GPS-ABC Radiated Chamber Testing Overview and Results

GPS-ABC Workshop VI

RTCA Washington, DC

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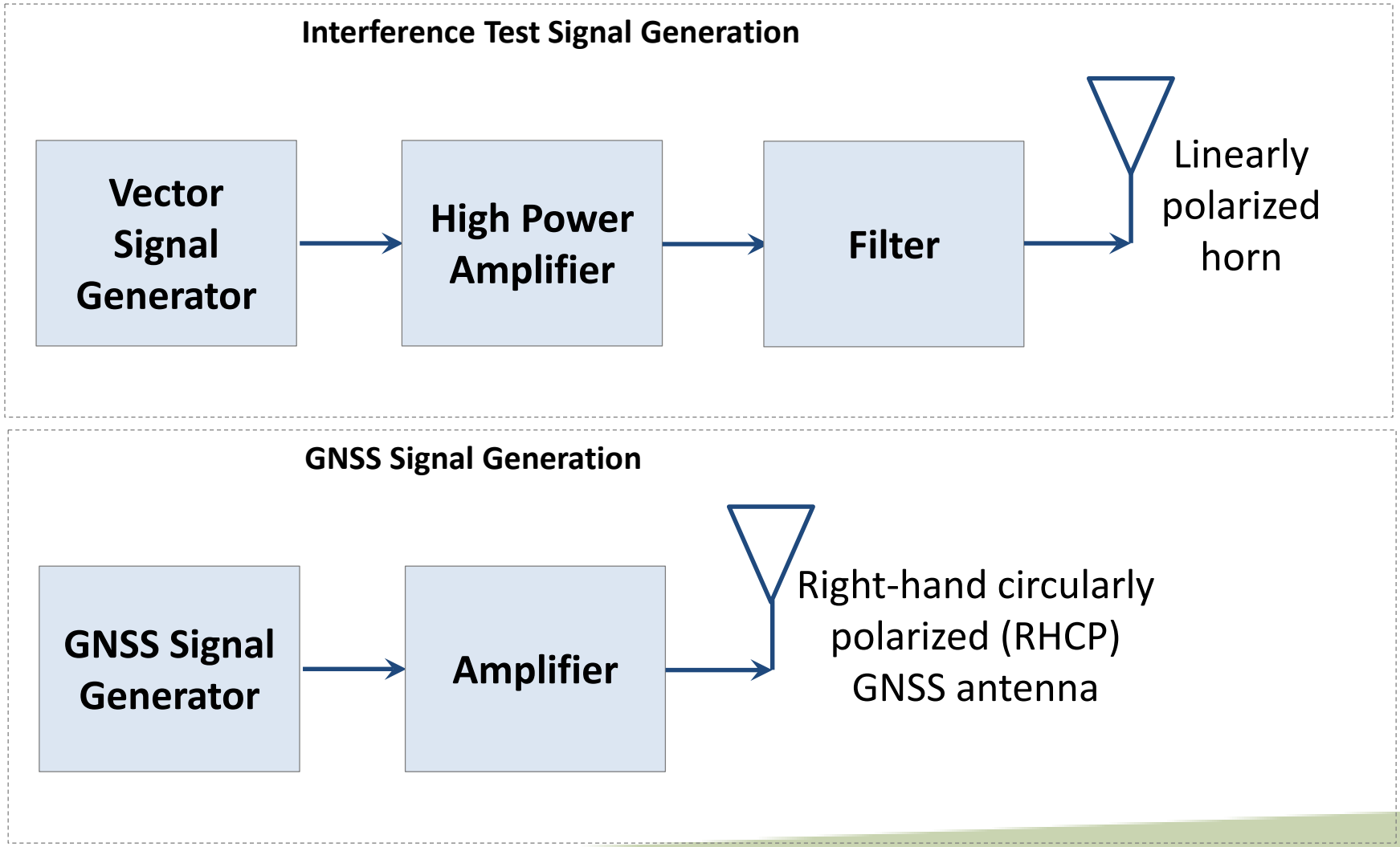
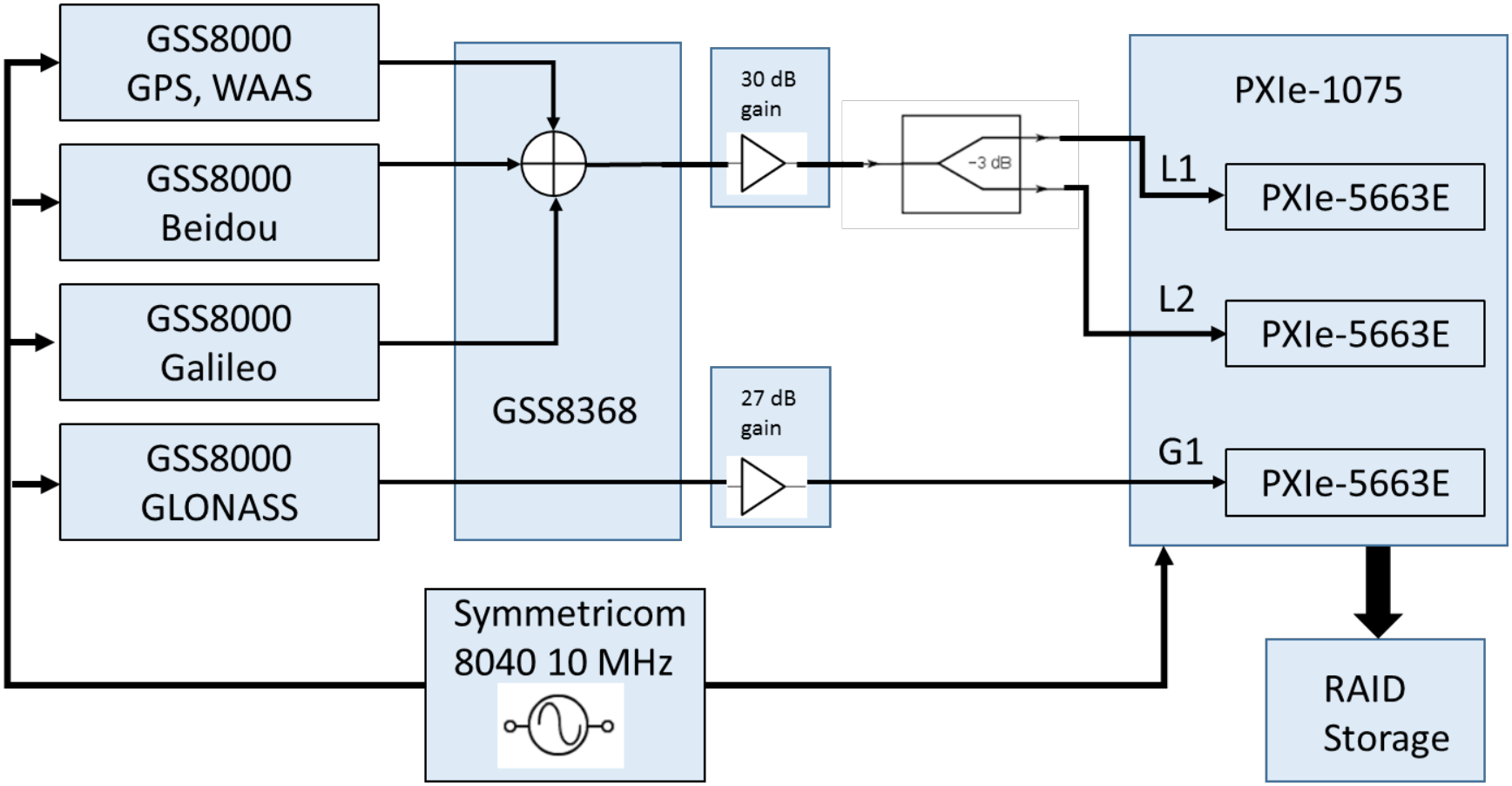
Radiated Testing Overview

- 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 (USCG, NASA, NOAA, USGS, and FAA) and GPS manufacturers
  - Air Force/GPS Directorate conducted testing week of April 18th
- 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)
  - 1 MHz In-Band Noise (Type1)
  - 10 MHz Long Term Evolution (LTE) (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

