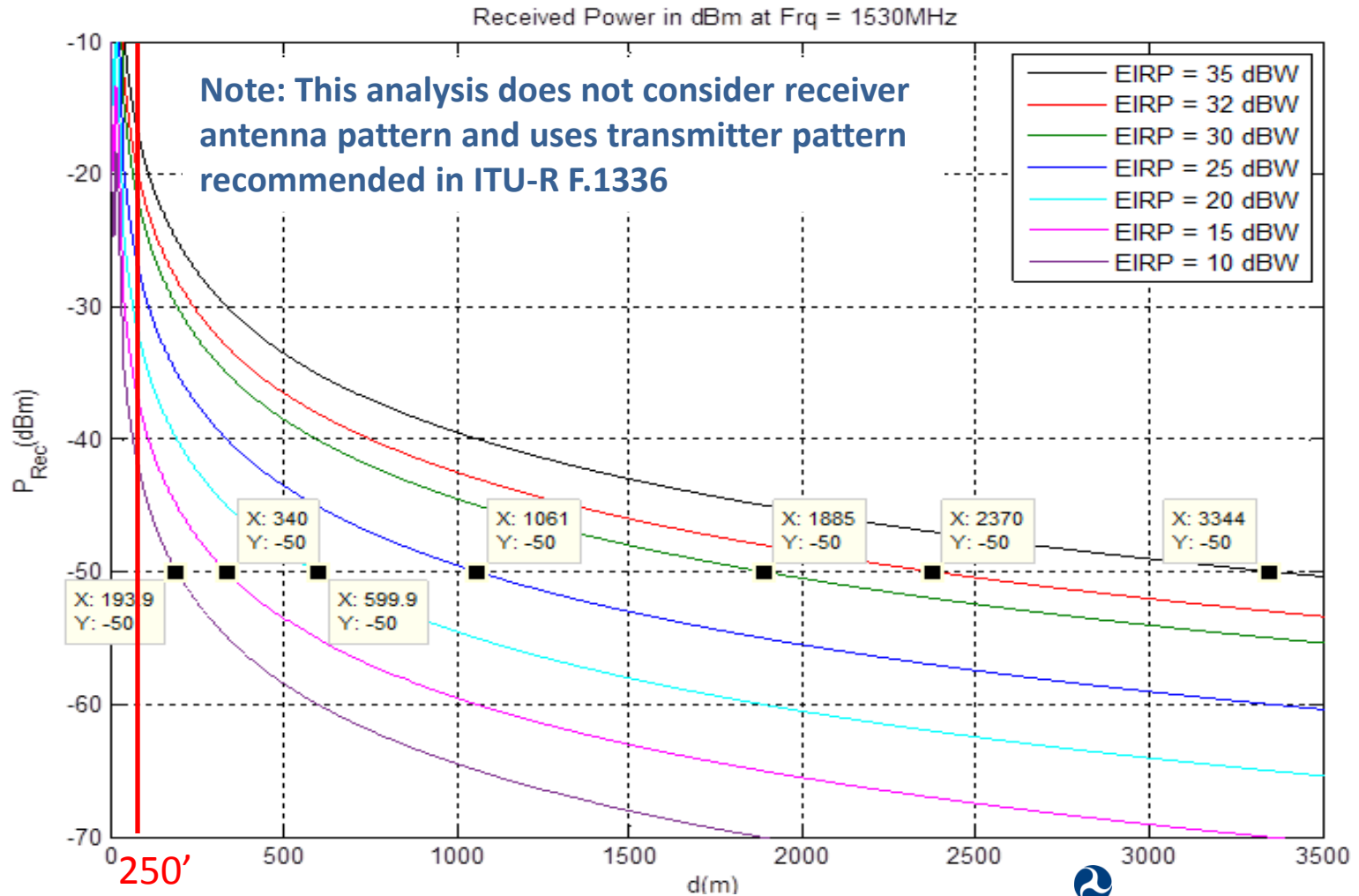
The lower the ITM percentile the more protection it offers. The bounding ITM (black) protects all tested receivers