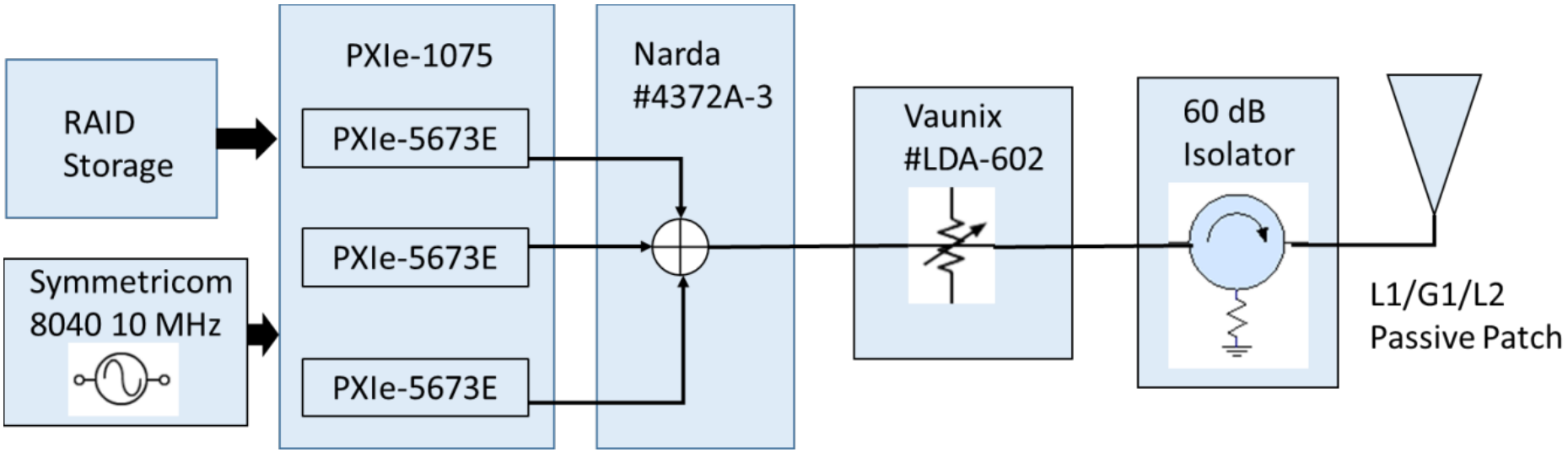
Signal Generation Approach



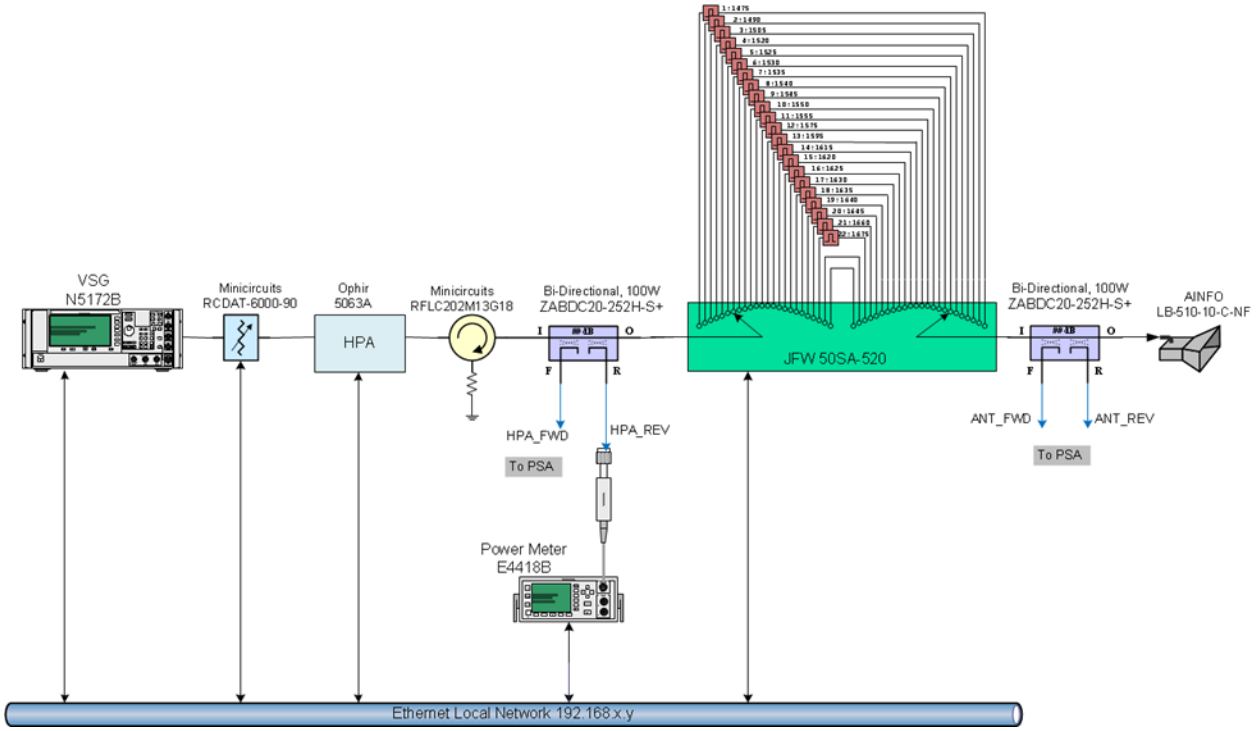
GNSS Signal Generation and Recording



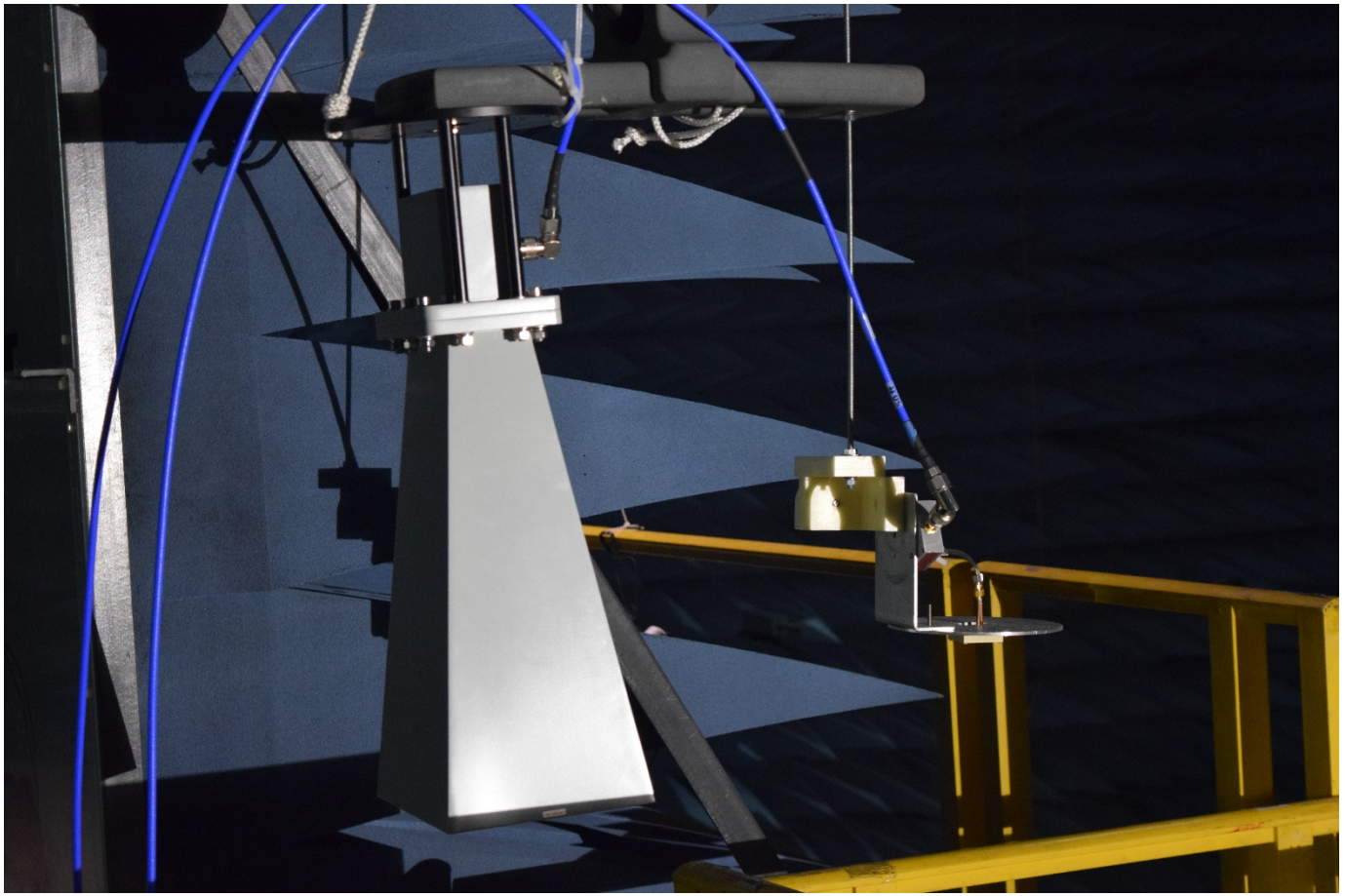
GNSS Signal Playback and Transmission



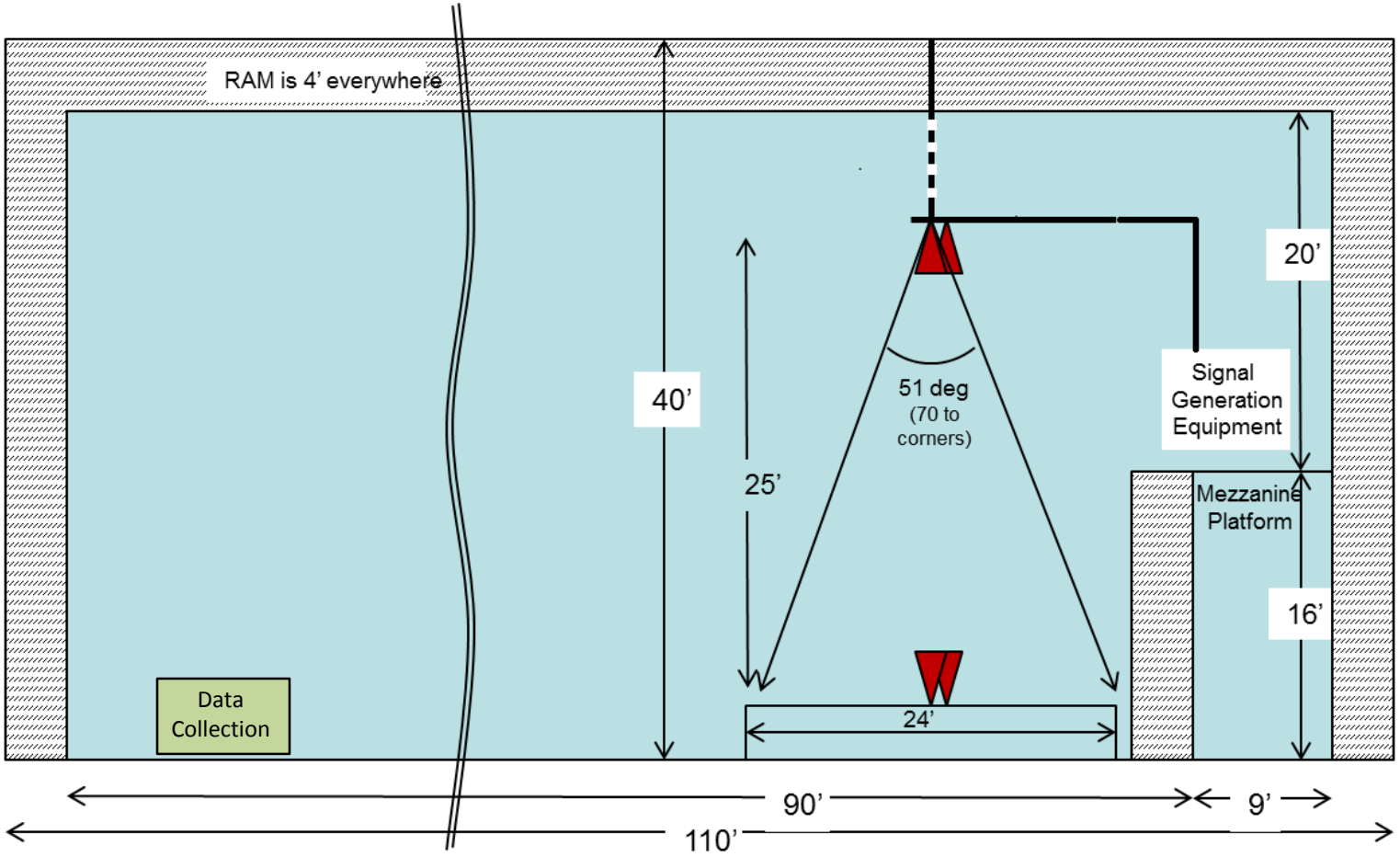
Interference Signal Generation Diagram



RF Antennas Setup



Chamber Diagram

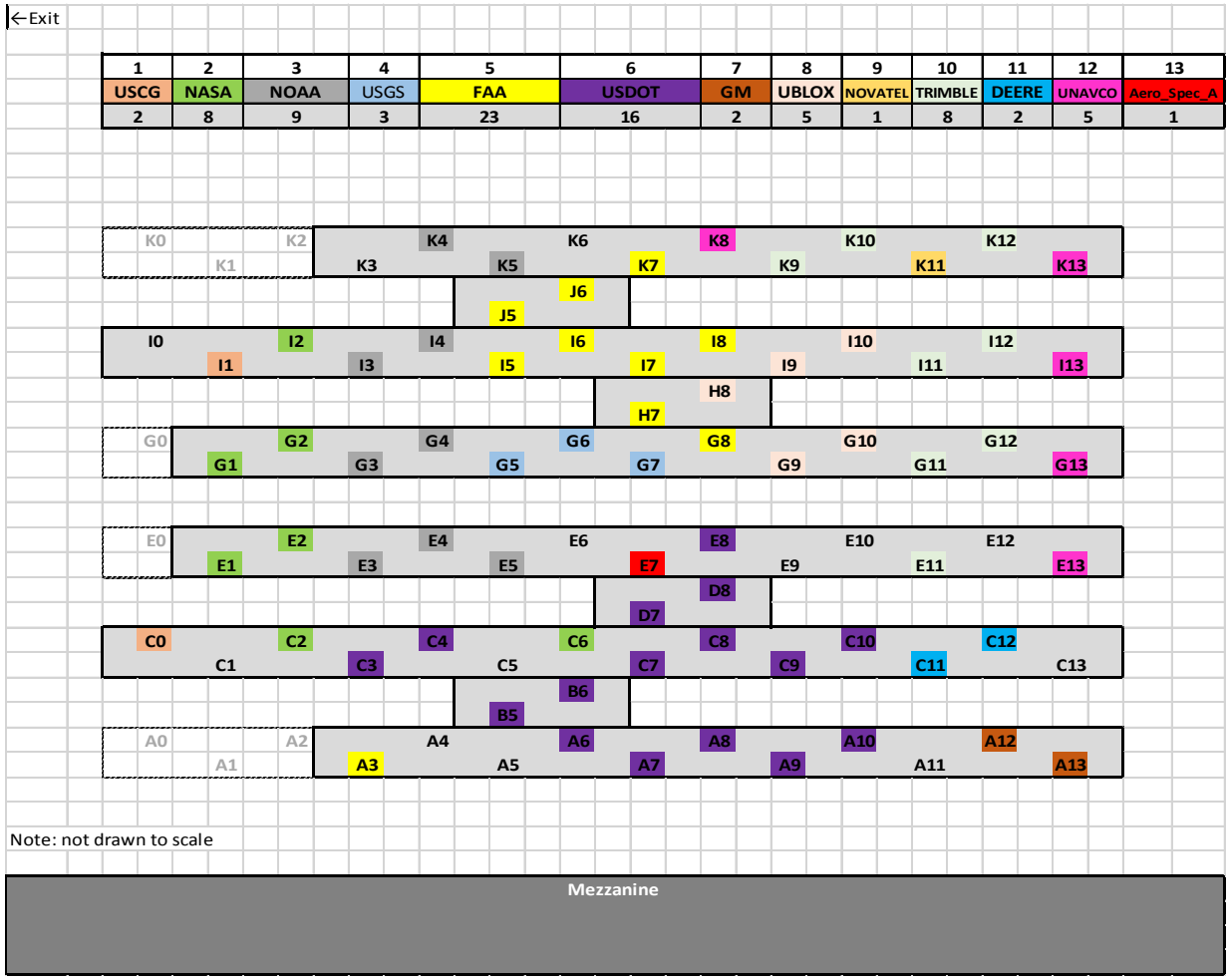


8

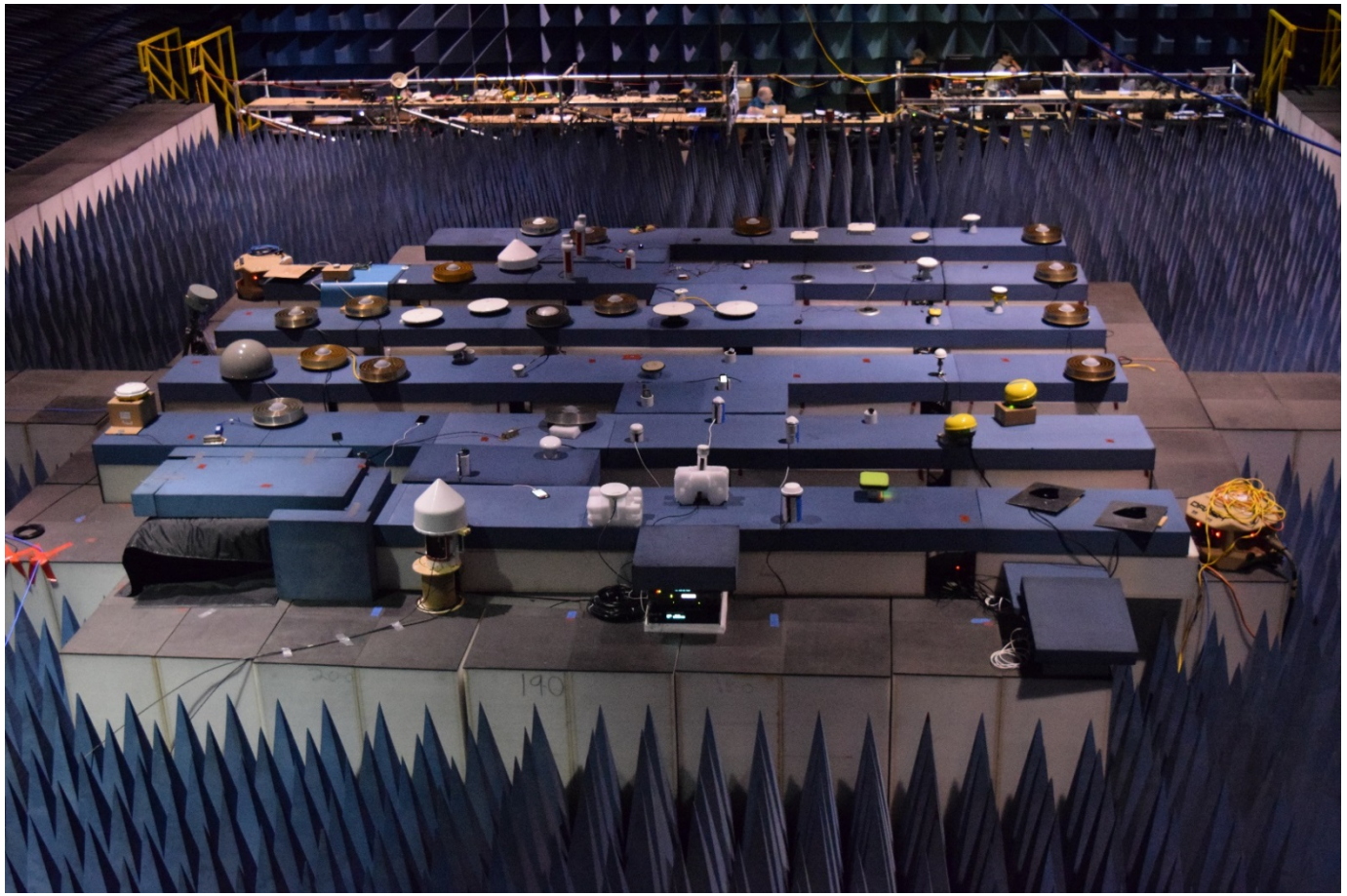
Participants

- 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

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
K0 K1 K2 K3 K4 K5 K6 K7 K8 K9 K10 K11 K12 K13
J5 J6
I0 I1 I2 I3 I4 I5 I6 I7 I8 I9 I10 I11 I12 I13
H7 H8
G0 G1 G2 G3 G4 G5 G6 G7 G8 G9 G10 G11 G12 G13
E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 E10 E11 E12 E13
D7 D8
C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13
B5 B6
A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13
Note: not drawn to scale
Mezzanine

Chamber Test Grid and 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

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

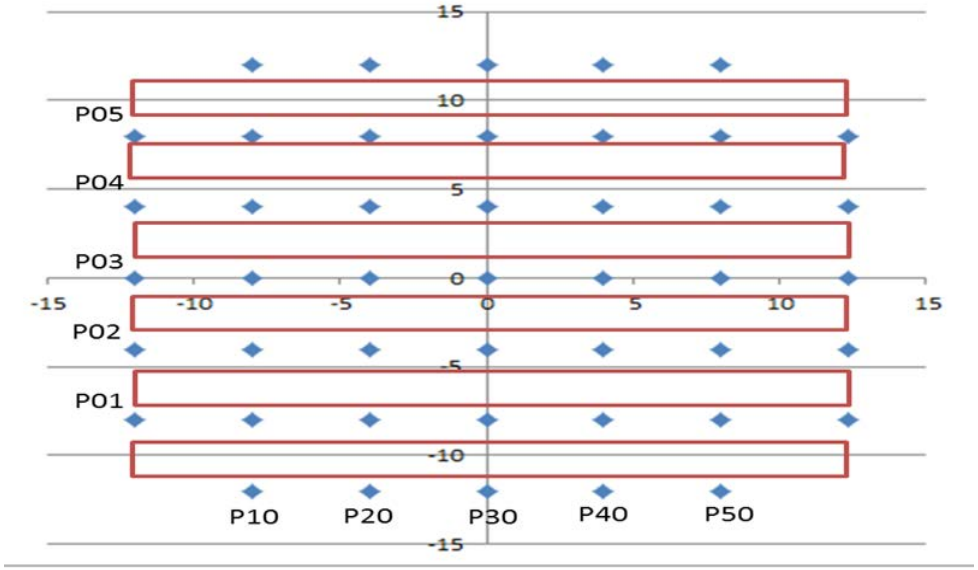
GNSS Signals Used in Testing

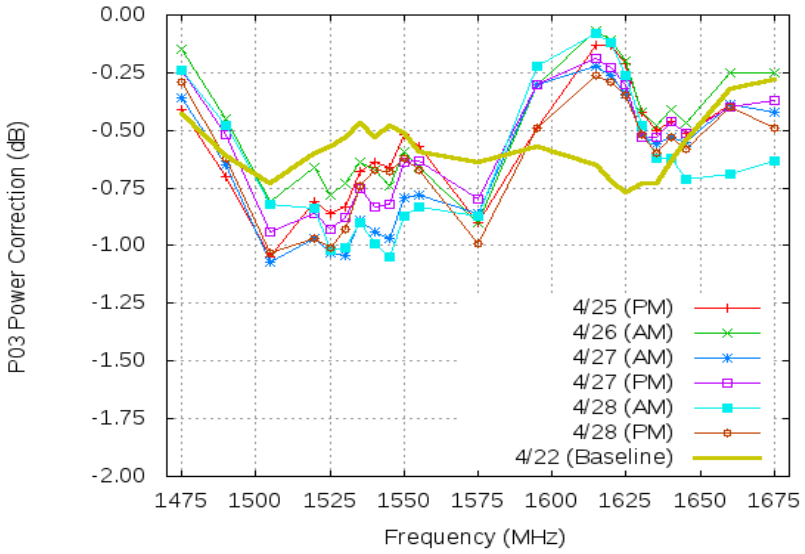
Signal
GPS L1 C/A-code
GPS L1 P-code
GPS L1C
GPS L1 M-code
GPS L2 P-code
SBAS L1
GLONASS L1 C
GLONASS L1 P
BeiDou B1I
Galileo E1 B/C

Data Collected

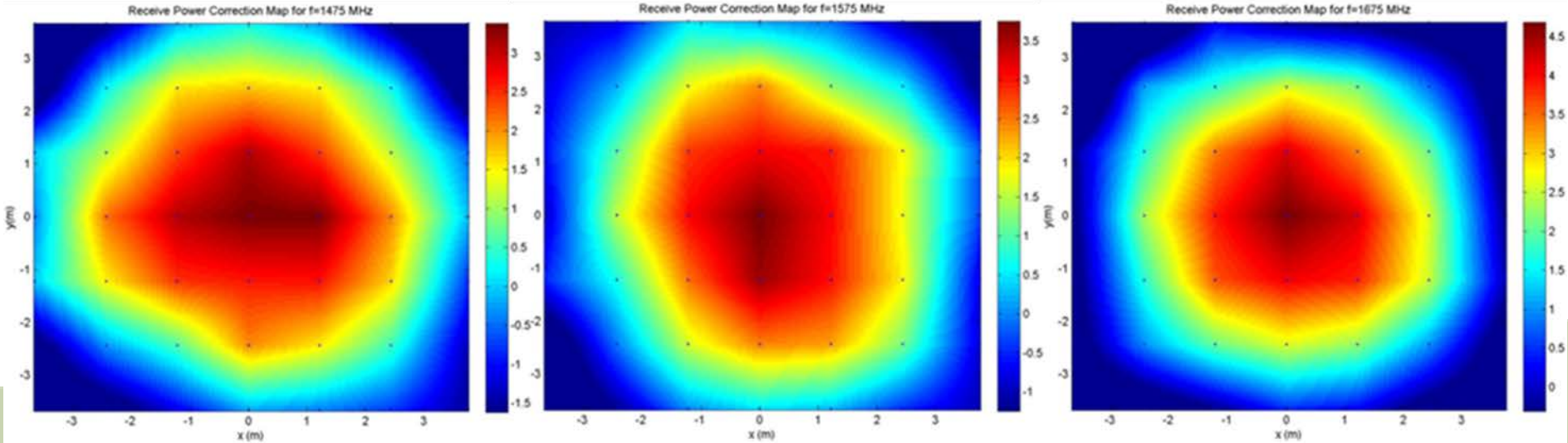
- Data Needed to Develop an ITM for each receiver:
  - $CNR(s, i, j.\Delta t)$ (here, *s* identifies the GNSS, *i* the SV, Δt is the reporting time increment)
- To the extent possible, additional data to report the state of the receiver at each time step
  - Number of satellites tracked for each GNSS 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)

Signal Power Mapping WSMR

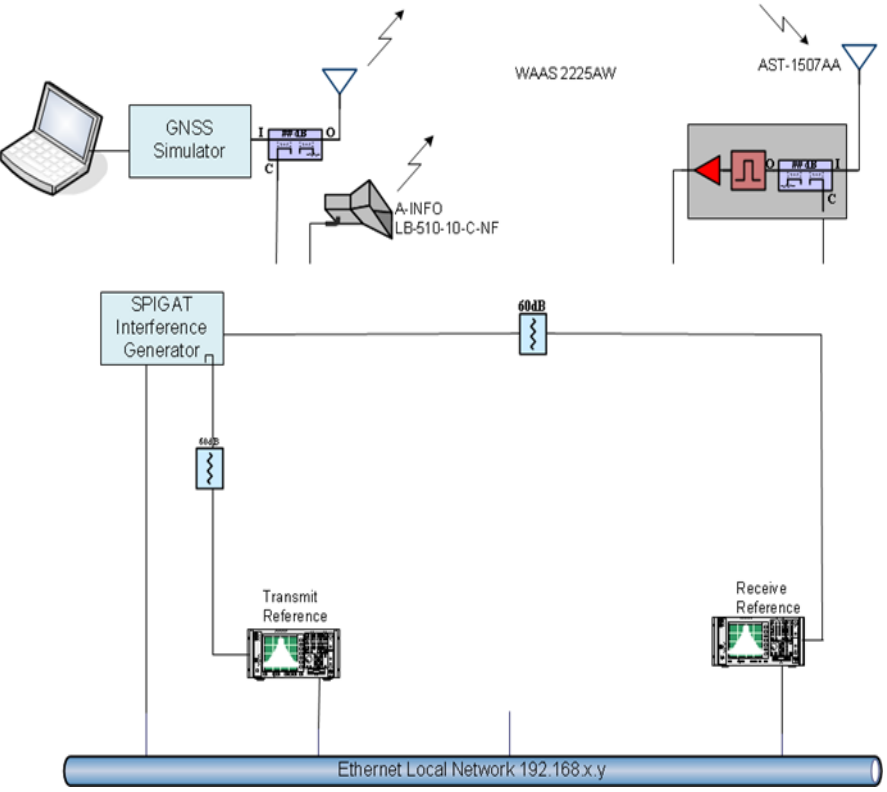


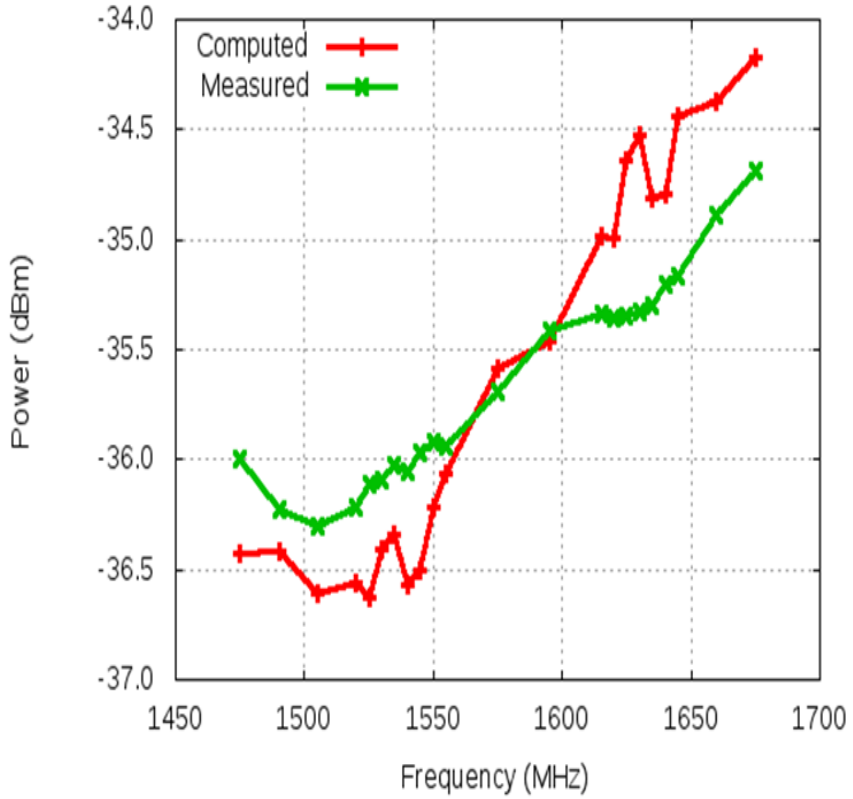


1475 MHz **1575 MHz** **1675 MHz**

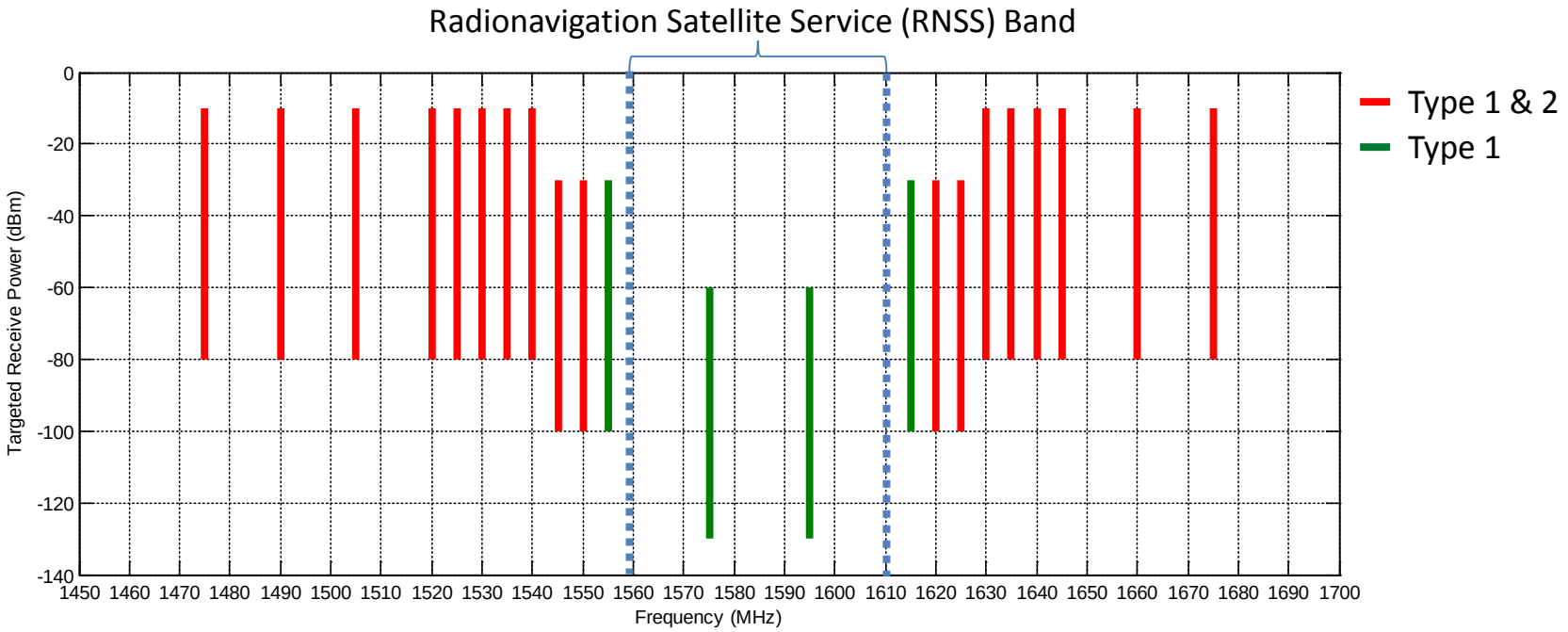


Signal Power Comparison
Measured vs. Predicted



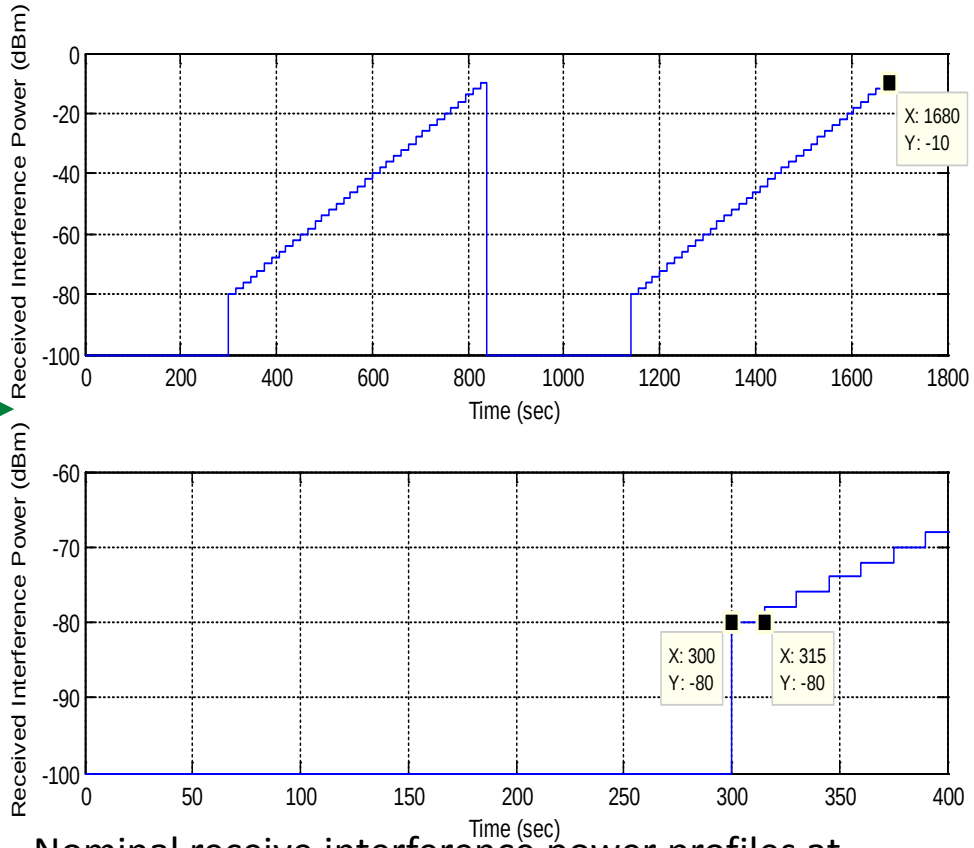


Interference Test Signal Frequencies and Power Profiles



Interference Test Signal Frequencies and Power Profiles

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



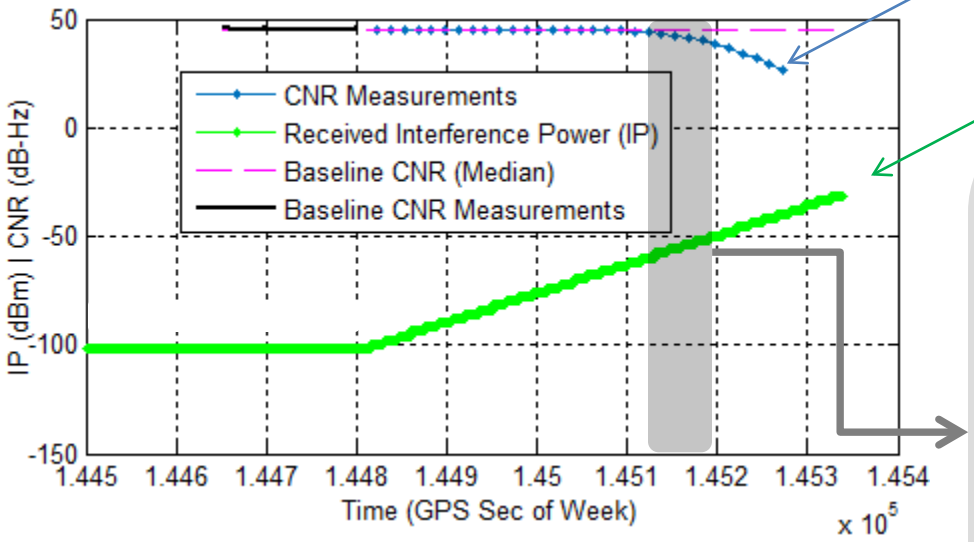
Nominal receive interference power profiles at GNSS antenna location for the (1475 to 1540 MHz) and (1630 to 1675 MHz) frequency ranges.

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



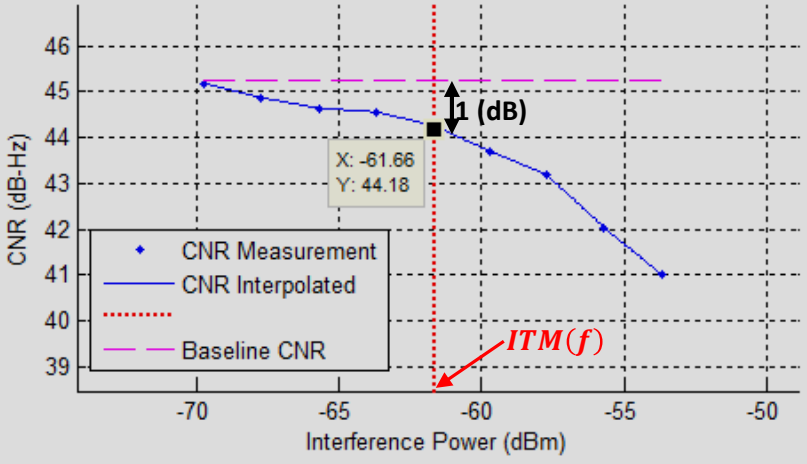
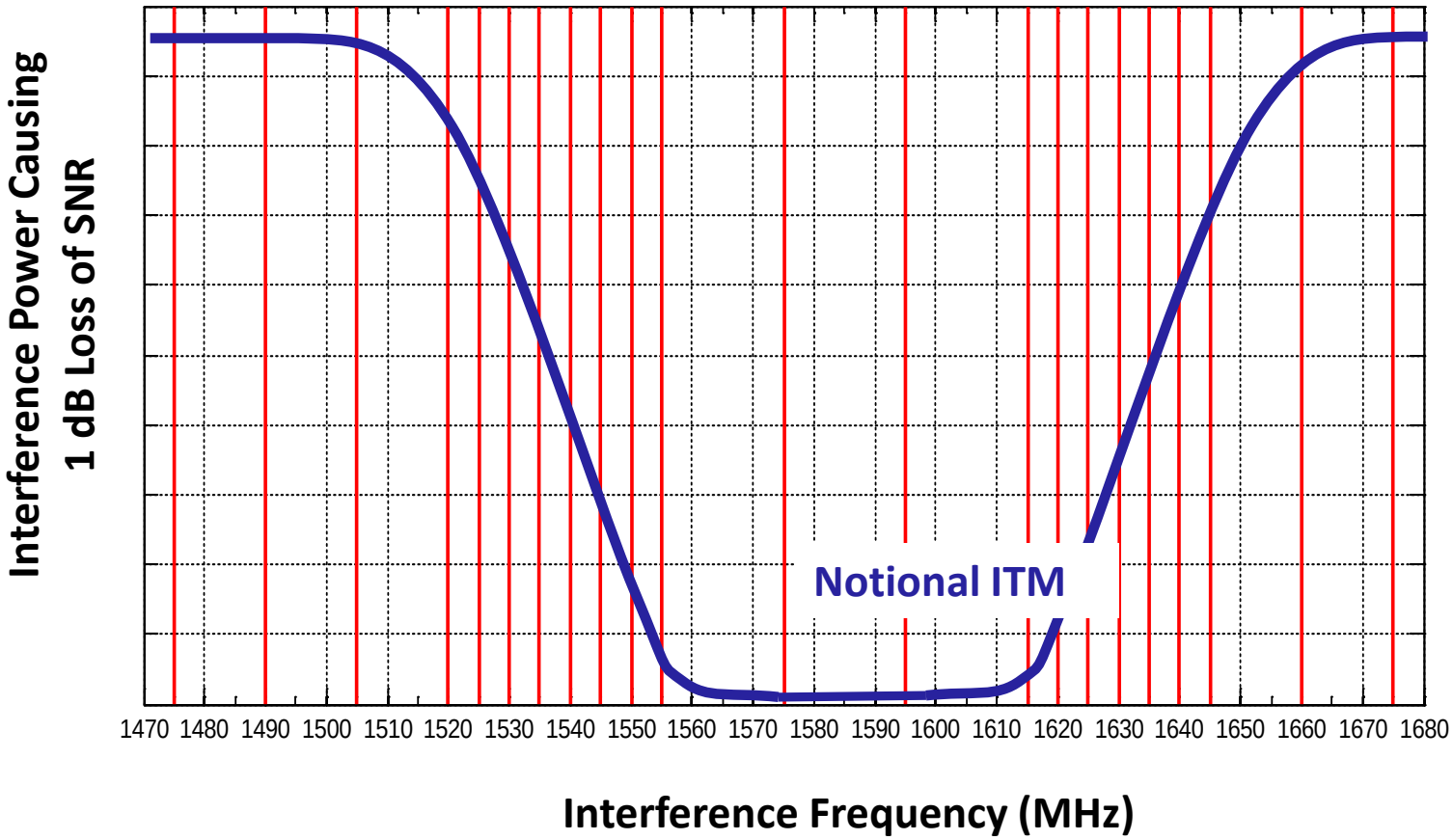


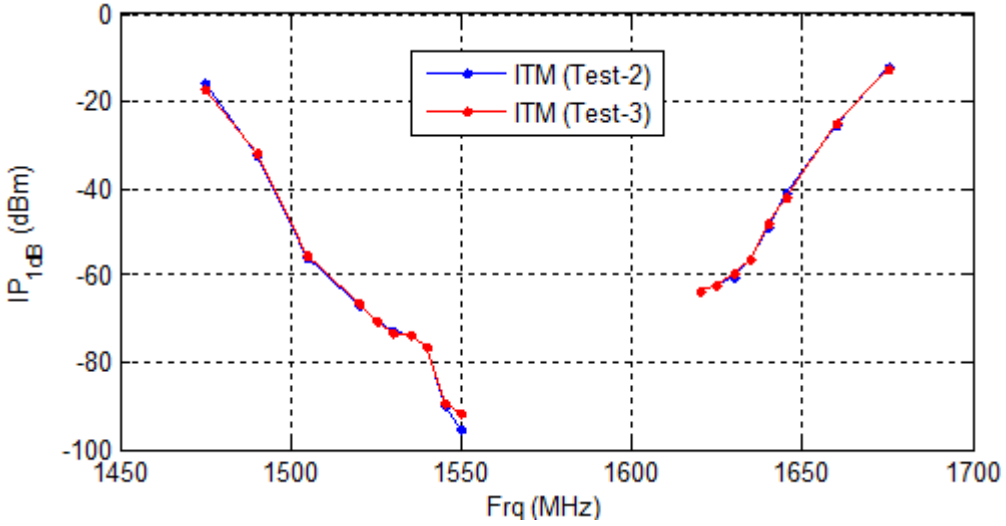
Illustration of ITM



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:

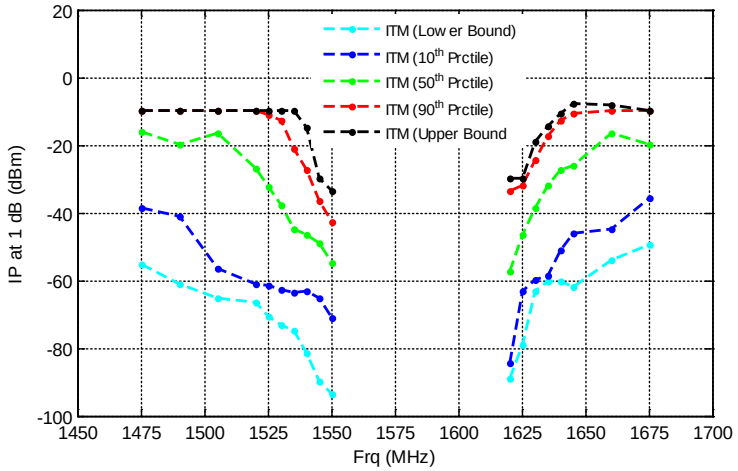


Results on the Next Few Slides

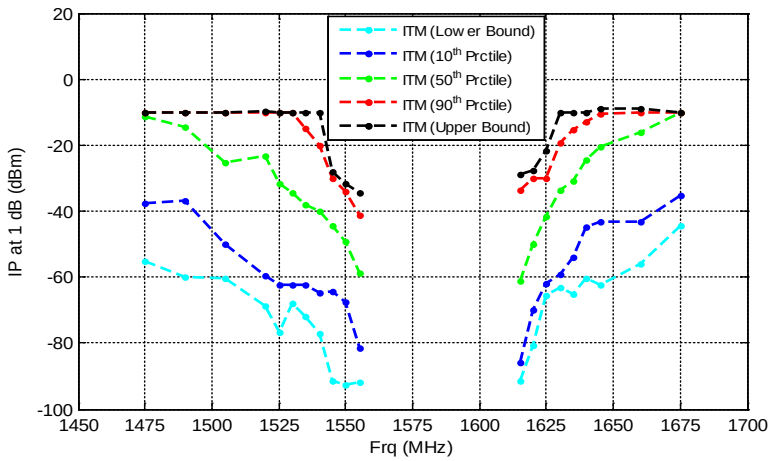
- ITMs for GPS L1 C/A RNSS signal in the presence of 1 MHz LTE interference vs. LTE center frequency
- ITMs for GPS L1 C/A RNSS signal in the presence of 10 MHz LTE interference vs. LTE center frequency
- ITMs for GPS L1 C/A RNSS signal in the presence of 1 MHz in-band LTE interference vs. LTE center frequency

L1 C/A Statistical Mask Results for HPR receivers

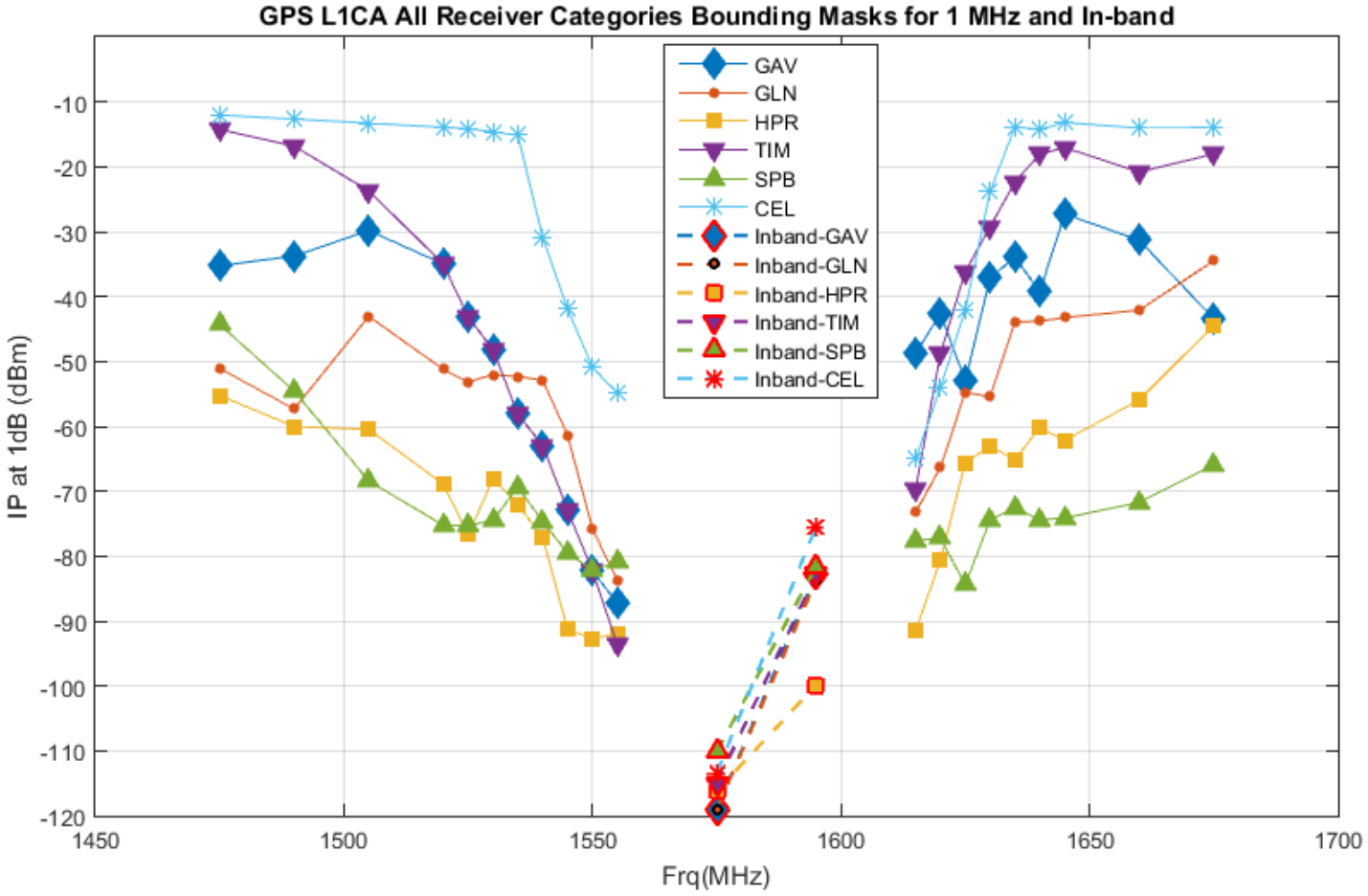
10 MHz LTE



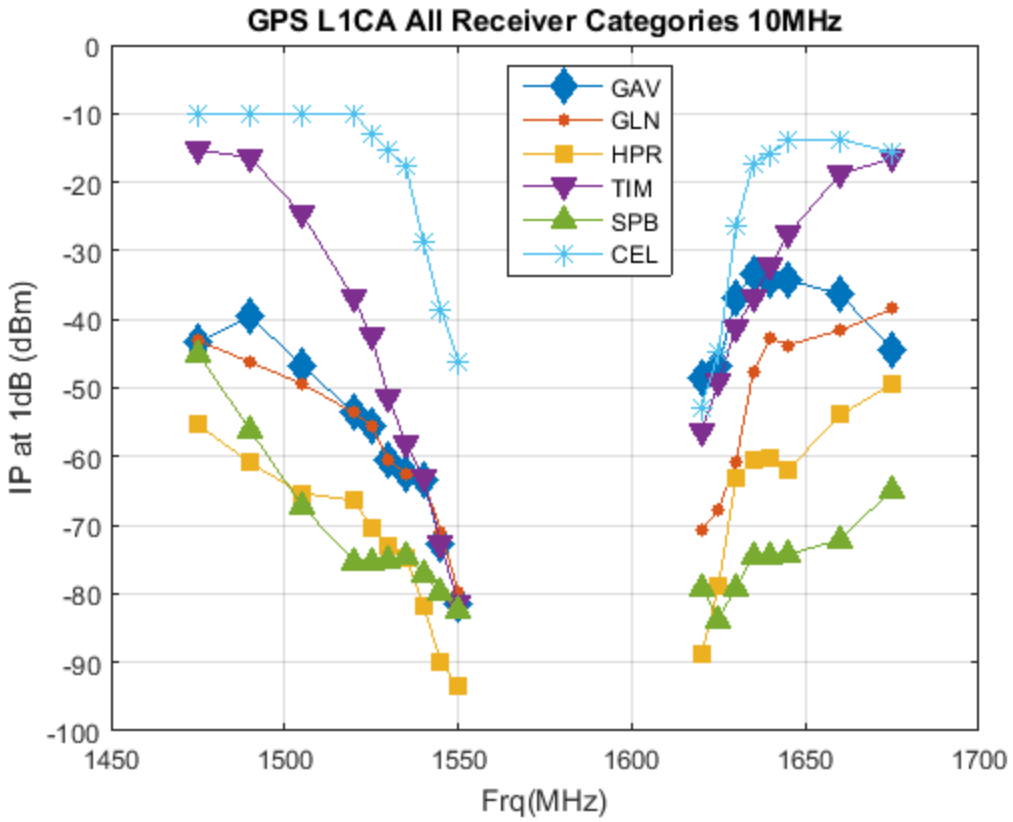
1 MHz AWGN



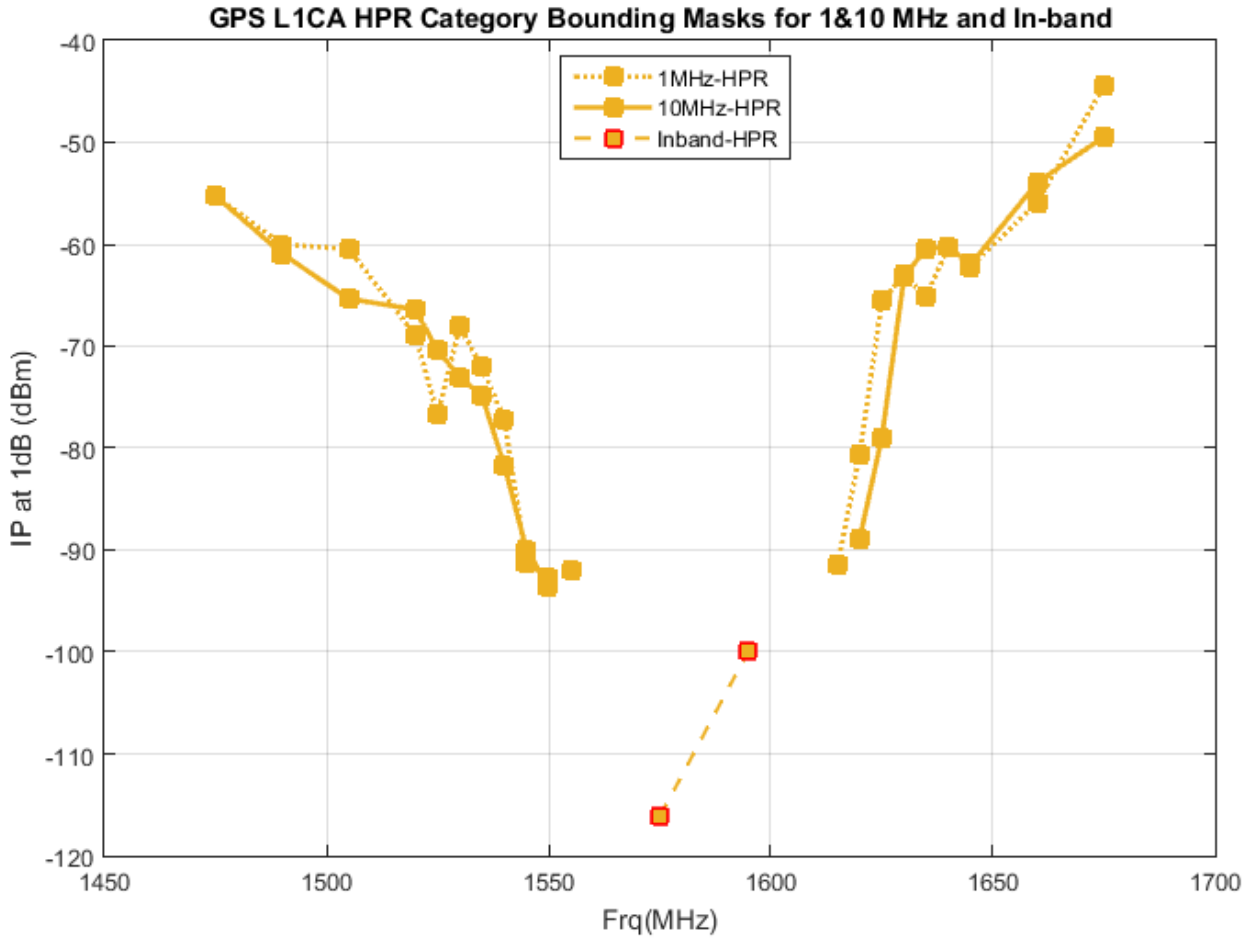
Summary of 1 MHz and In-band Bounding Masks GPS L1 C/A



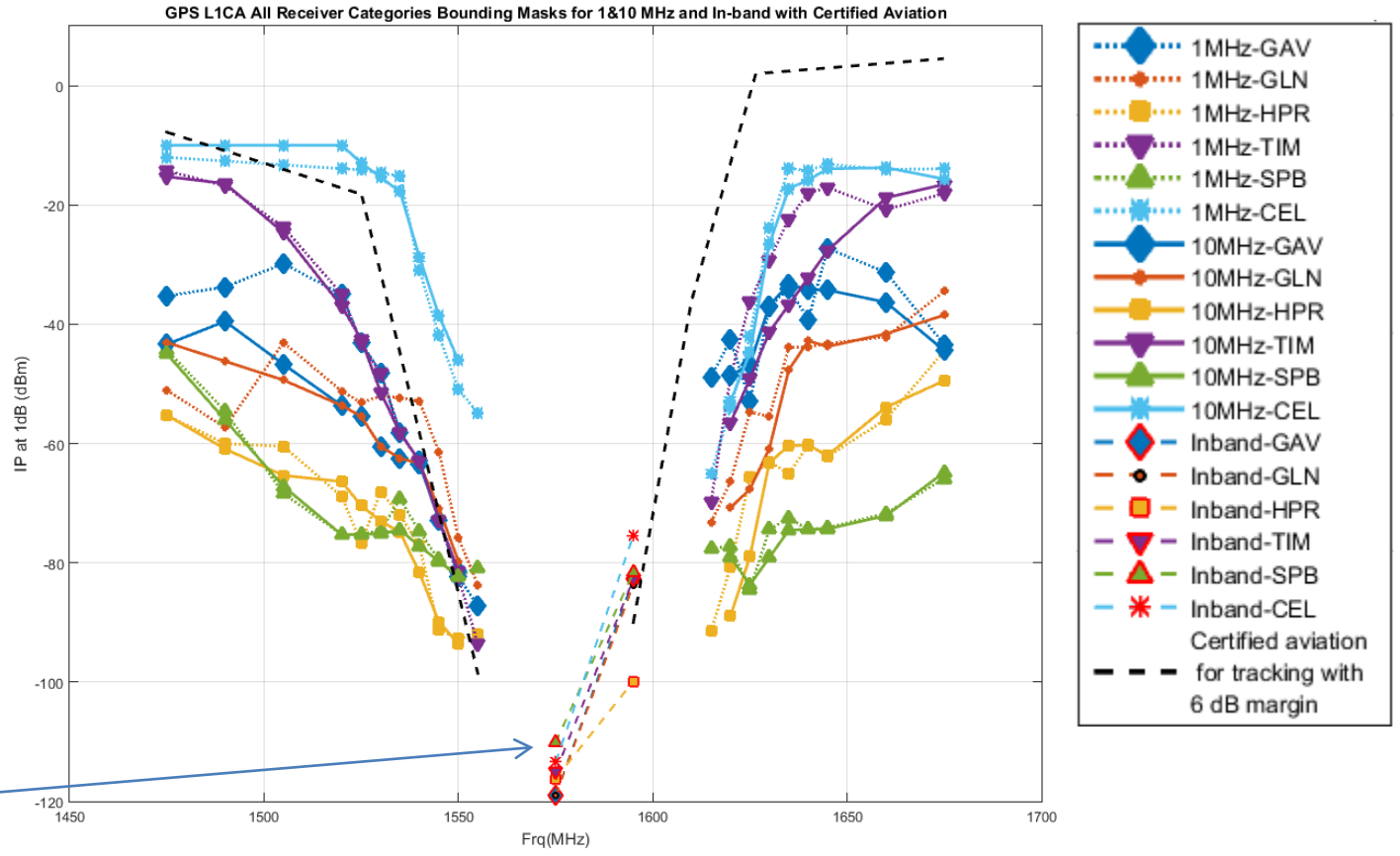
Summary of 10 MHz Bounding Masks GPS L1 C/A