L1 C/A Bounding Masks Compared With Certified Aviation Mask



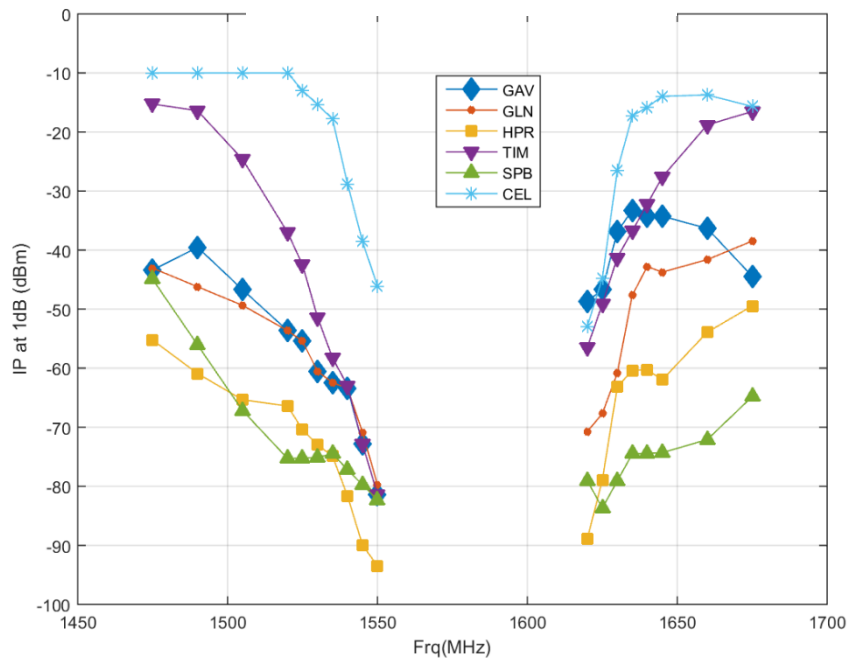
Example Min. Separation Distance vs. Received Power