Summary of 1&10 MHz and In-band Bounding Masks GPS L1 C/A - HPR

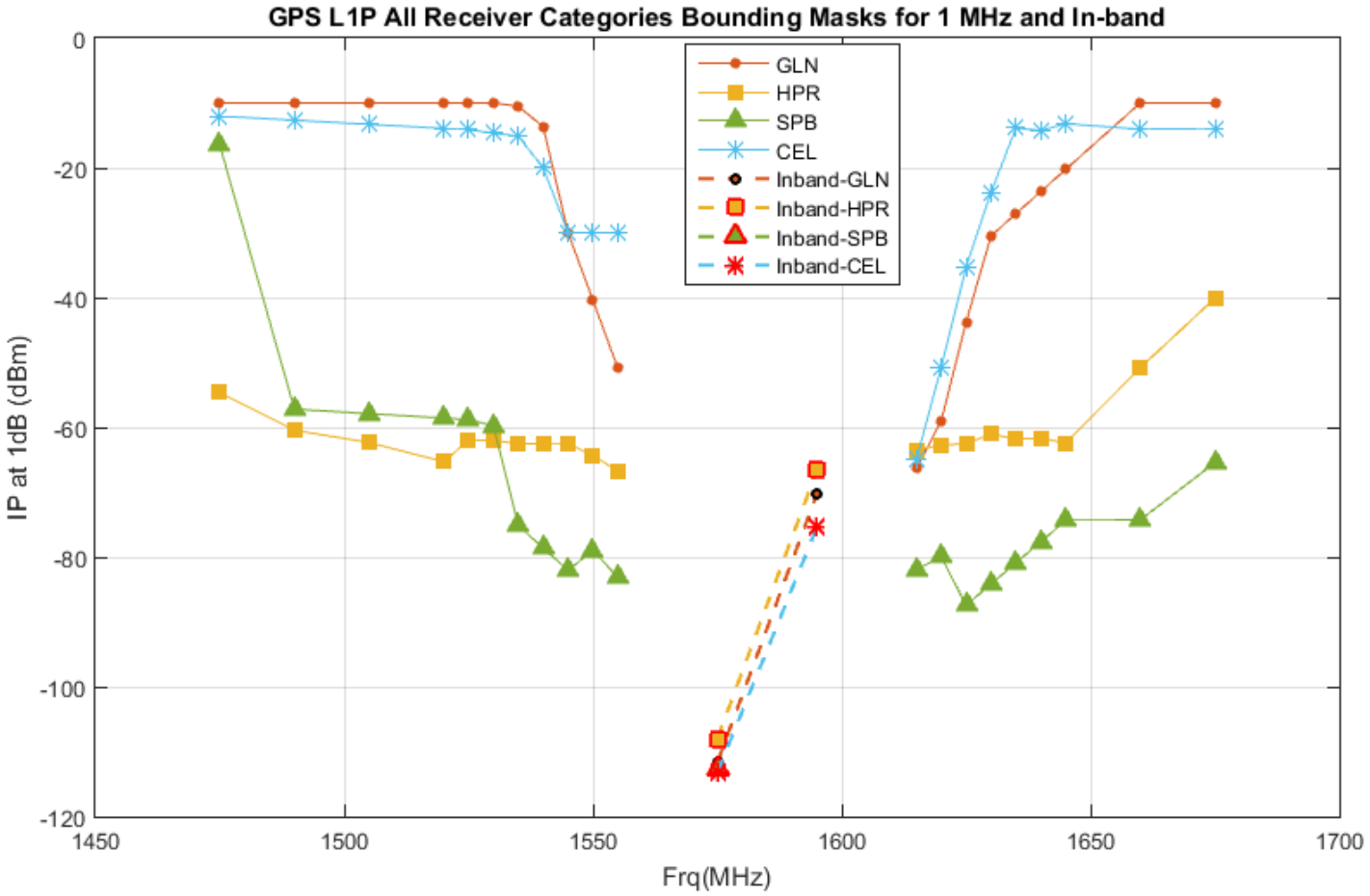


Summary of 1&10 MHz and In-band with Certified Aviation Bounding Masks GPS L1 C/A

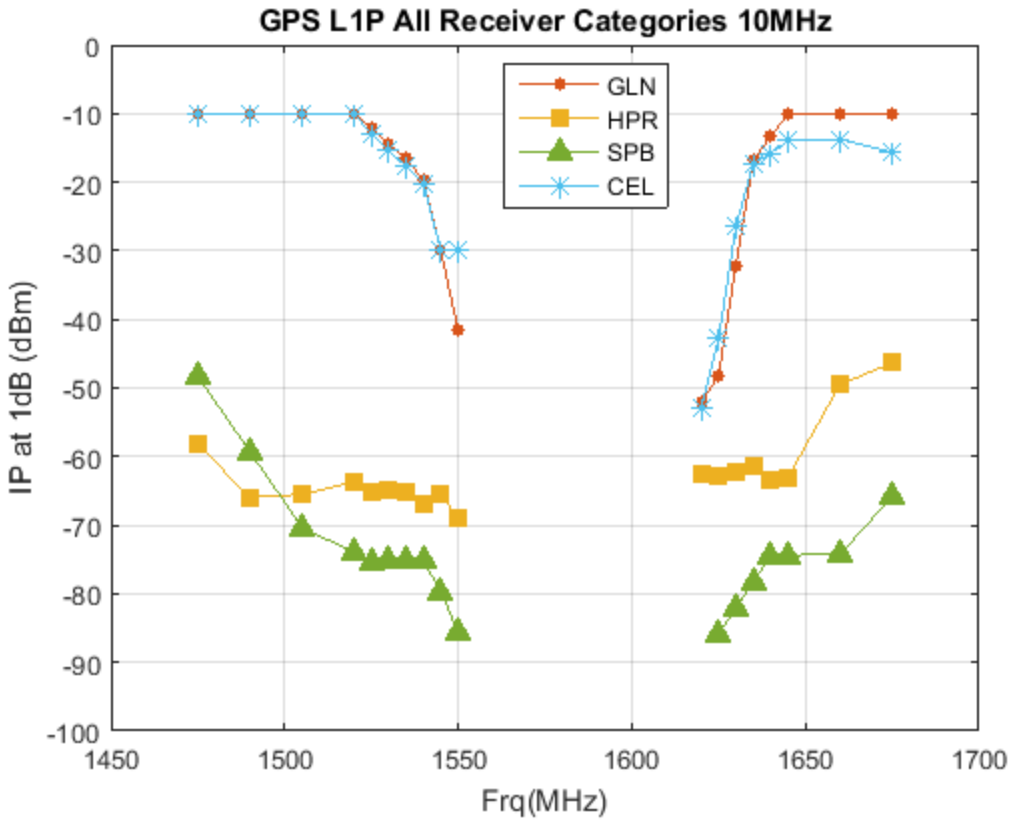


Note: Certified Aviation Mask has a value of -110 dBm for 1 MHz in band interference

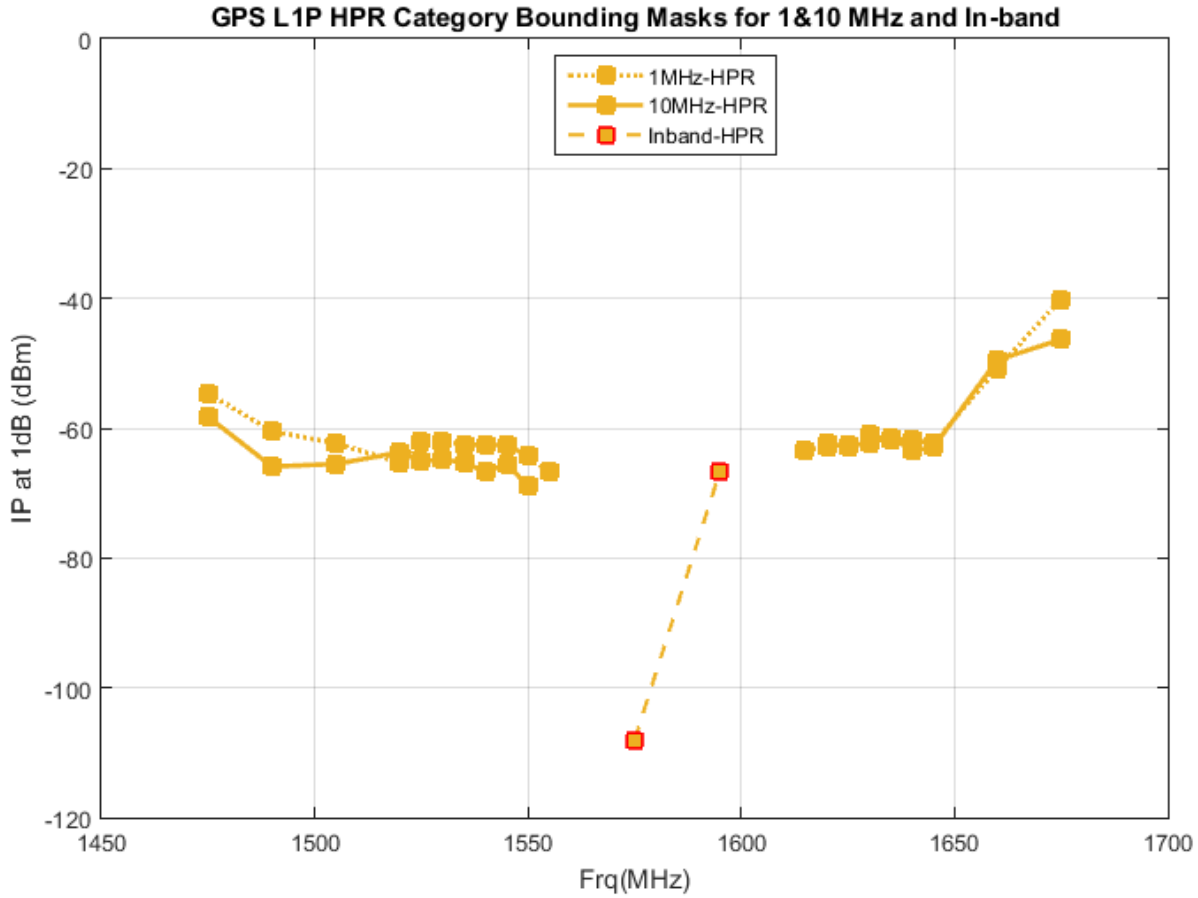
Summary of 1 MHz and In-band Bounding Masks GPS L1 P



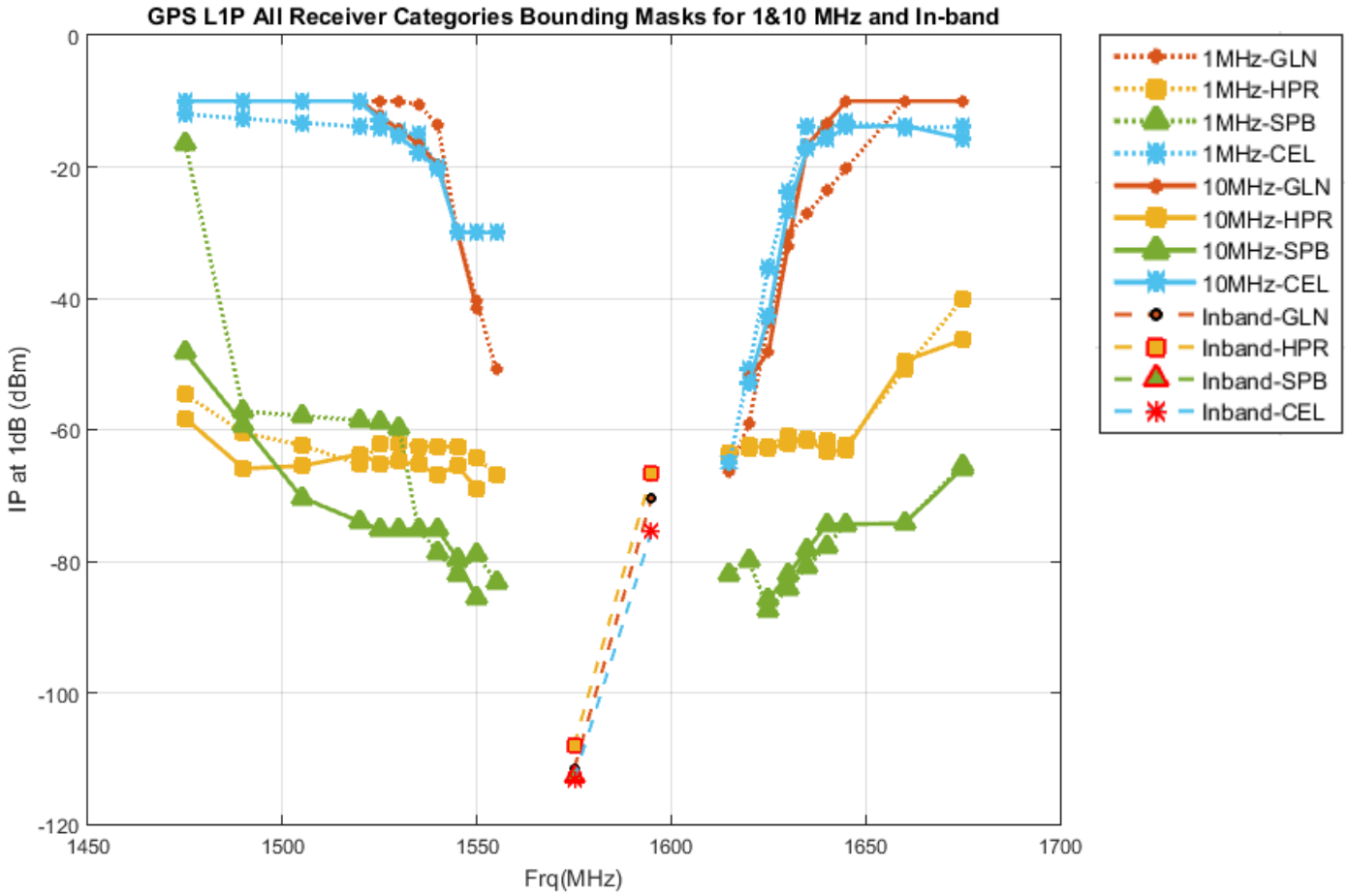
Summary of 10 MHz Bounding Masks GPS L1 P



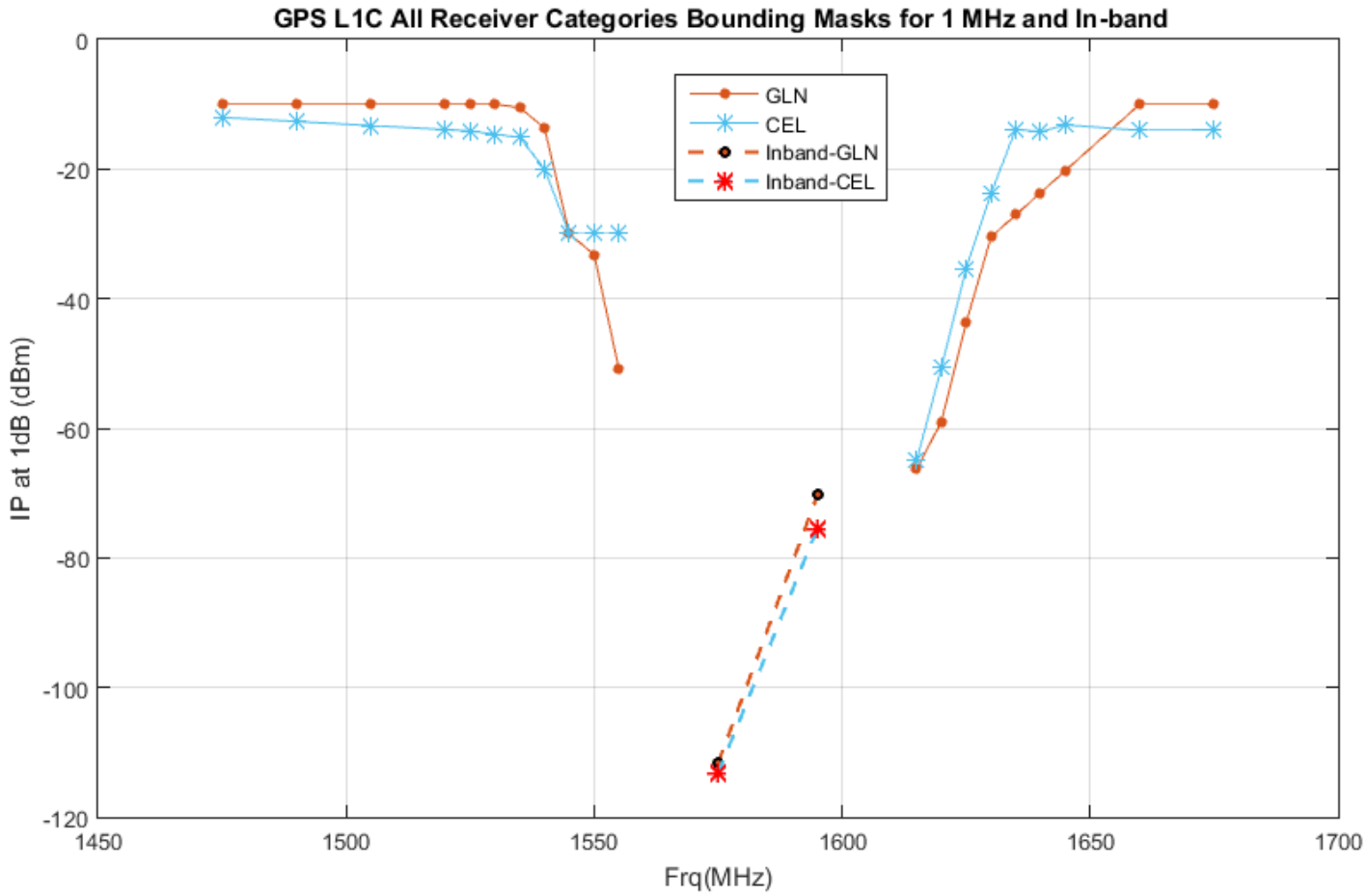
Summary of 1&10 MHz and In-band Bounding Masks GPS L1 P - HPR



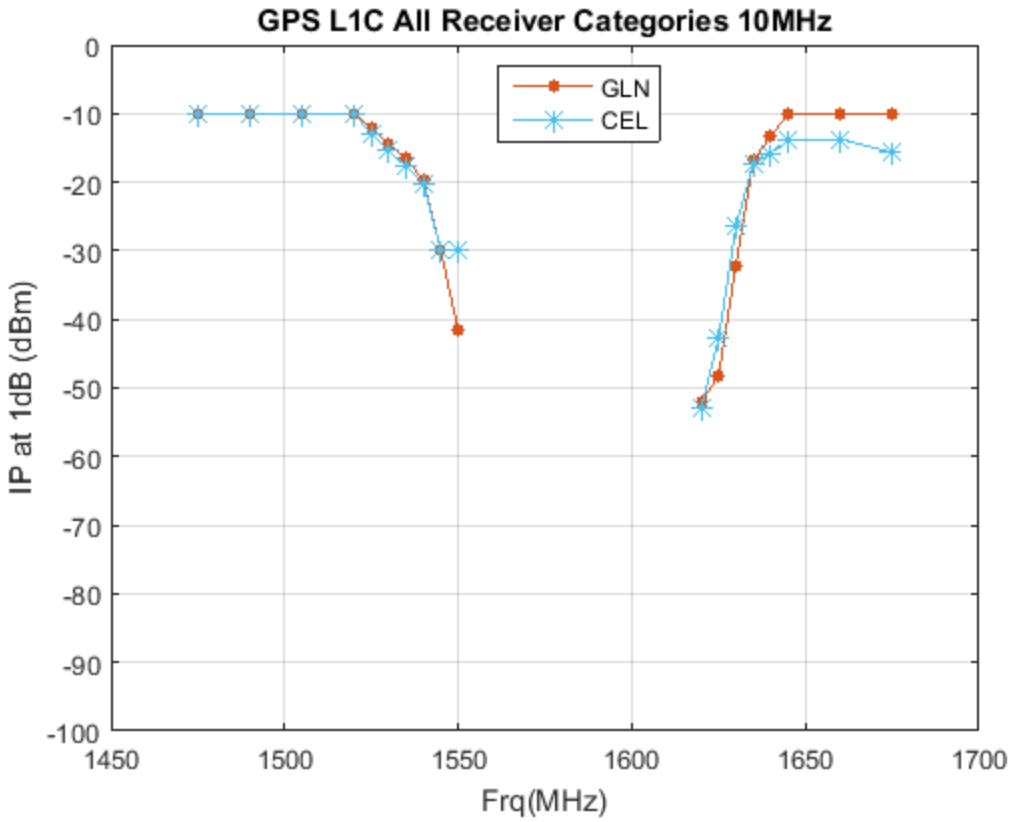
Summary of 1&10 MHz and In-band Bounding Masks GPS L1 P



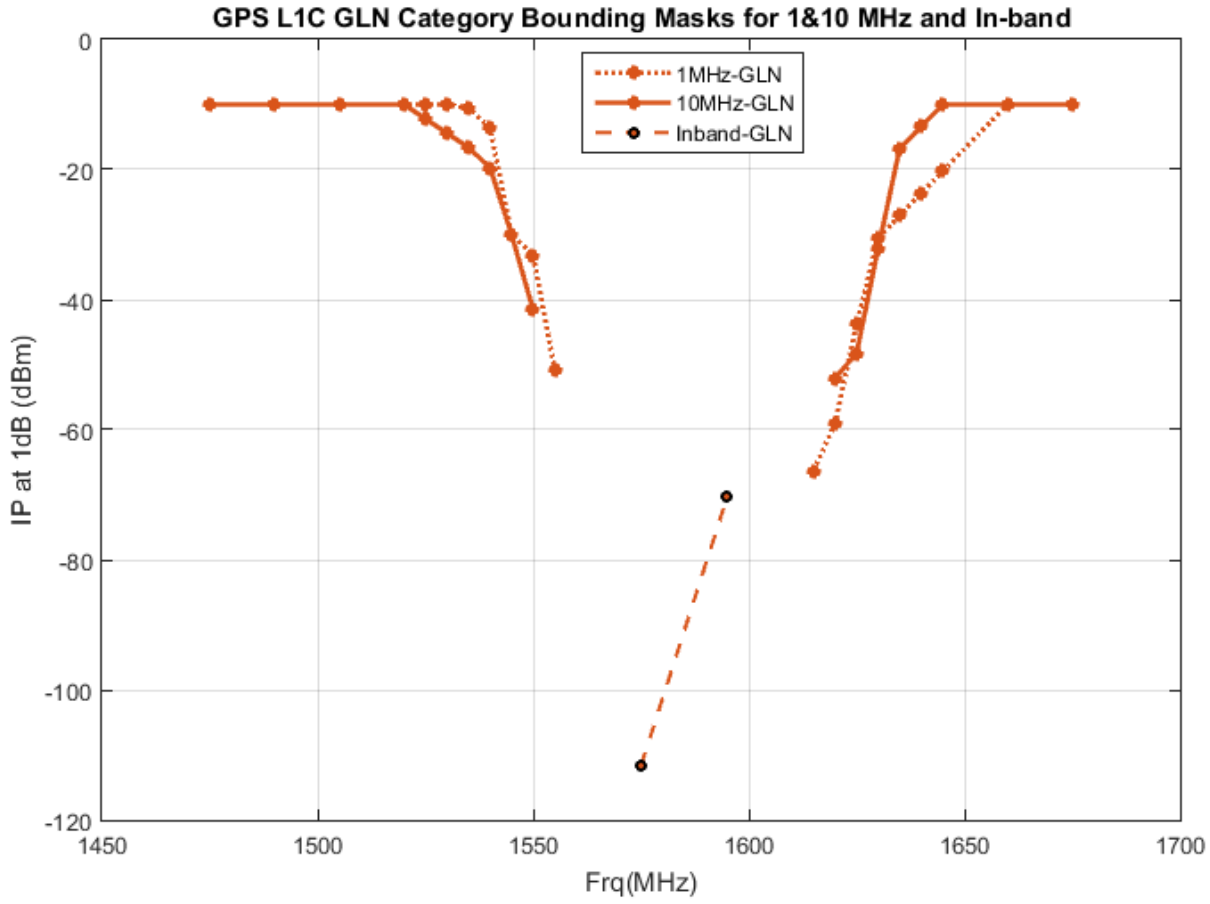
Summary of 1 MHz and In-band Bounding Masks GPS L1 C



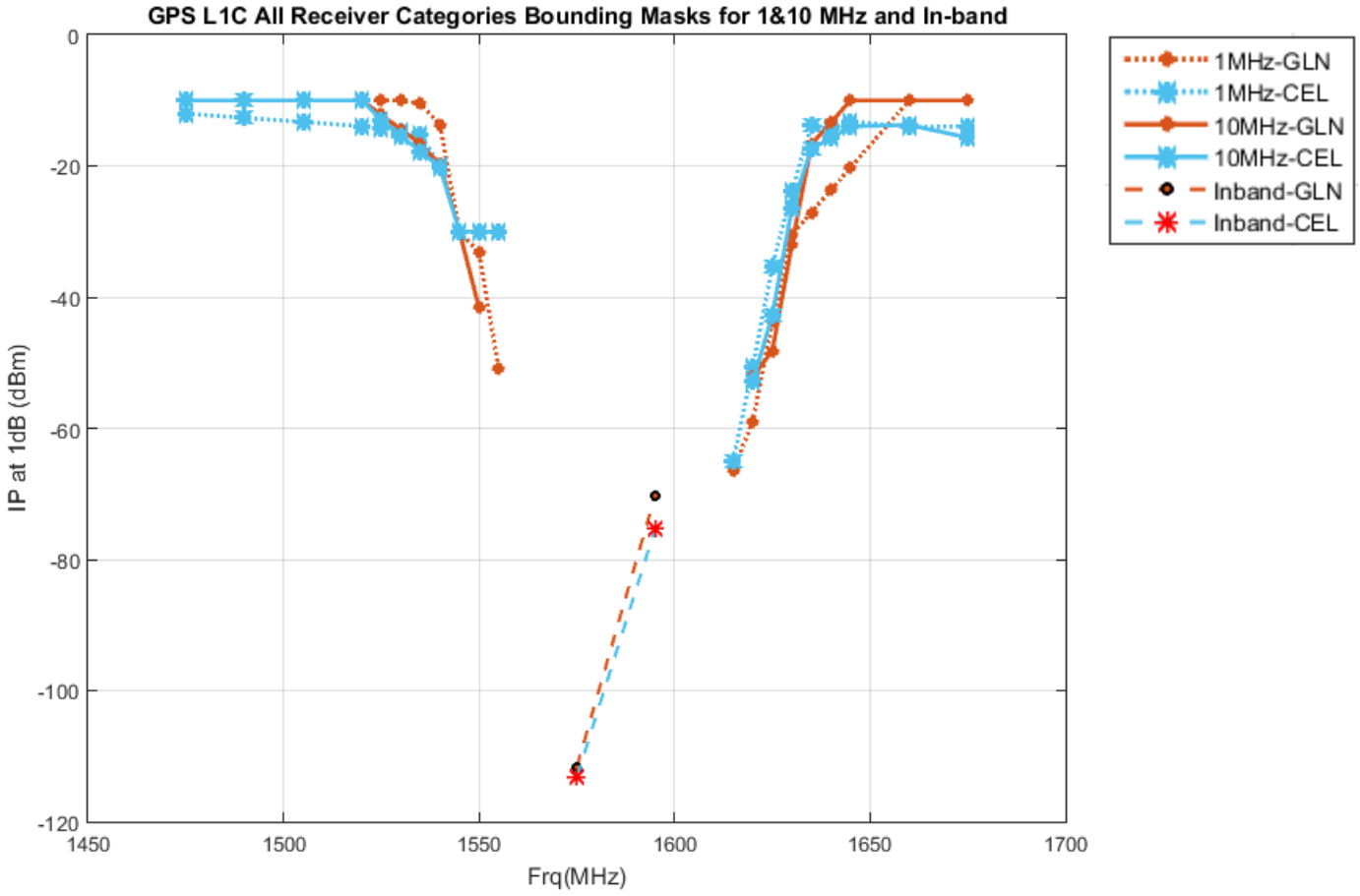
Summary of 10 MHz Bounding Masks GPS L1 C



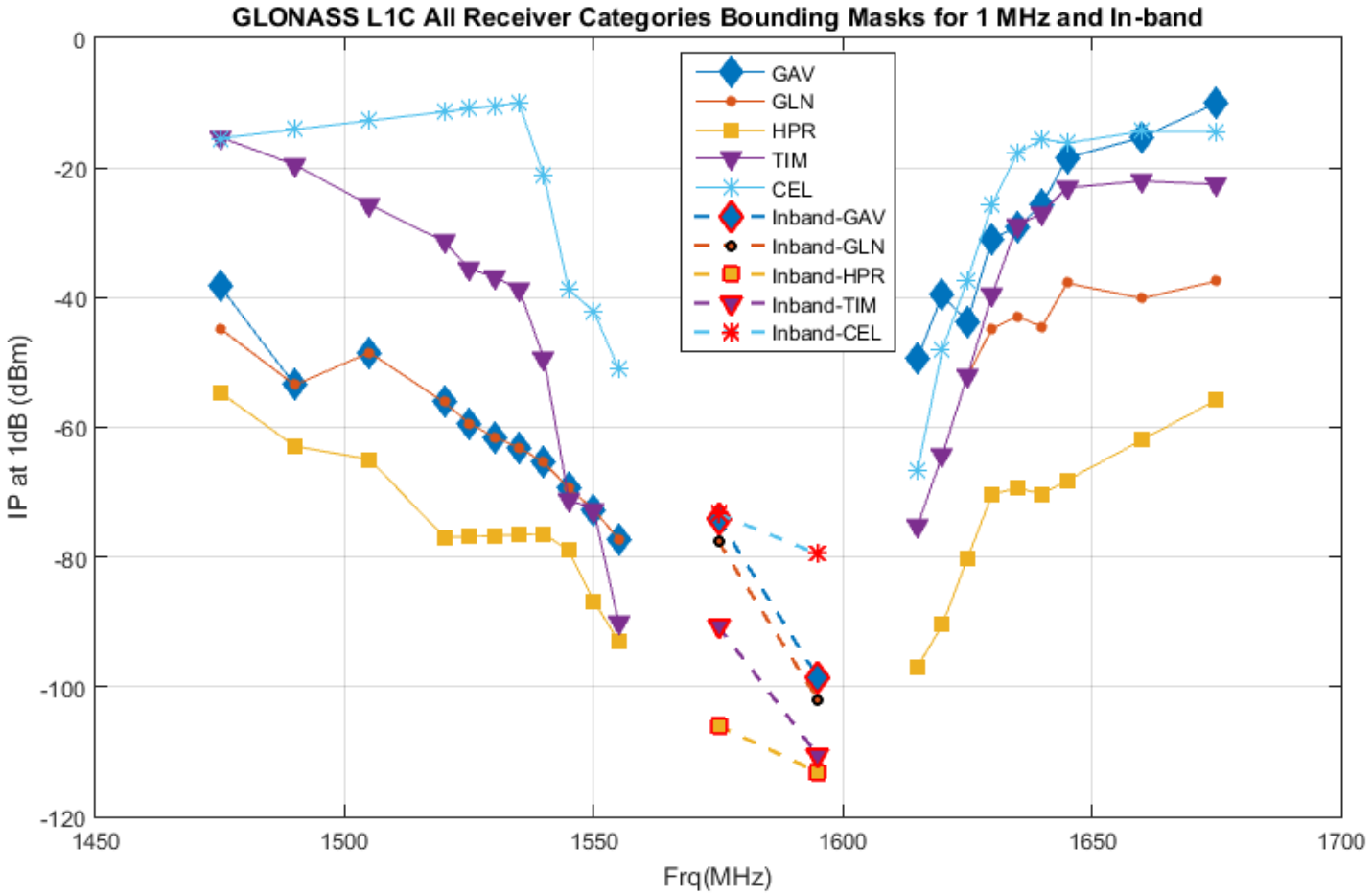
Summary of 1&10 MHz and In-band Bounding Masks GPS L1 C - GLN



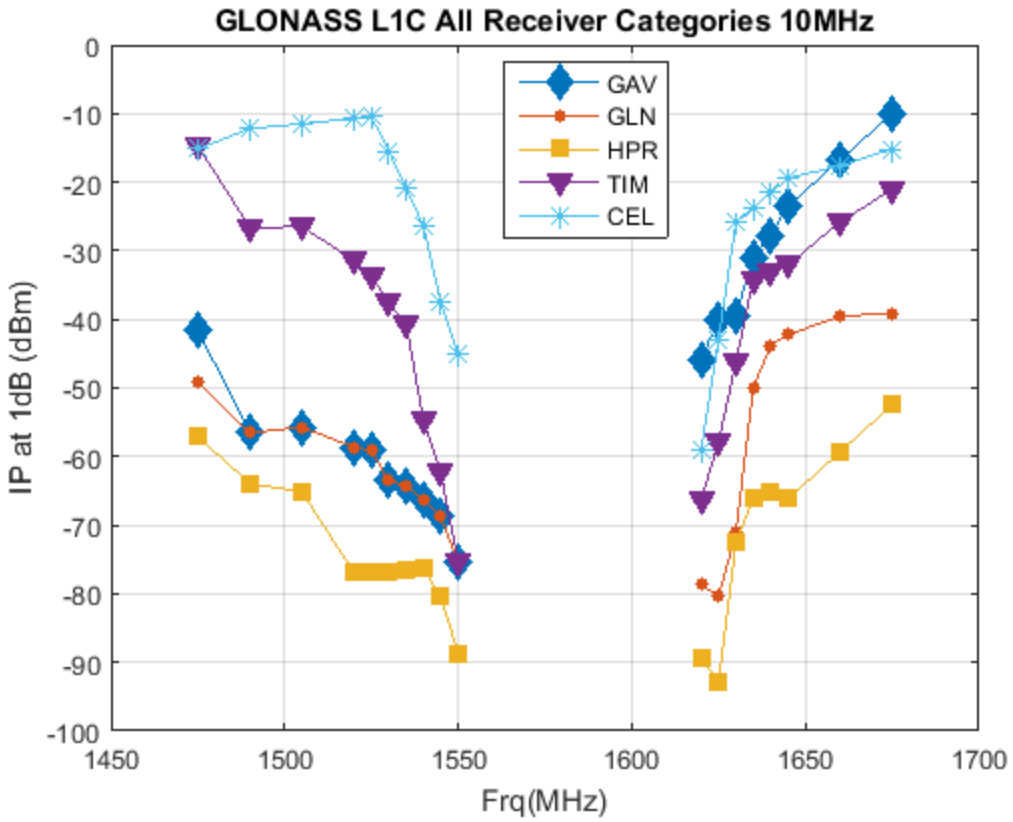
Summary of 1&10 MHz and In-band Bounding Masks GPS L1 C



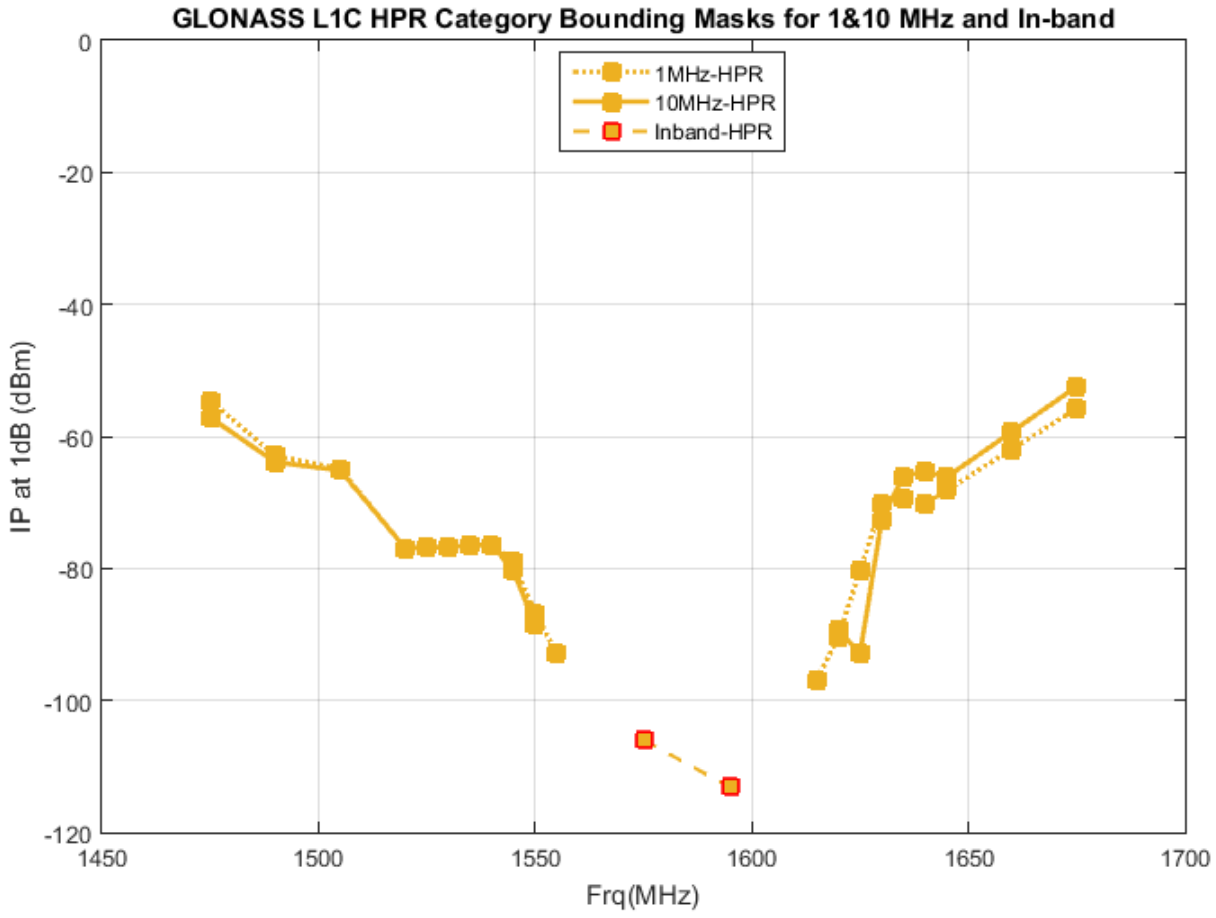
Summary of 1 MHz and In-band Bounding Masks GLONASS L1 C



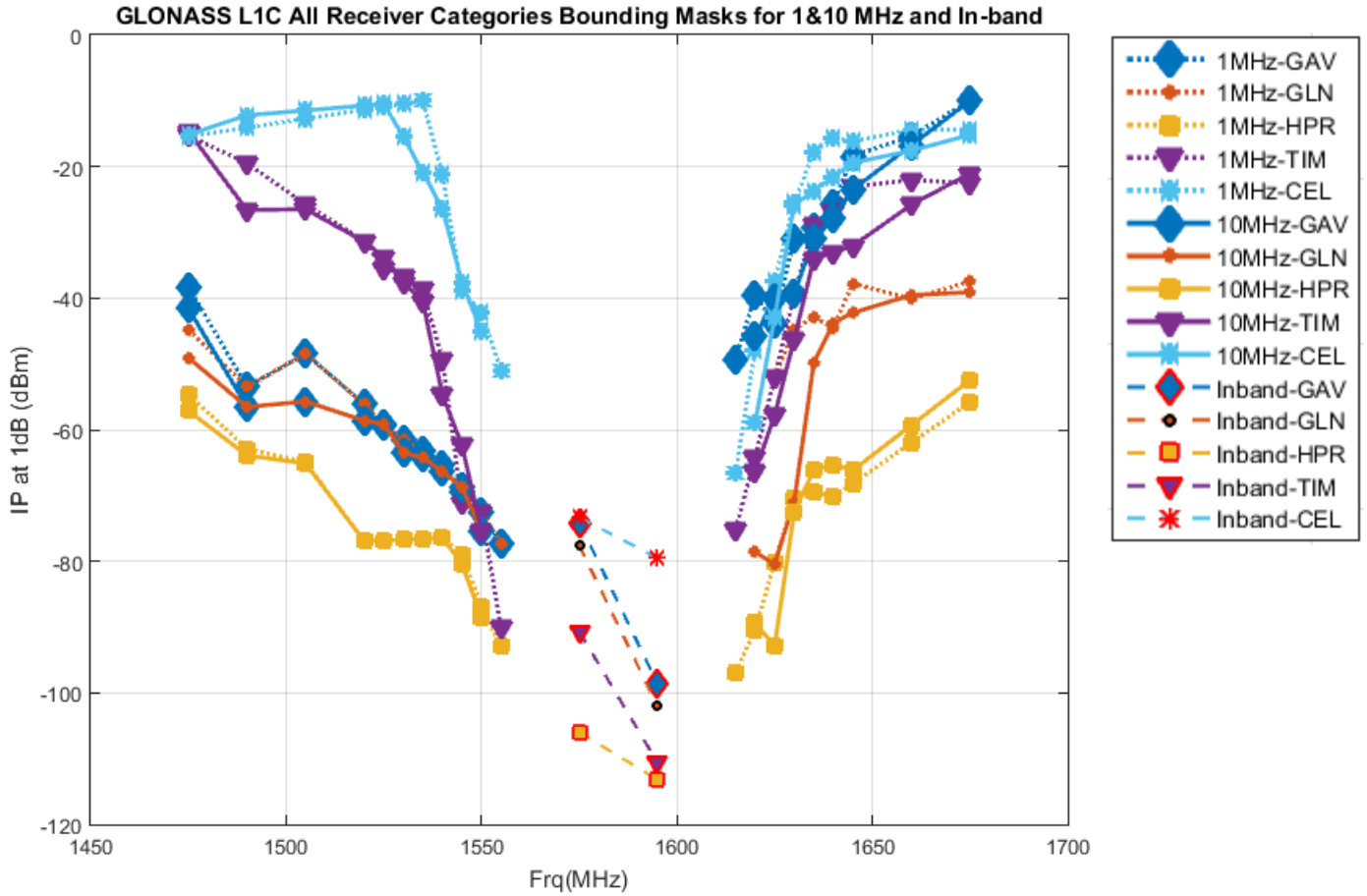
Summary of 10 MHz Bounding Masks GLONASS L1 C



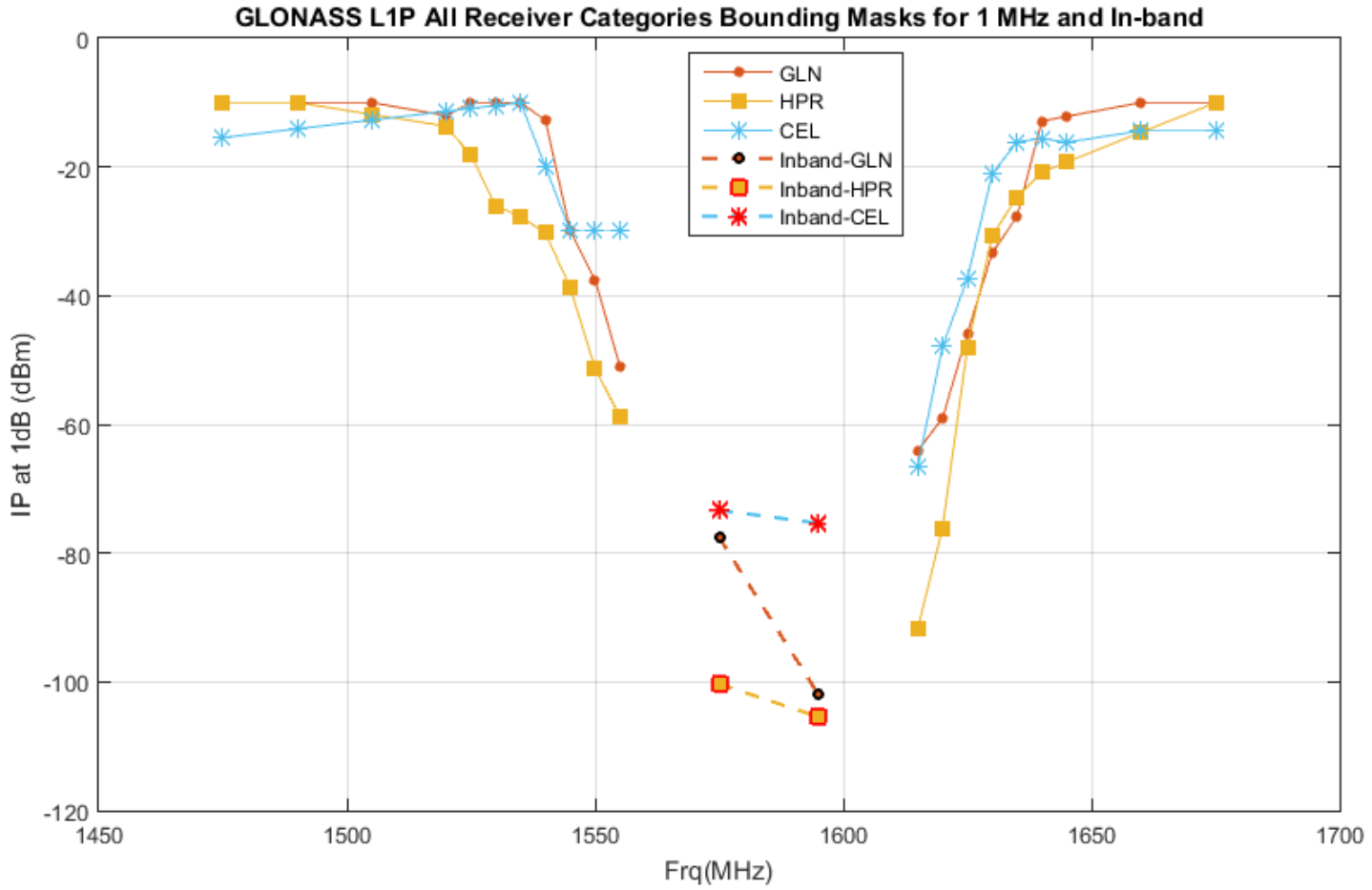
Summary of 1&10 MHz and In-band Bounding Masks GLONASS L1 C - HPR