Single Transmitter with Free Space Path Loss

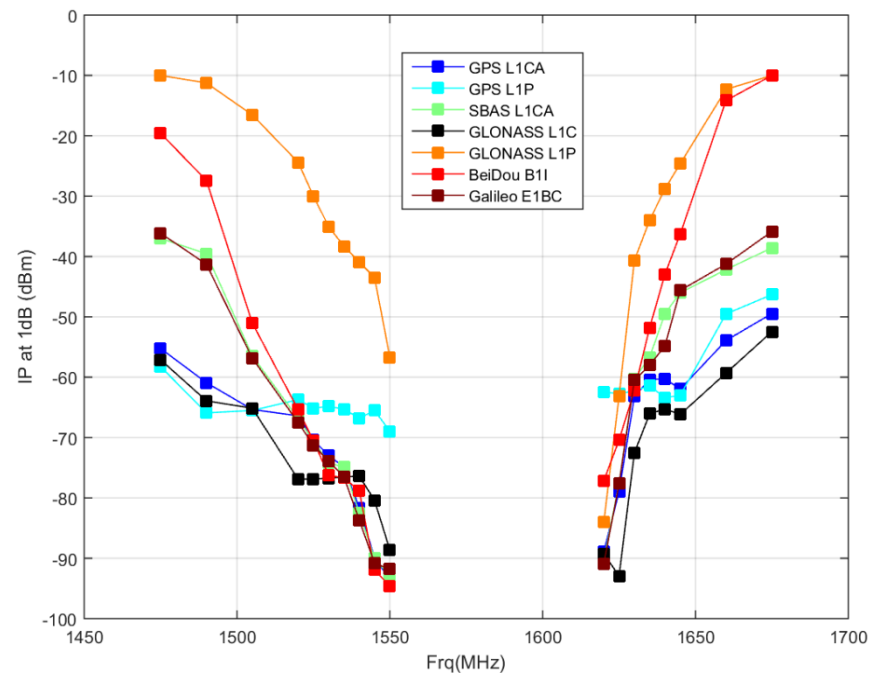


Summary of Bounding Mask Results

LI C/A Bounding Mask Results for All Categories of Receivers



HPR Bounding Mask Results for All Emulated GNSS Signals



Wired/Conducted Testing Overview

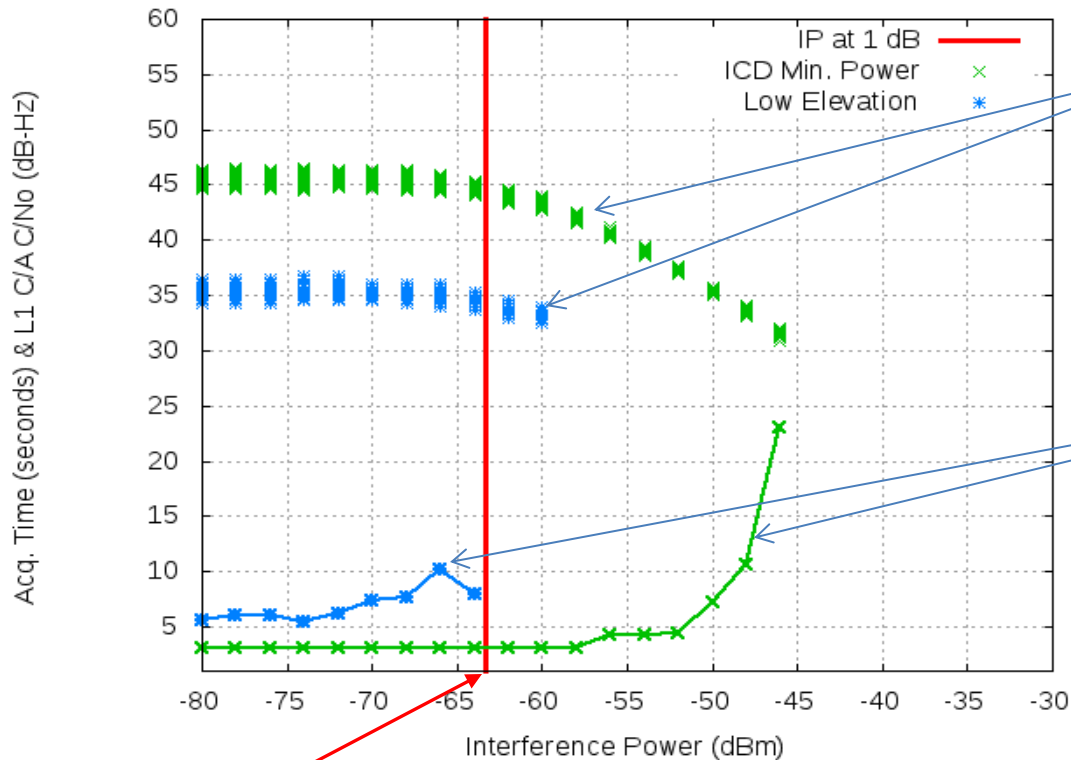
- ❑ Tests executed week of 25 July with 14 GNSS receivers
 - Representative set of equipment from chamber testing from each receiver category (except space based)
 - Receivers tested were USG provided

- ❑ Test Objectives
 - Receiver characterizations for comparison with chamber results
 - Inclusion of OOB interference at
 - FCC limit of -70 dBW/MHz
 - Proposed limits of -100 (base stations) and -105 (handsets) dBW/MHz
 - GNSS signal re-acquisition characterizations

- ❑ Same test instrumentation for wired as with radiated tests
 - GNSS playback (MITRE)
 - Interference system with modifications to support OOBE and acquisition test requirements