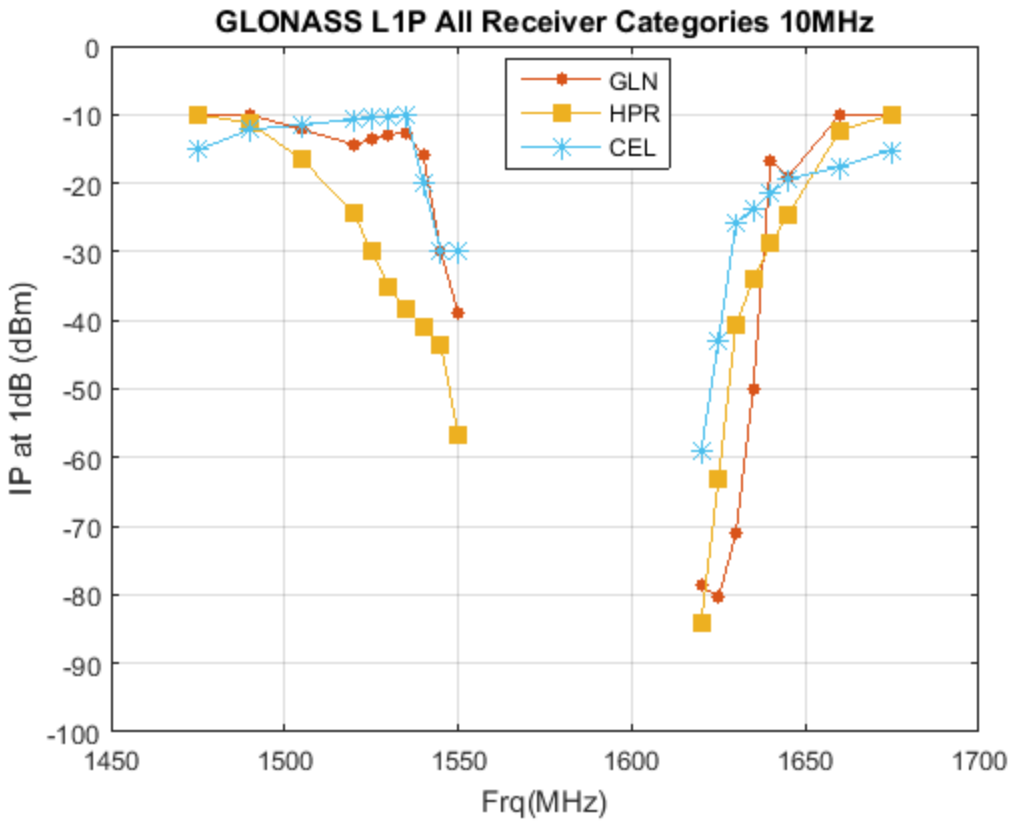
Summary of 1&10 MHz and In-band Bounding Masks GLONASS L1 C



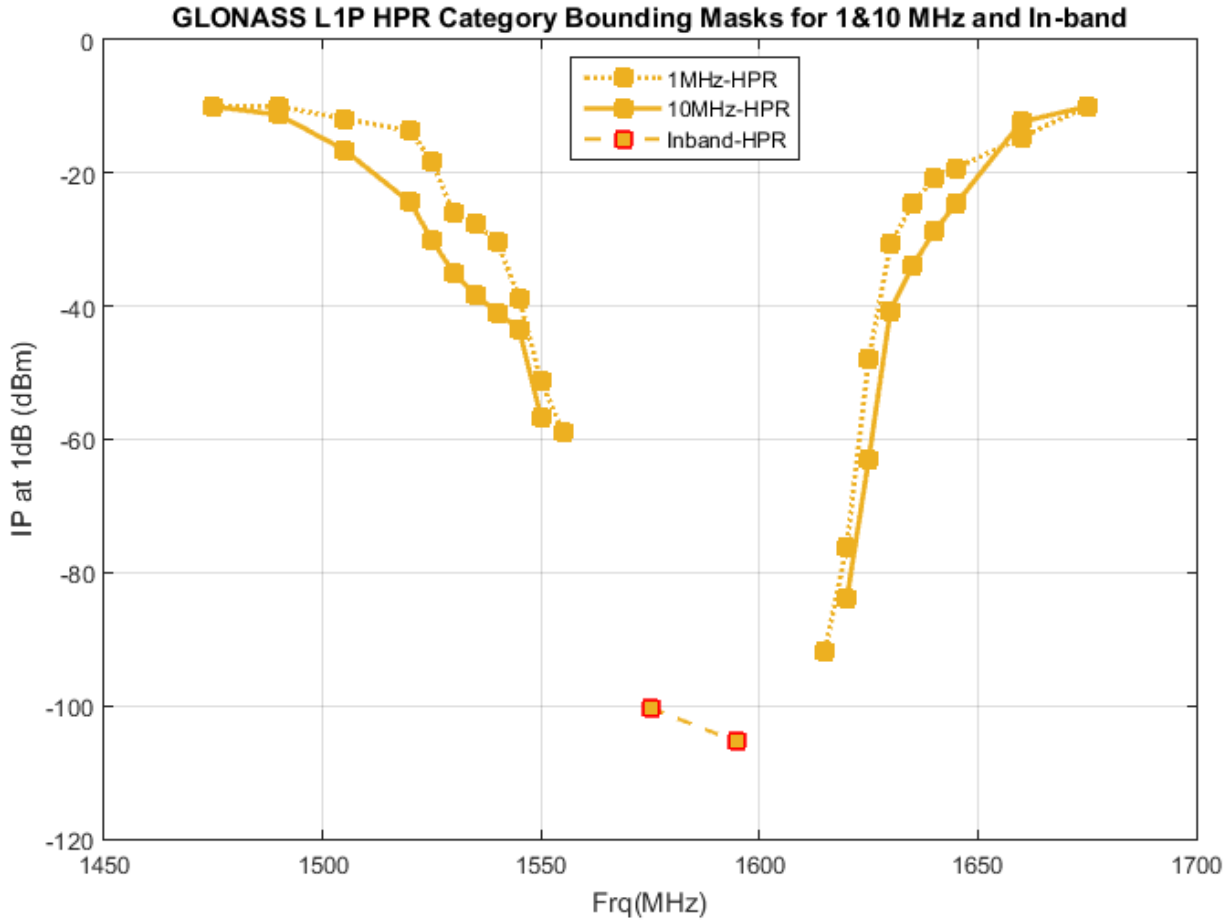
Summary of 1 MHz and In-band Bounding Masks GLONASS L1 P



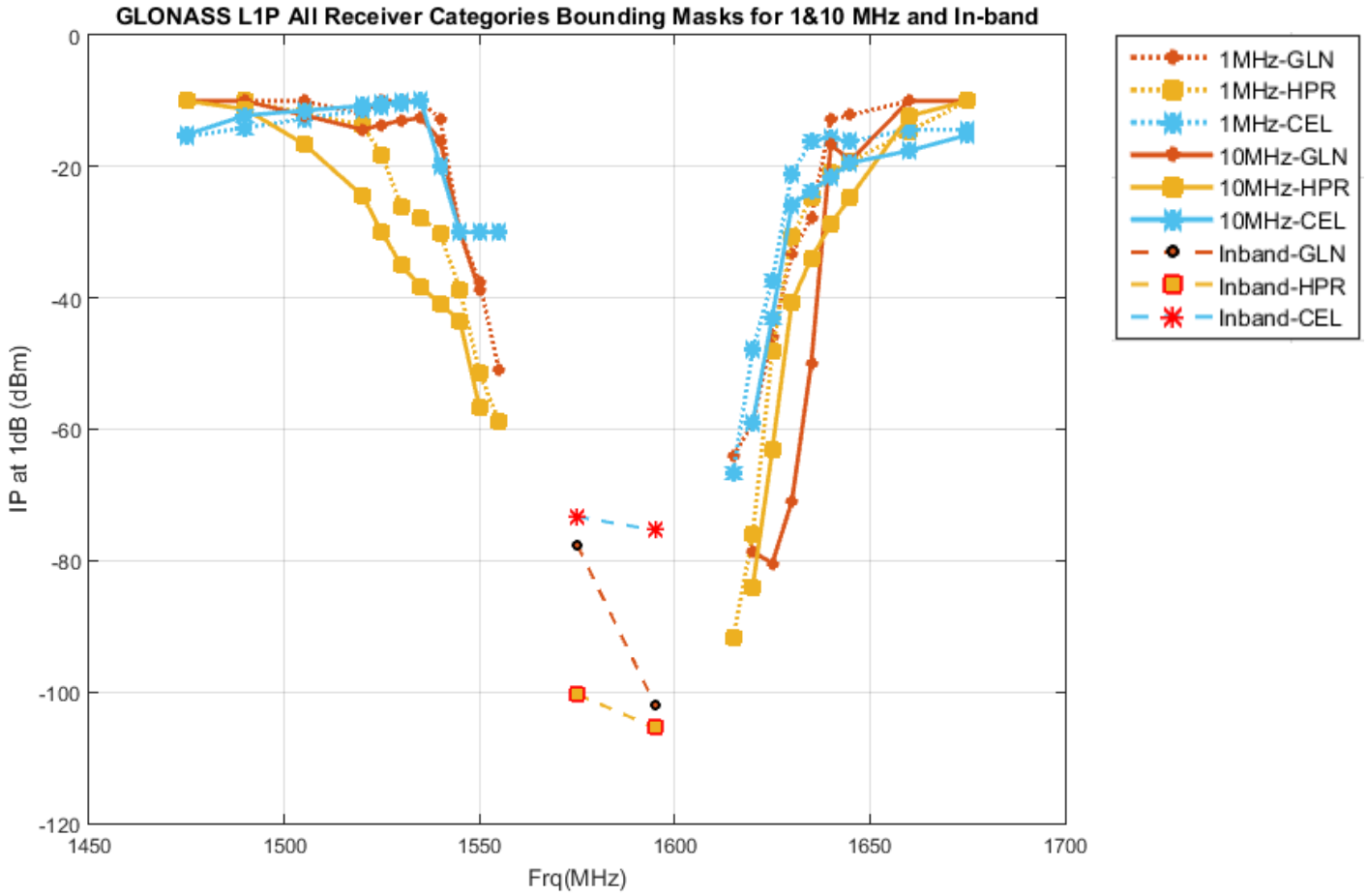
Summary of 10 MHz Bounding Masks GLONASS L1 P



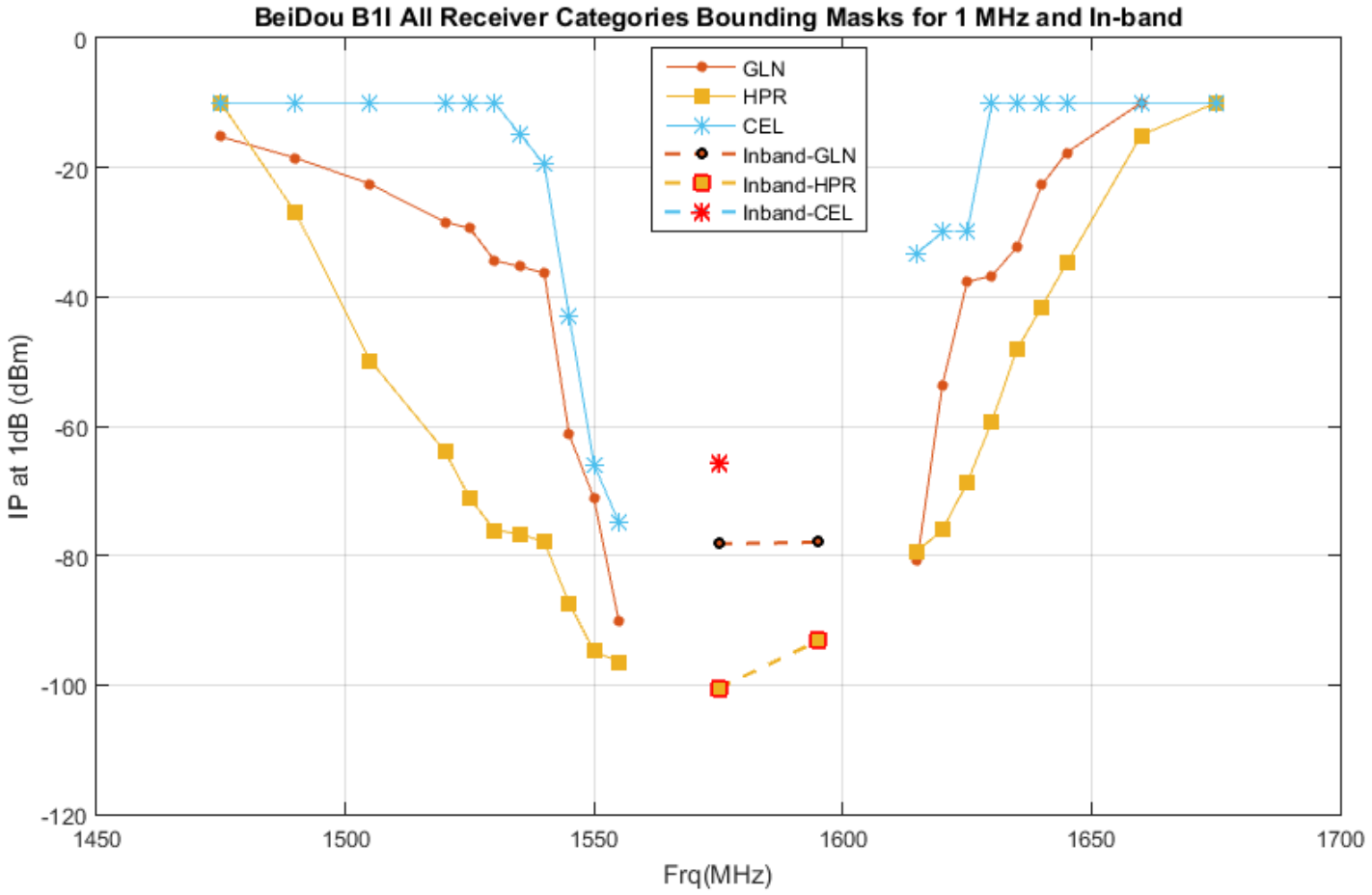
Summary of 1&10 MHz and In-band Bounding Masks GLONASS L1 P - HPR



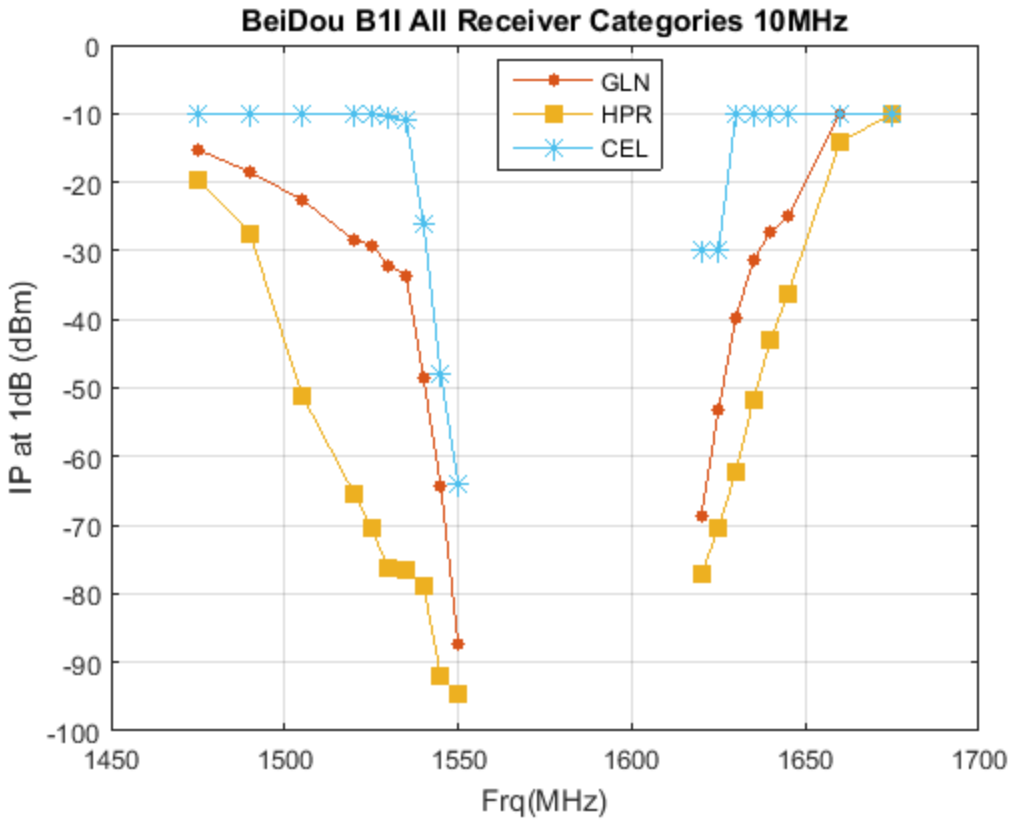
Summary of 1&10 MHz and In-band Bounding Masks GLONASS L1 P



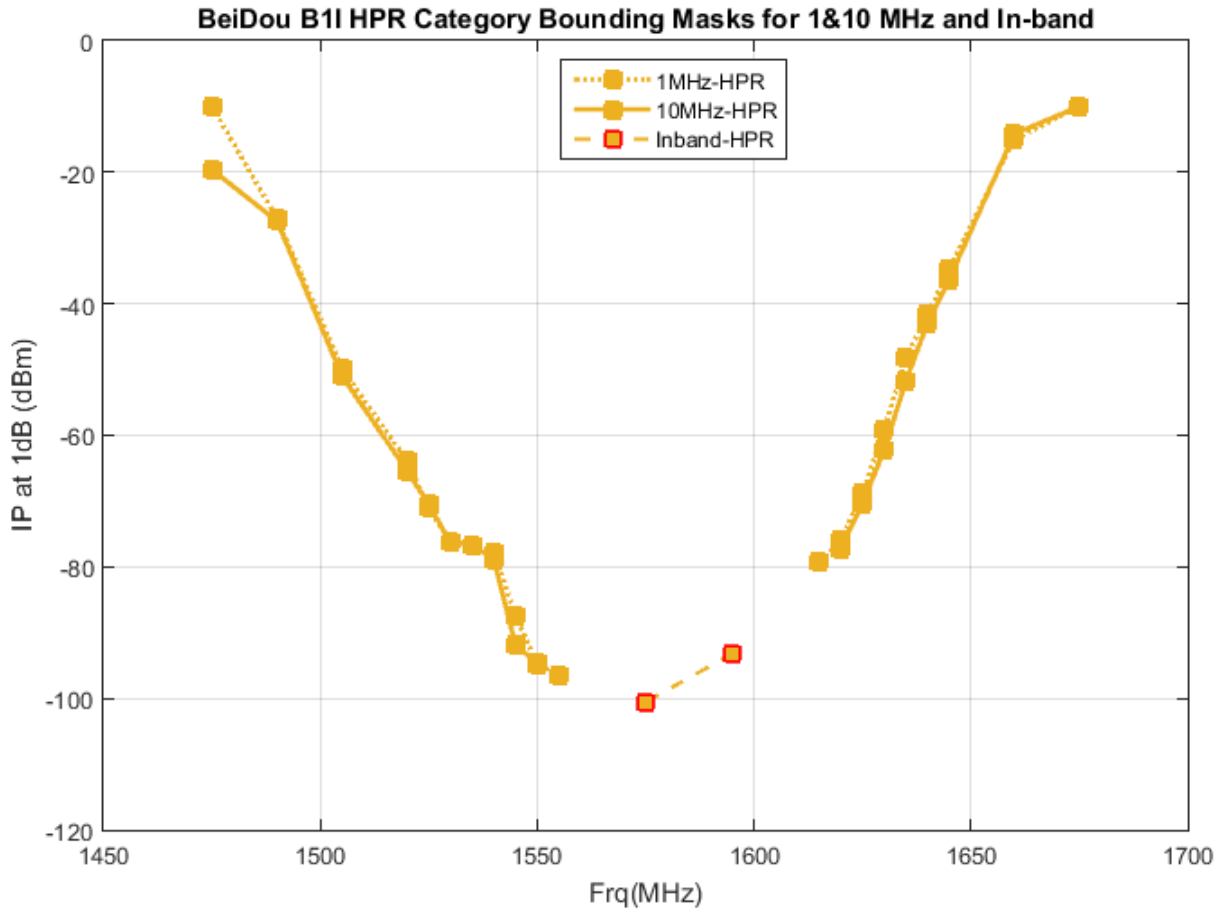
Summary of 1 MHz and In-band Bounding Masks BeiDou B1 I