Normalizing Interference Power to IP@1dB in the Acquisition Analysis



IP @ 1dB

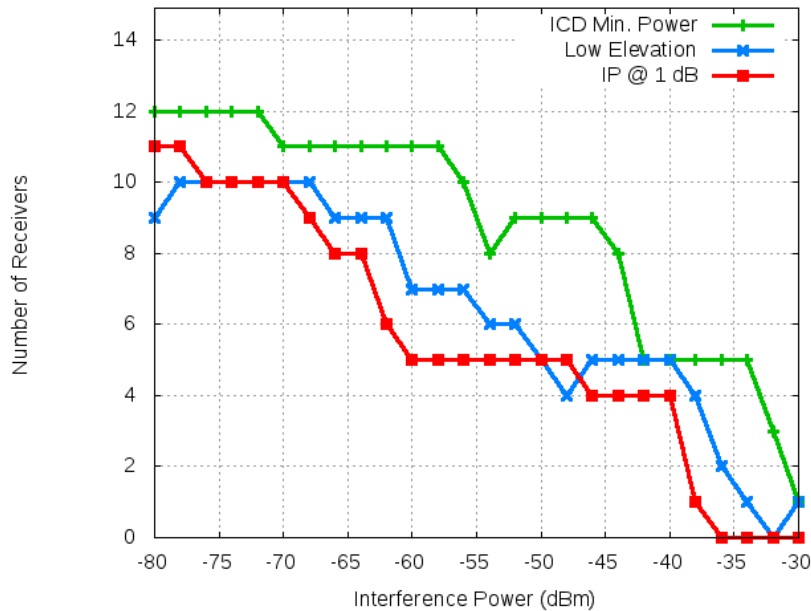
CNR vs. Interference Power

Acquisition Time vs. Interference Power

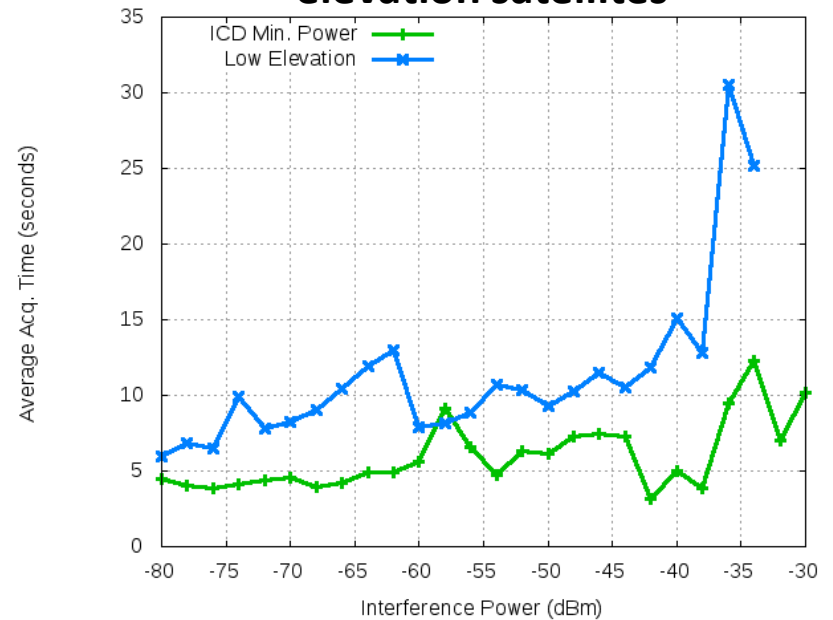


Summary of Acquisition Performance at 1550 MHz

Number of DUTs



Average acquisition time for ICD minimum and low elevation satellites



Summary and Next Steps

□ Results:

- Tolerable interference power in form of bounding ITMs have been developed for all category of receivers tested on a per GNSS signal type basis
- Wired (lab) tests show good consistency with radiated test results when antenna filtering characteristics are taken into account.
- 1-dB degradation proved to be a good indicator of the onset of acquisition degradation especially for low elevation satellites

□ Next Steps:

- Evaluate use case scenarios
- Use inverse modeling to transform the bounding masks to allowable transmit power levels for each category
- Develop final report



Backup



U.S. Department of Transportation

**Office of the Assistant Secretary for
Research and Technology**

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

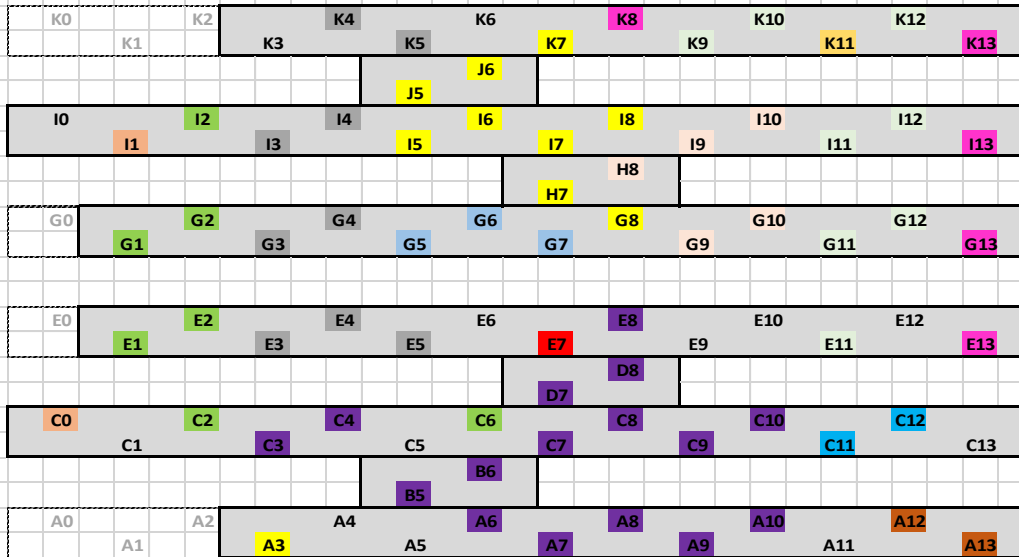
Receivers included in the wired/conducted test



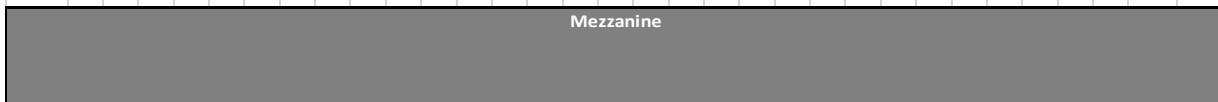
Test Grid

← Exit

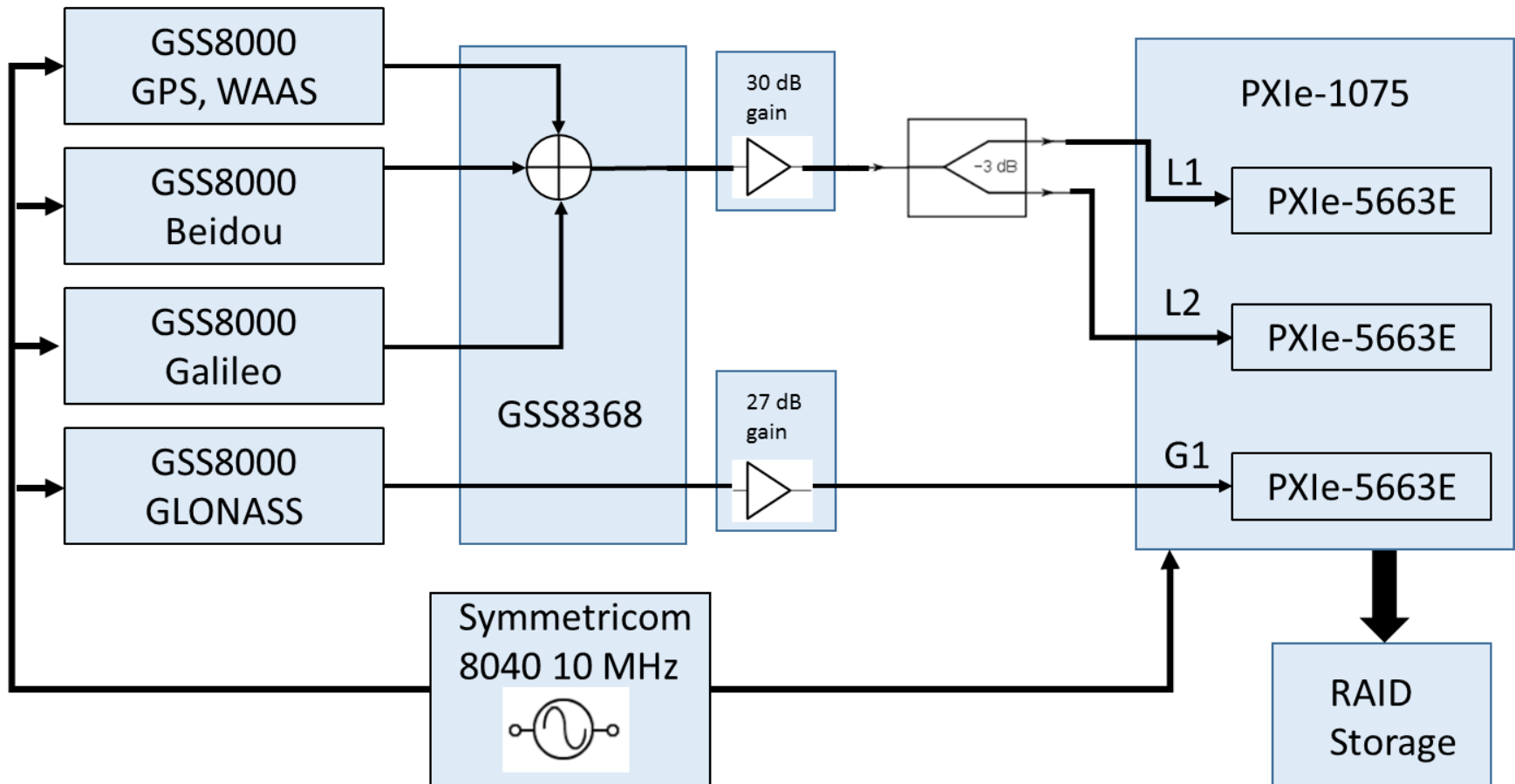
1	2	3	4	5	6	7	8	9	10	11	12	13
USCG	NASA	NOAA	USGS	FAA	USDOT	GM	UBLOX	NOVATEL	TRIMBLE	DEERE	UNAVCO	Aero_Spec_A
2	8	9	3	23	16	2	5	1	8	2	5	1