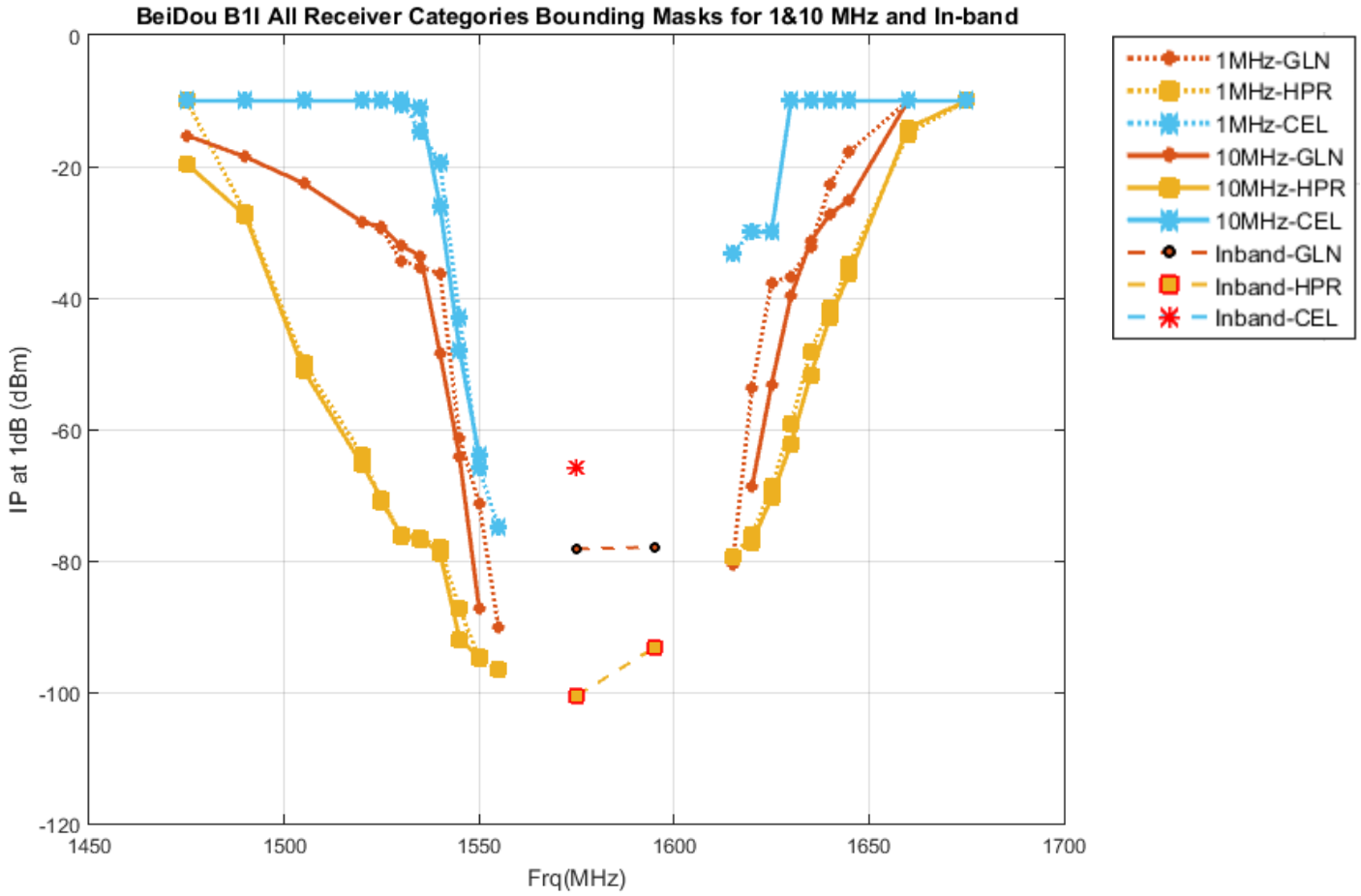
Summary of 10 MHz Bounding Masks BeiDou B1 I



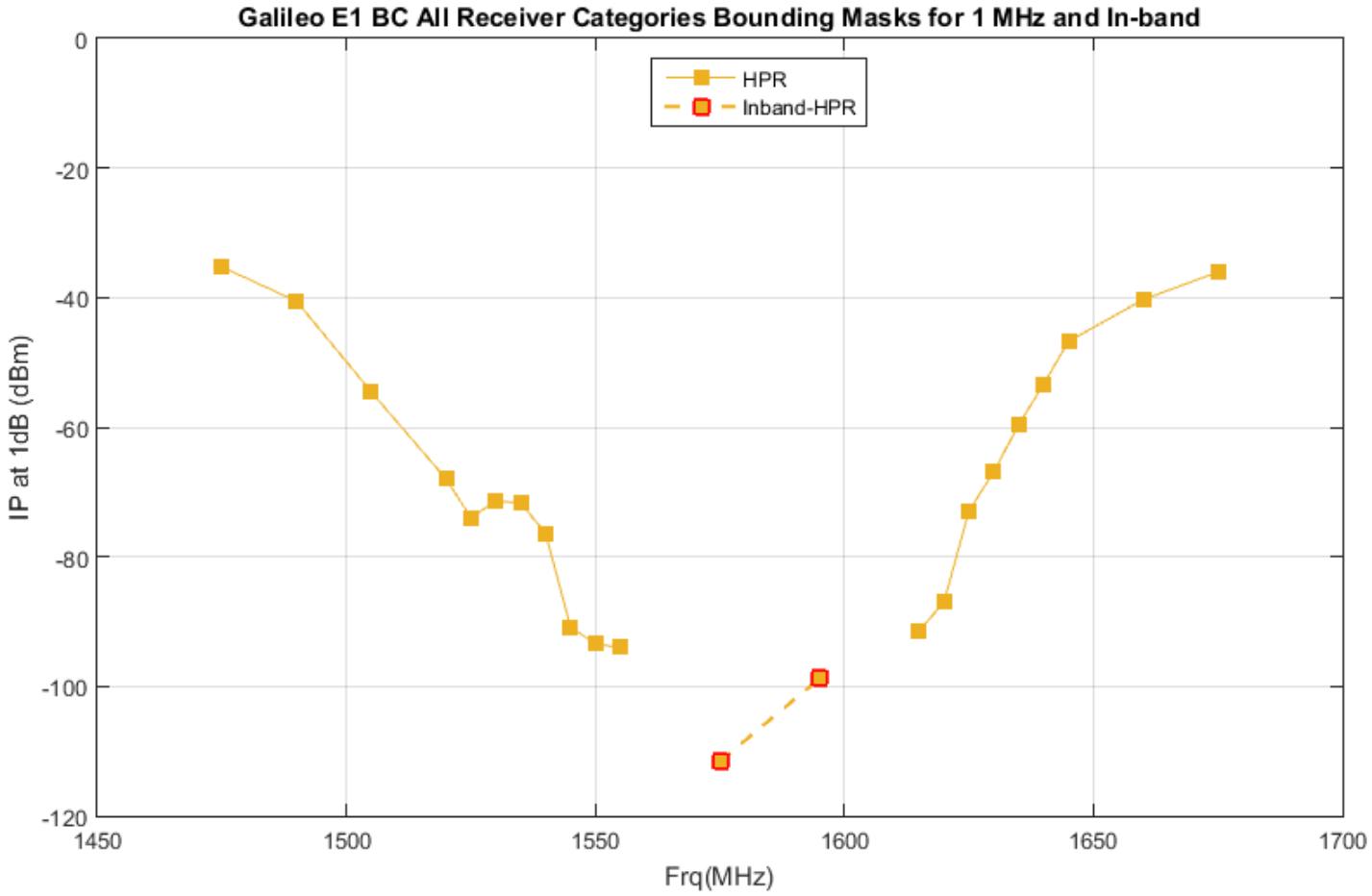
Summary of 1&10 MHz and In-band Bounding Masks BeiDou B1 I - HPR



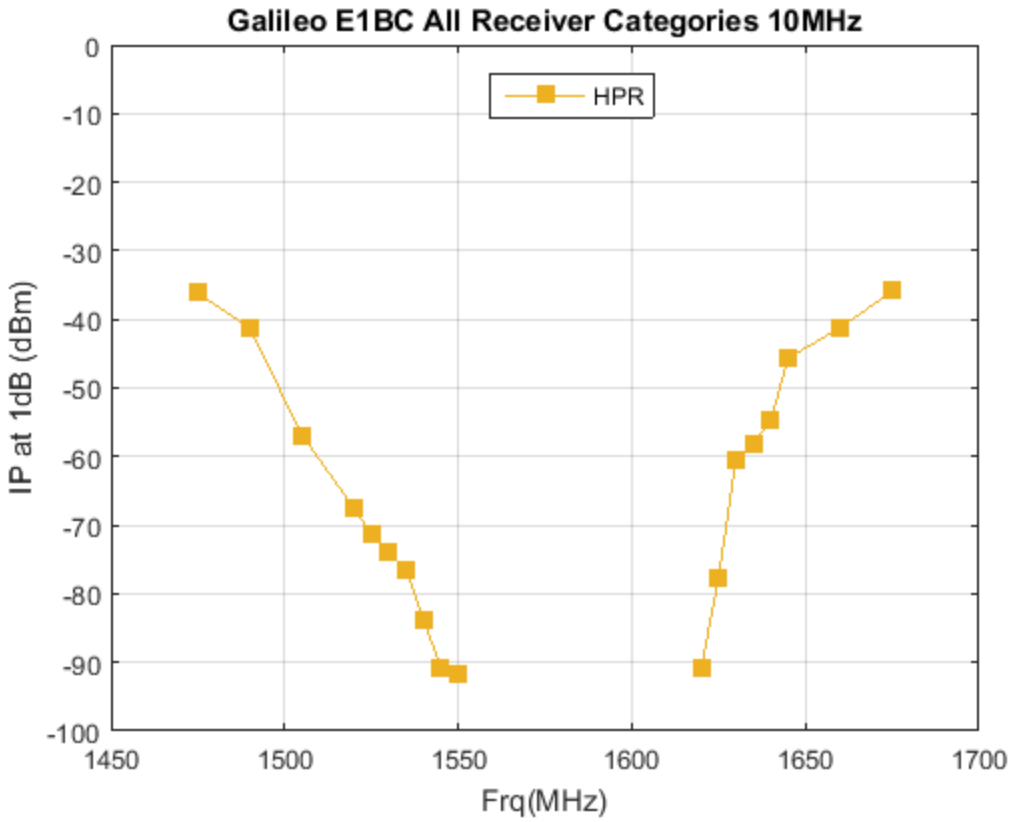
Summary of 1&10 MHz and In-band Bounding Masks BeiDou B1 I



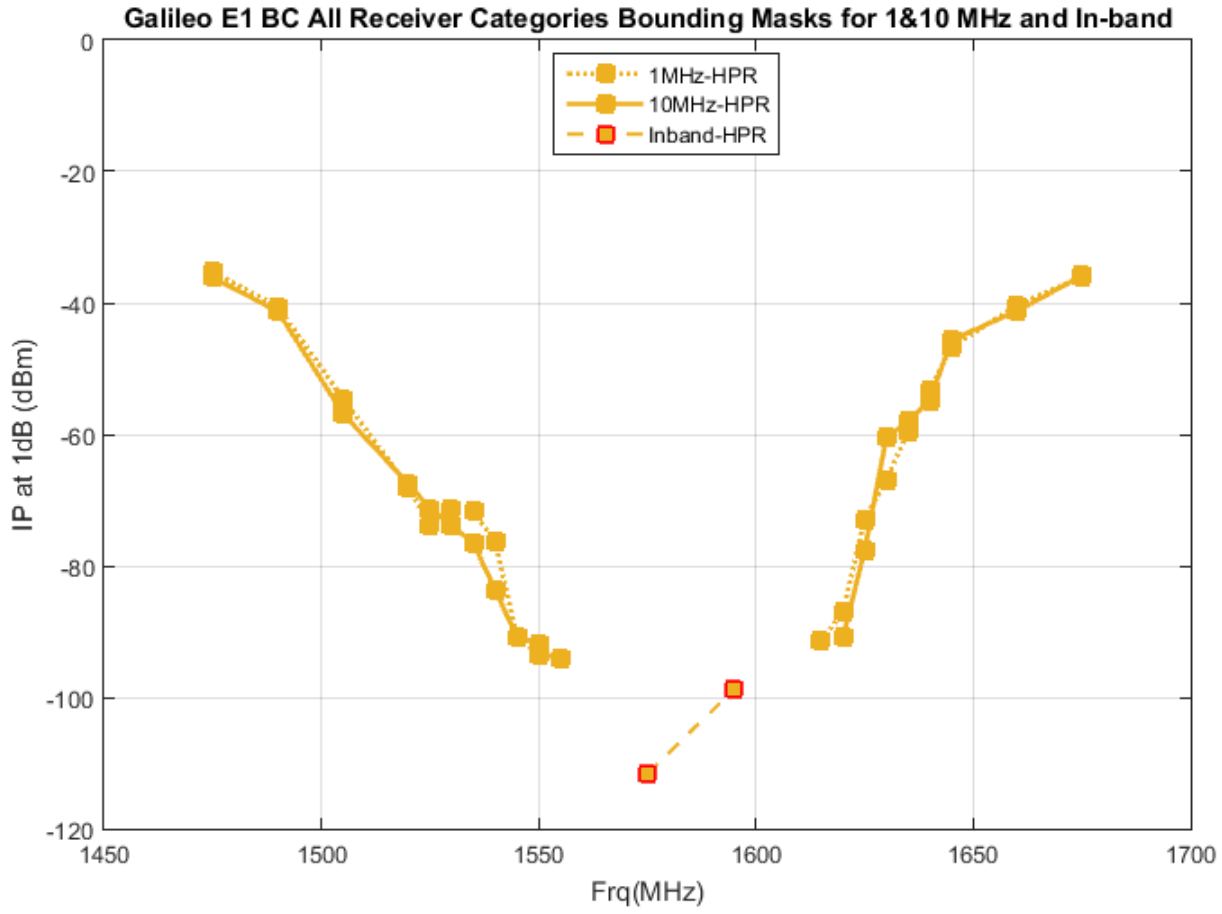
Summary of 1 MHz and In-band Bounding Masks Galileo E1 BC



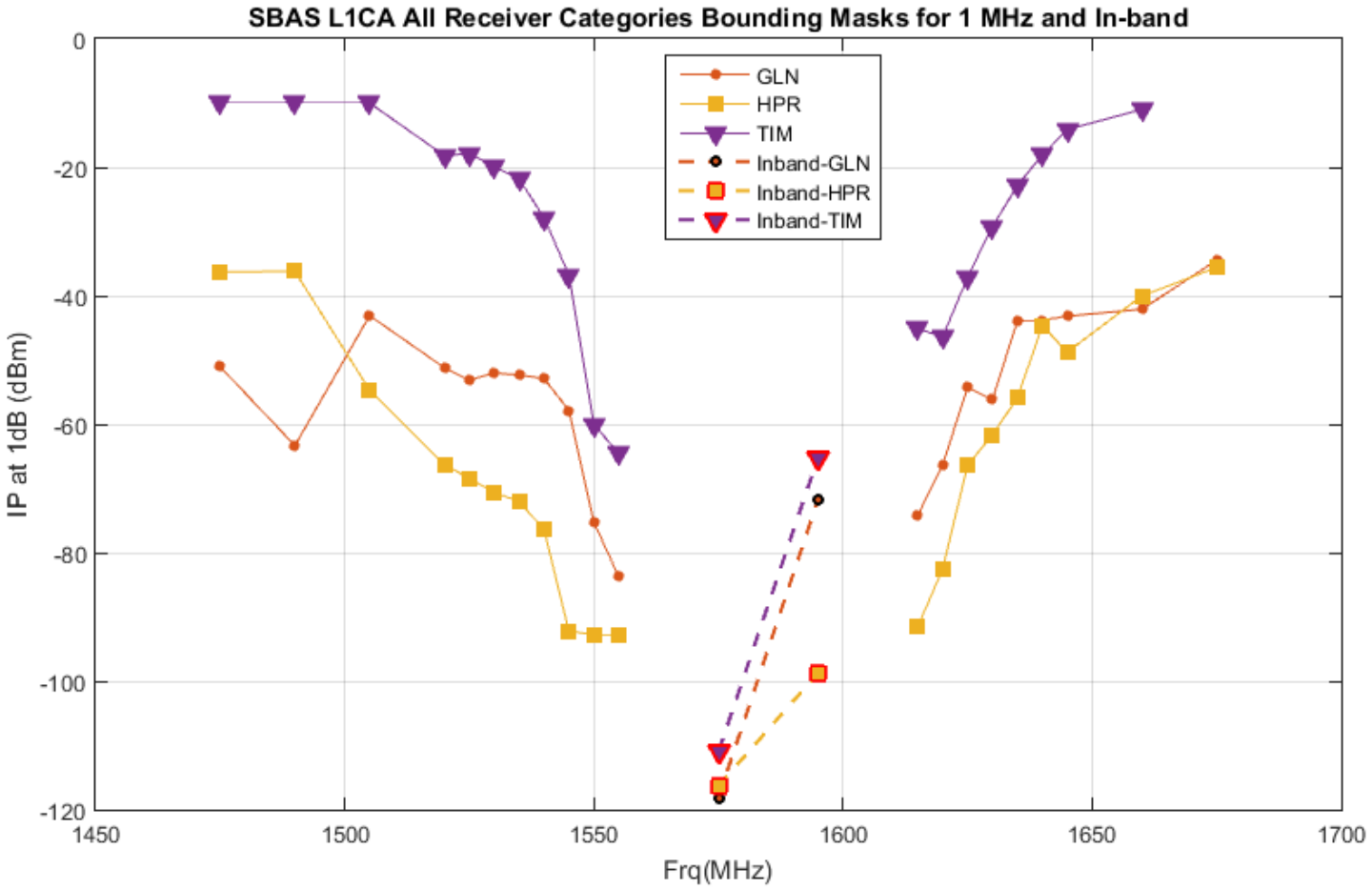
Summary of 10 MHz Bounding Masks Galileo E1 BC



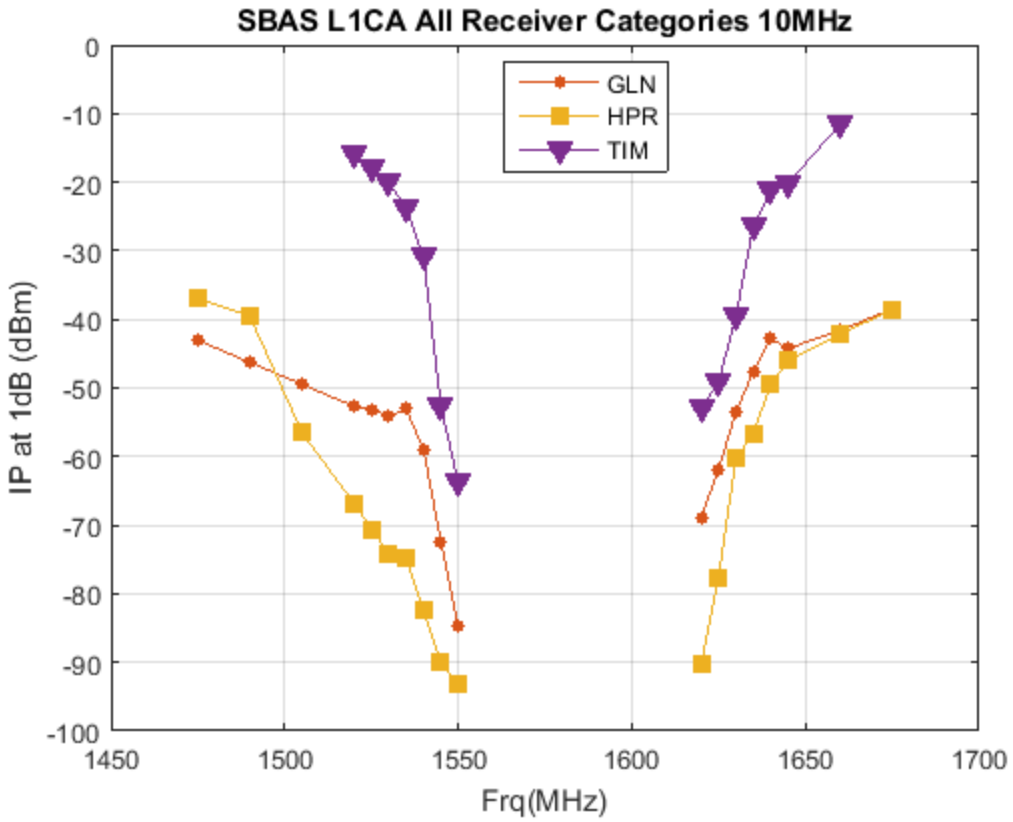
Summary of 1&10 MHz and In-band Bounding Masks Galileo E1 BC



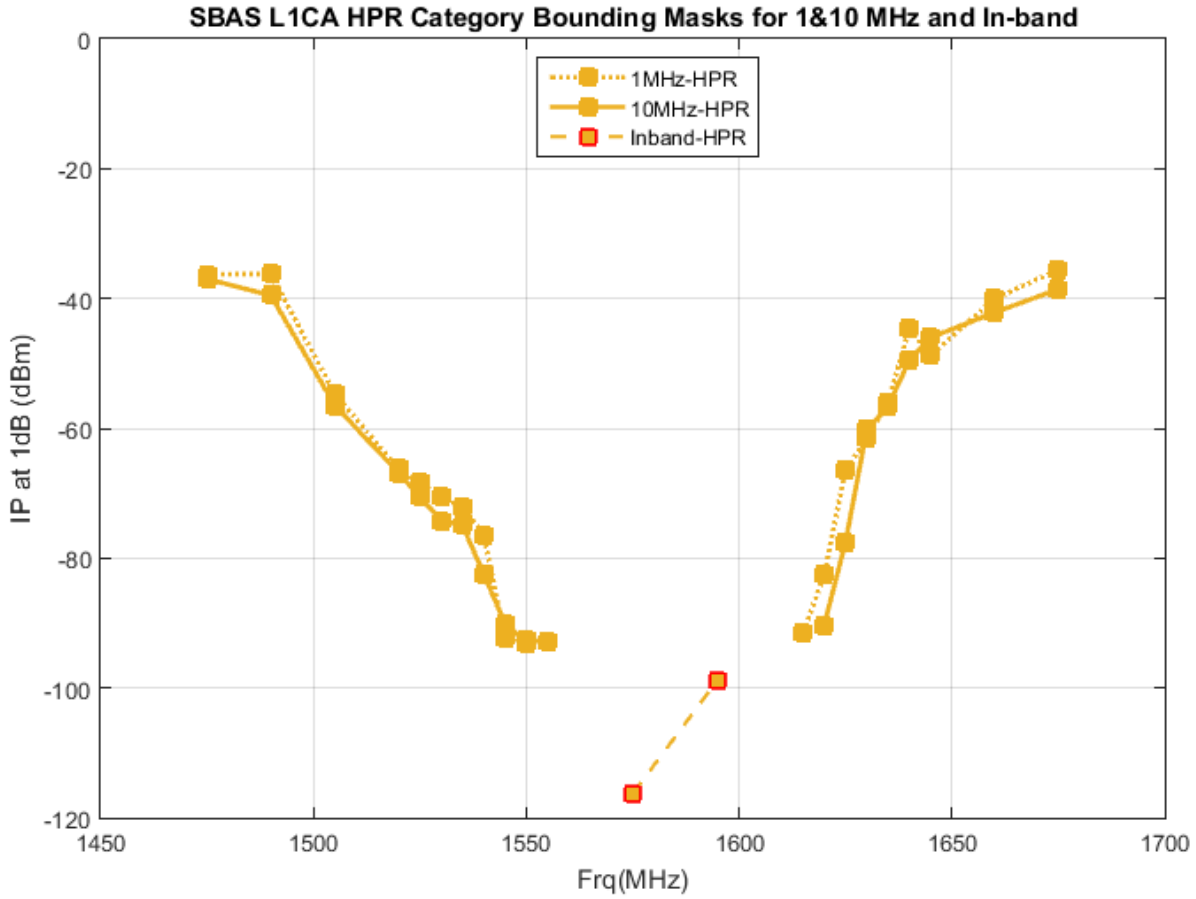
Summary of 1 MHz and In-band Bounding Masks SBAS L1 C/A