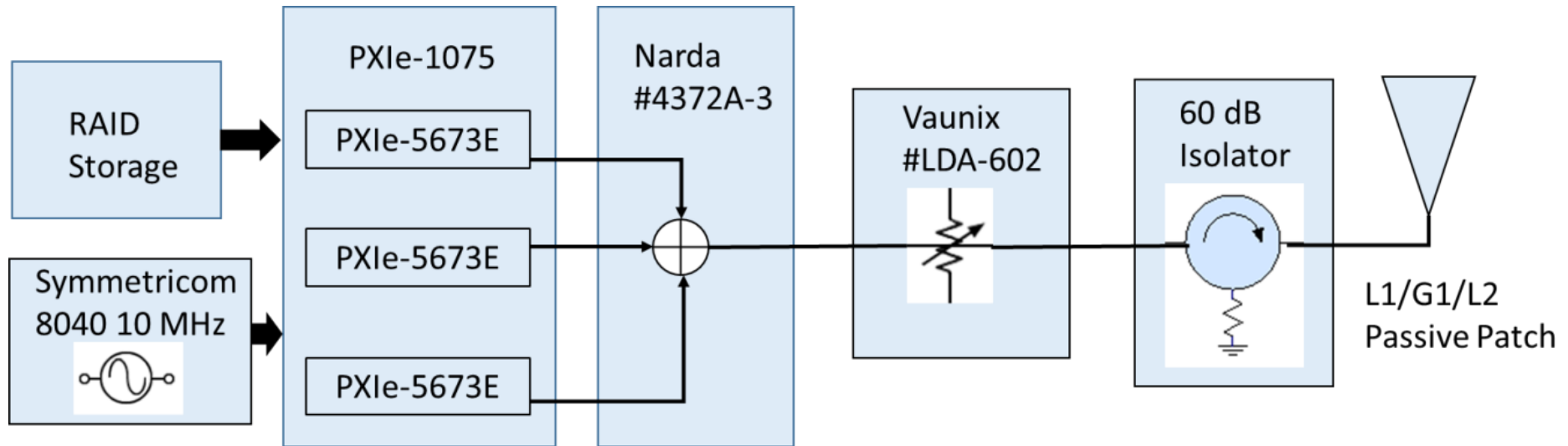
Note: not drawn to scale



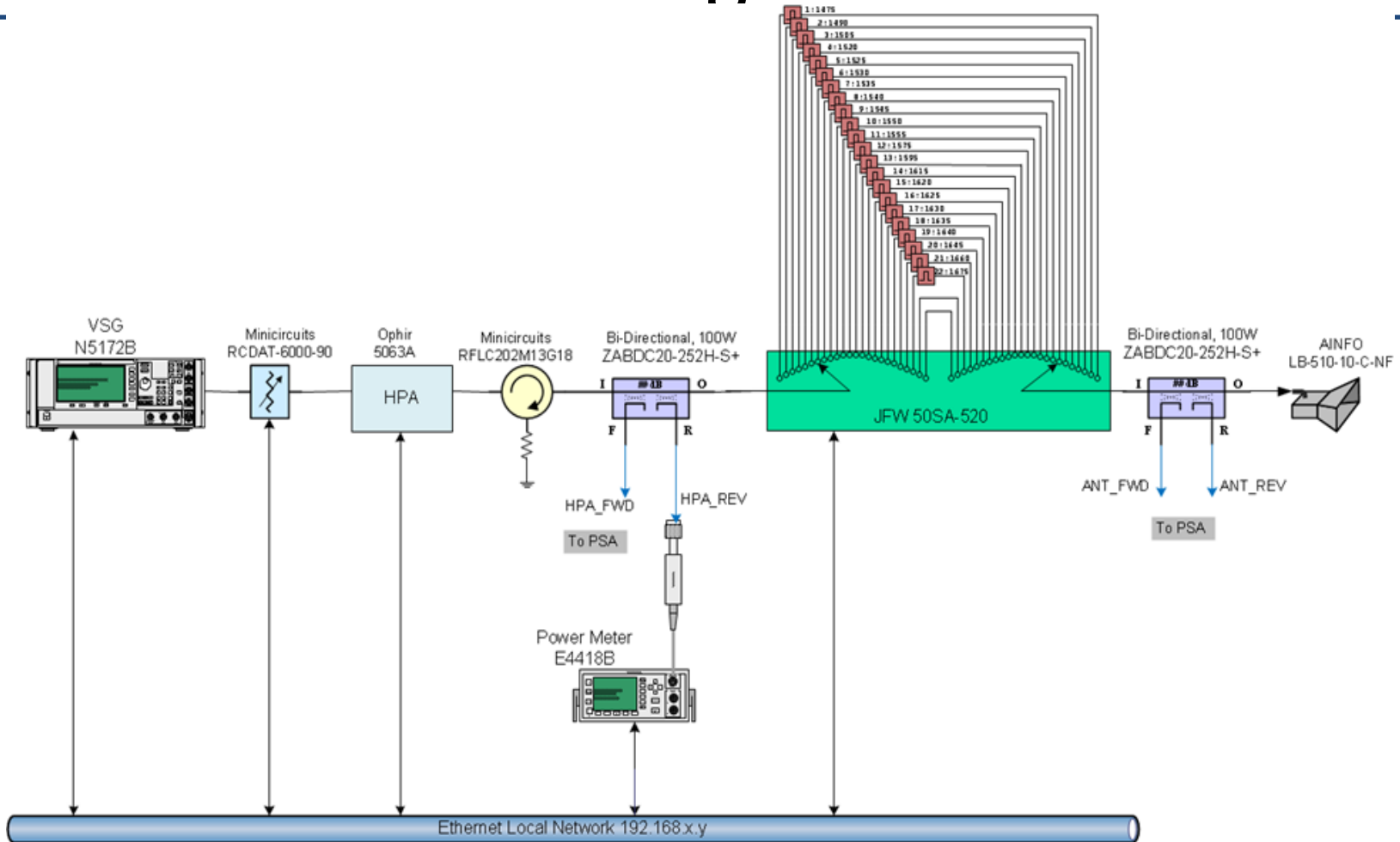
GNSS Signal Generation and Recording



GNSS Signal Playback and Transmission



Interference Signal Generation Diagram



List of External Antennas Tested

Manufacturer	Model
AeroAntenna	AT575-142-614-50
AeroAntenna	AT2775-42SYW-TNCF-000-RG-41_MN
Arbiter	AS0087800
Garmin	GA-25
Garmin	GA-38
Hemisphere	804-3059-0
Leica	AX1202GG
Navcom	82-001020-3001LF
PCTel	3977D
Trimble	Bullet 360 Antenna 101155-10
Trimble	Choke Ring 29659-00
Trimble	Zephyr 41249-00
Trimble	Zephyr Geodetic 2 55971-00
Ublox	ANN-MS-0-005