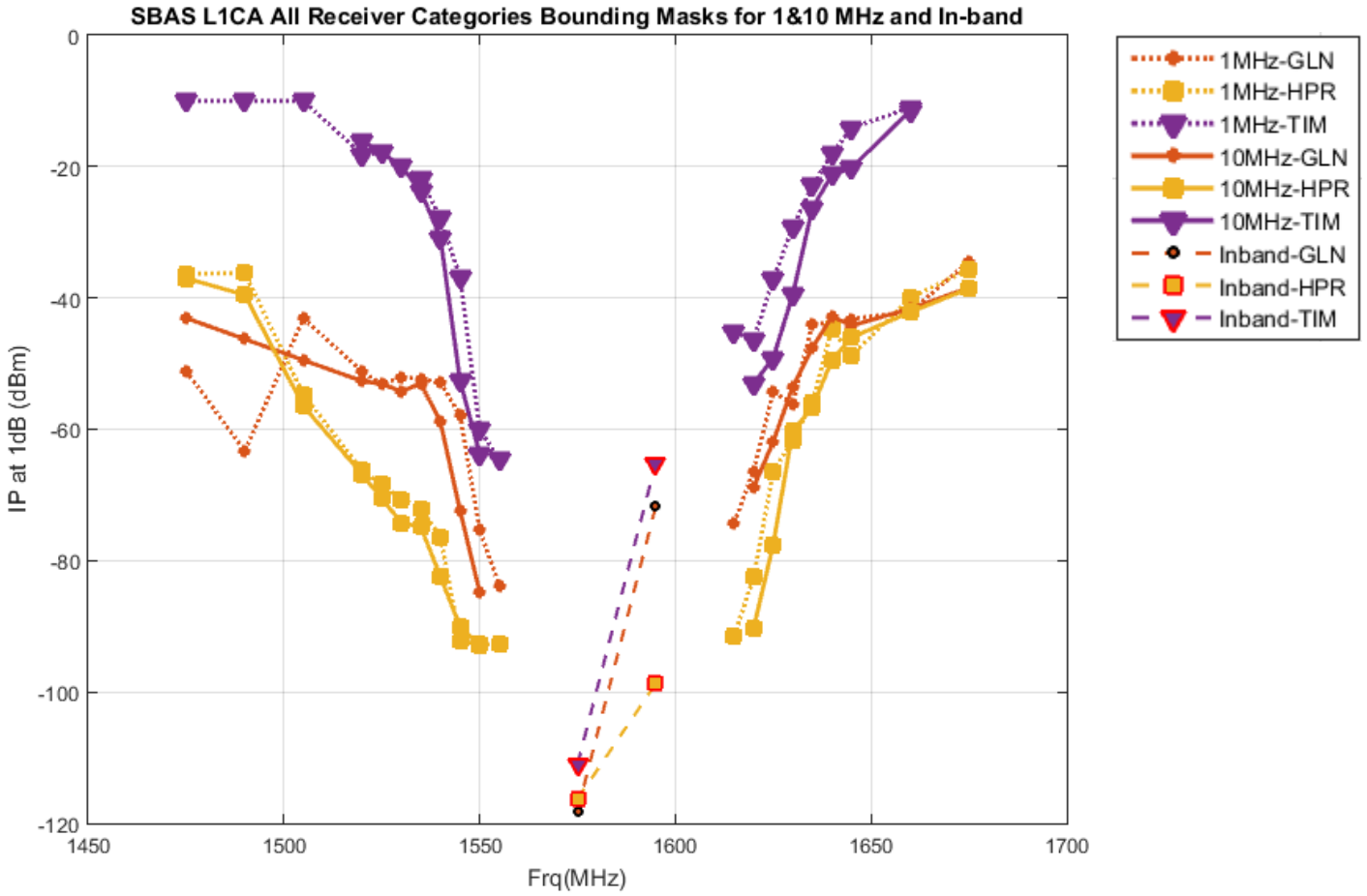
Summary of 10 MHz Bounding Masks SBAS L1 C/A



Summary of 1&10 MHz and In-band Bounding Masks SBAS L1 C/A - HPR



Summary of 1&10 MHz and In-band Bounding Masks SBAS L1 C/A



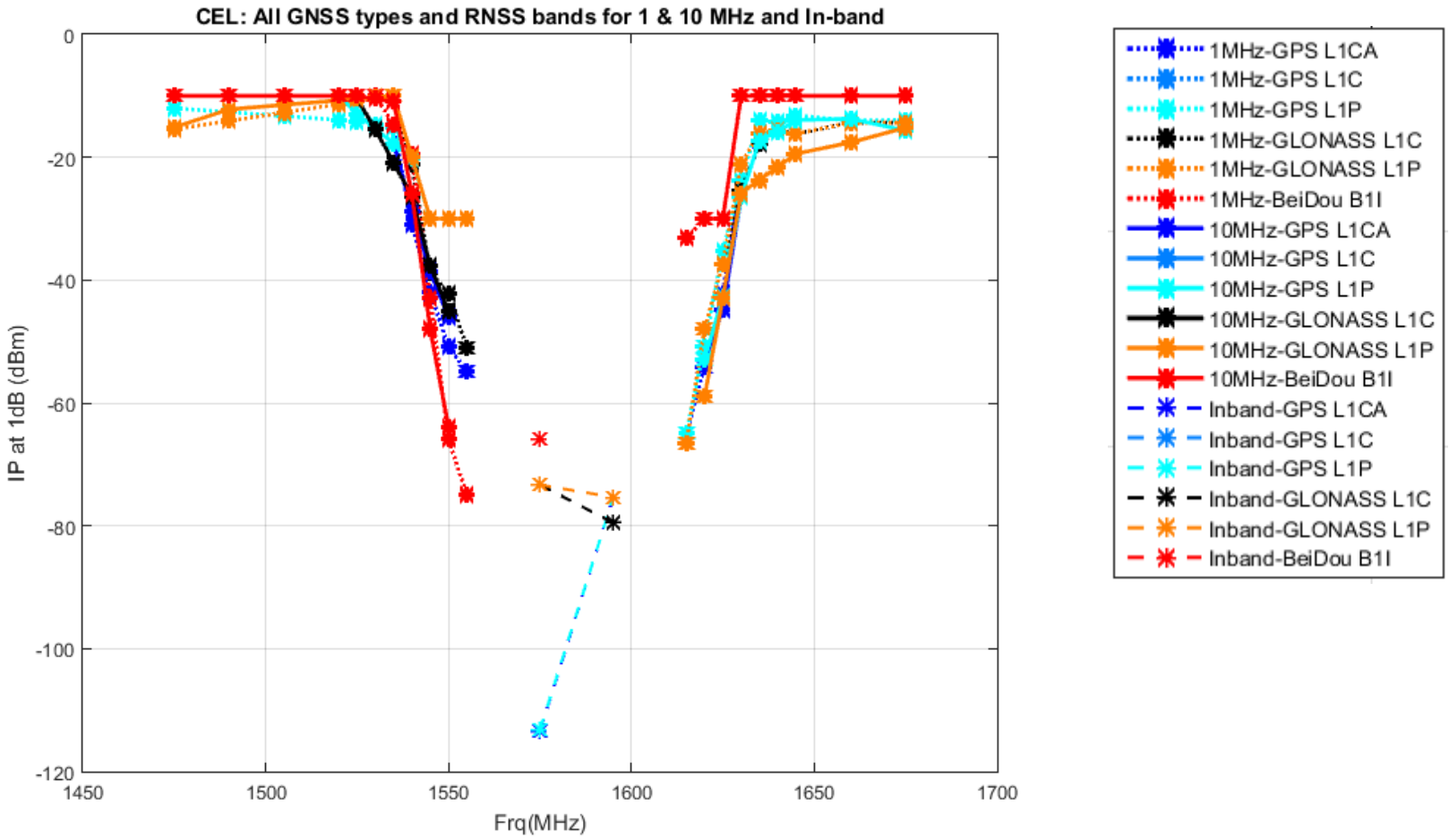
Summary of Radiated Test Results

- 1 MHz AWGN and 10 MHz LTE interference signals ITM bounds have been produced for all emulated GNSS signals
- Most bounding ITMs show little sensitivity to interference signal types (AWGN (1 MHz) and LTE (10 MHz))
- Certified aviation receiver mask does not bound the masks of the 6 civil receiver categories
- In-band interference 1-dB degradation levels are consistent with expectation (-110 to -120 dBm/MHz for the L1C/A ITMs)

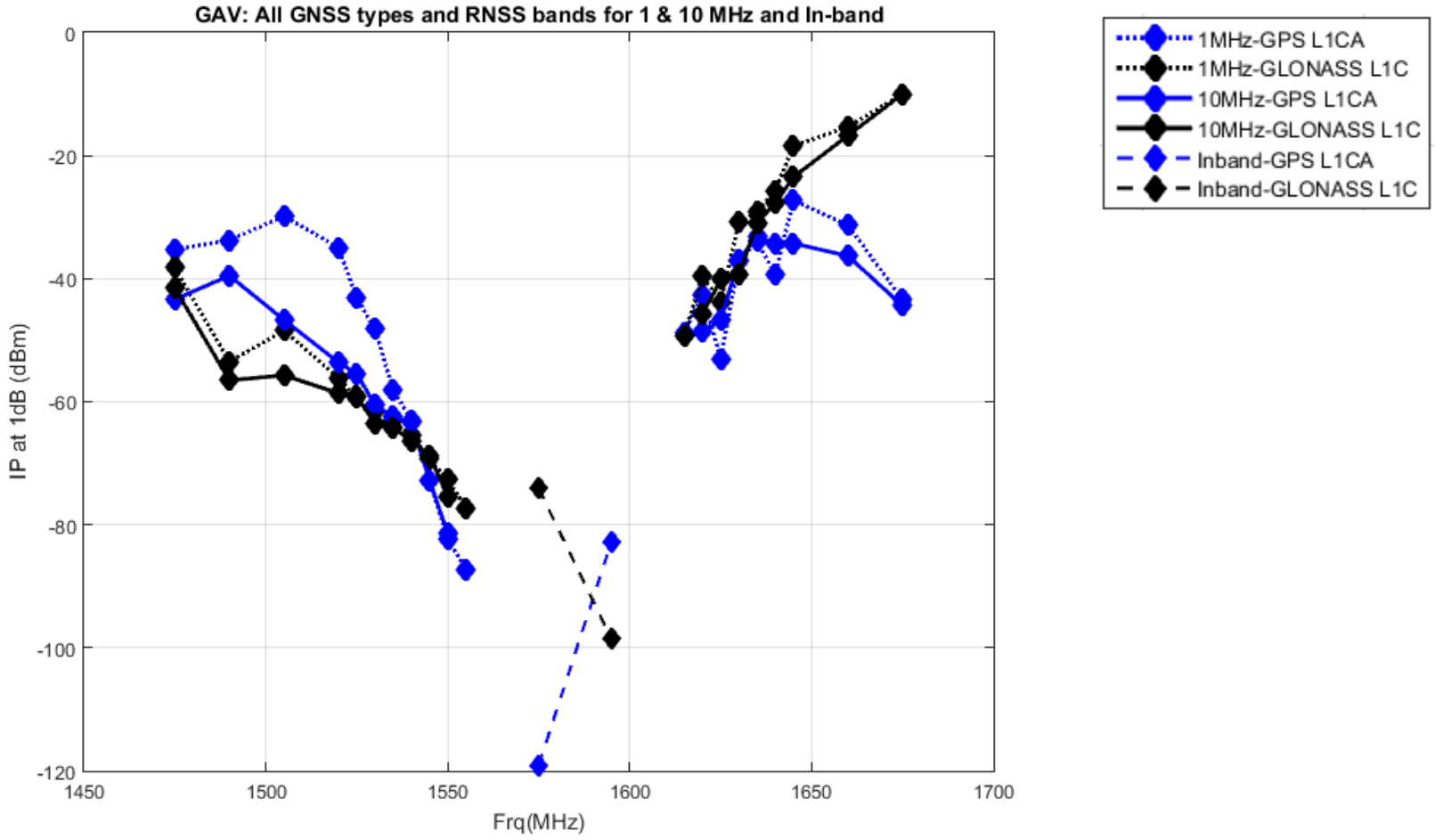
Questions?

Appendix

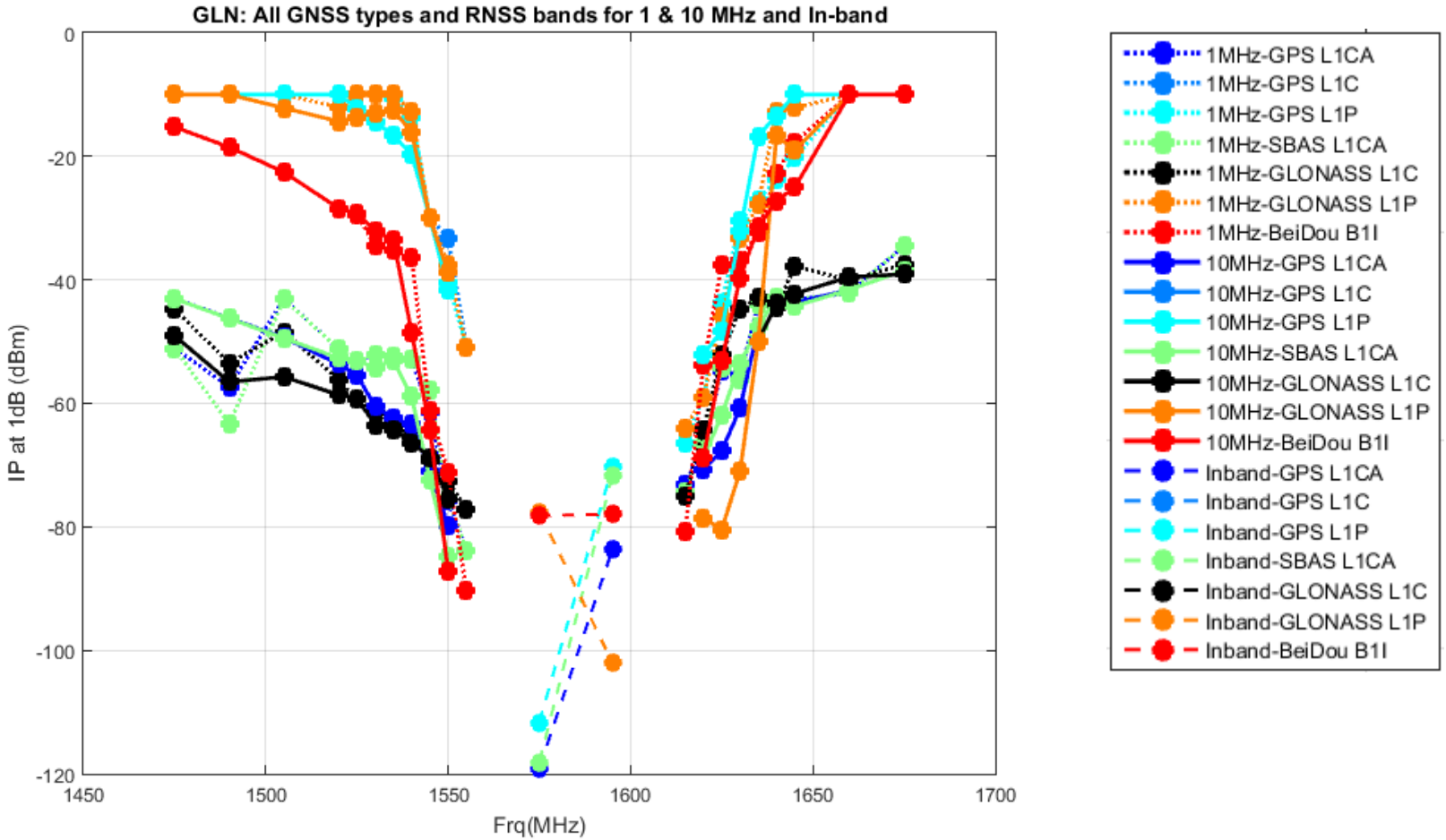
Cellular (1 &10 MHz and In-band) Summary of Bounding Masks



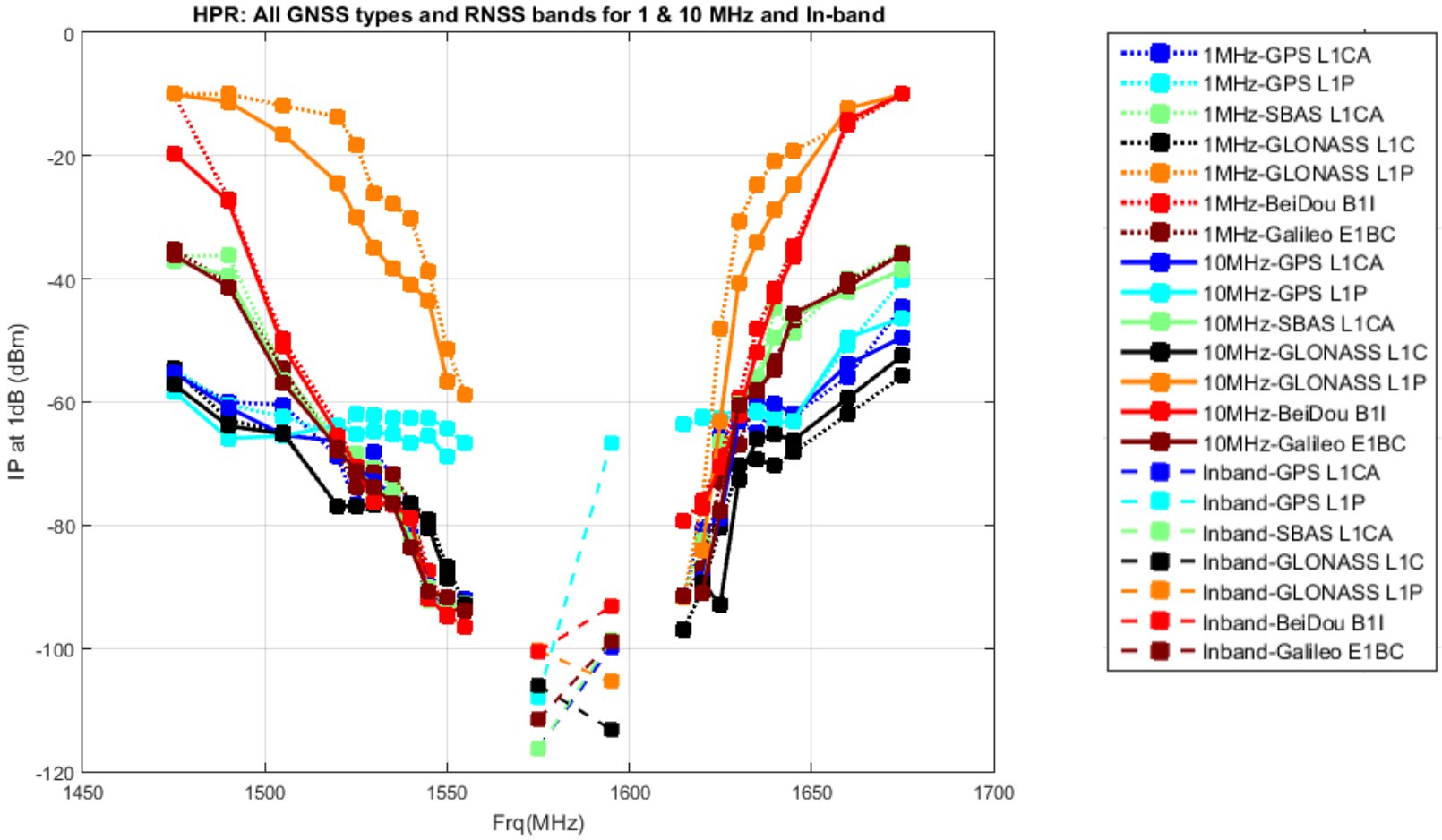
General Aviation (1 &10 MHz and In-band) Summary of Bounding Masks



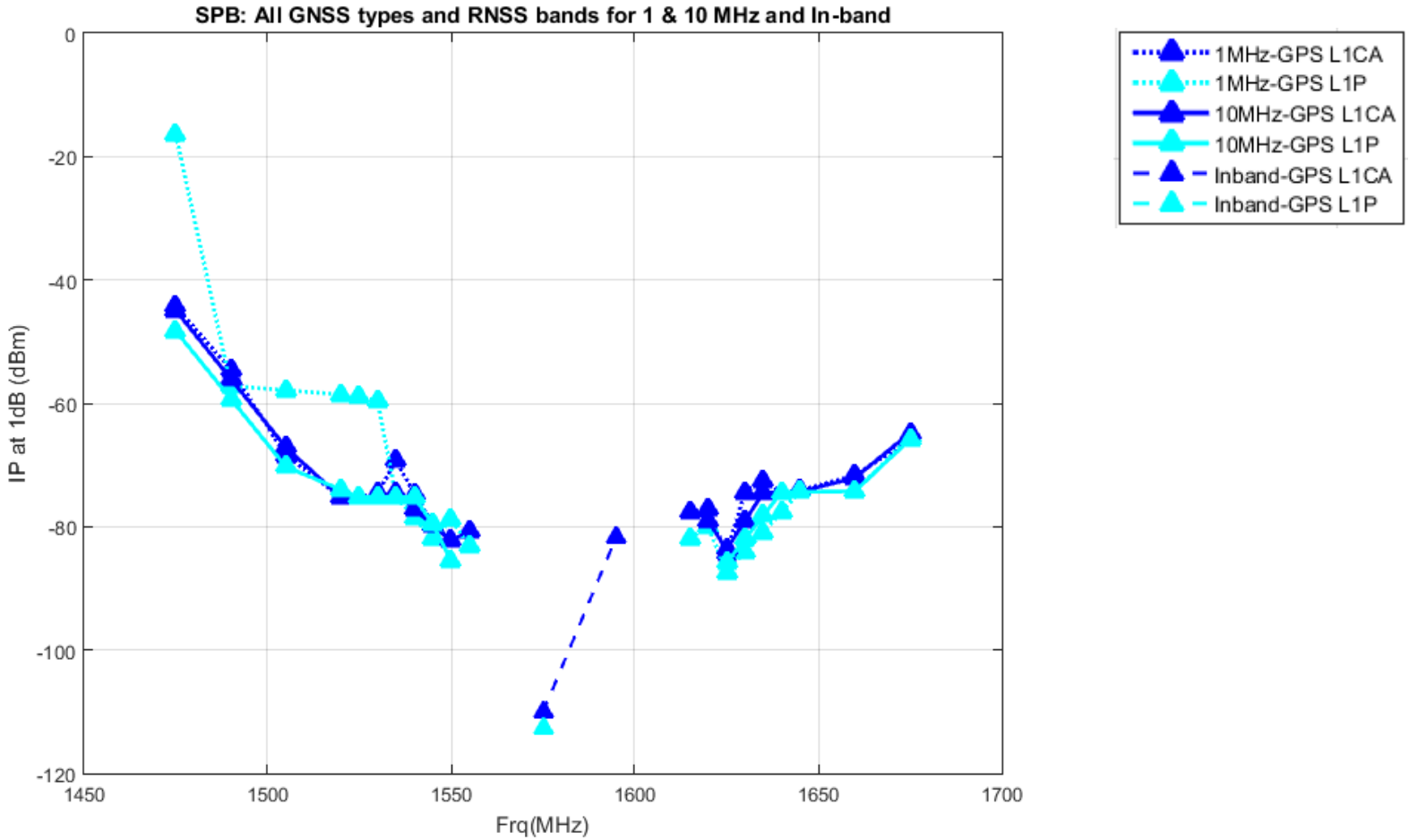
General Location Navigation (1 &10 MHz and In-band) Summary of Bounding Masks



High Precision (1 &10 MHz and In-band) Summary of Bounding Masks



Space Based (1 &10 MHz and In-band) Summary of Bounding Masks



Timing (1 &10 MHz and In-band) Summary of Bounding Masks