DOT GPS Adjacent Band Compatibility Assessment

UN International Committee on GNSS (ICG)

6th IDM Workshop

May 9-10, 2017

GPS Adjacent Radiofrequency Band Compatibility Assessment

- Identify adjacent band transmit power levels that can be tolerated by existing GNSS receivers for civil applications [excluding certified aviation applications - those are considered in a parallel FAA effort]
- Effort Led By DOT/OST-R/Volpe Center
- Accomplish this through:
  - An open and transparent approach
  - GNSS Receiver and Antenna Testing – Radiated, Wired, and Antenna characterization
  - Development of 1 dB Interference Tolerance Masks (ITMs)
  - Development of generic transmitter (base station and handheld) scenarios
  - Inverse and propagation modeling / use case scenarios

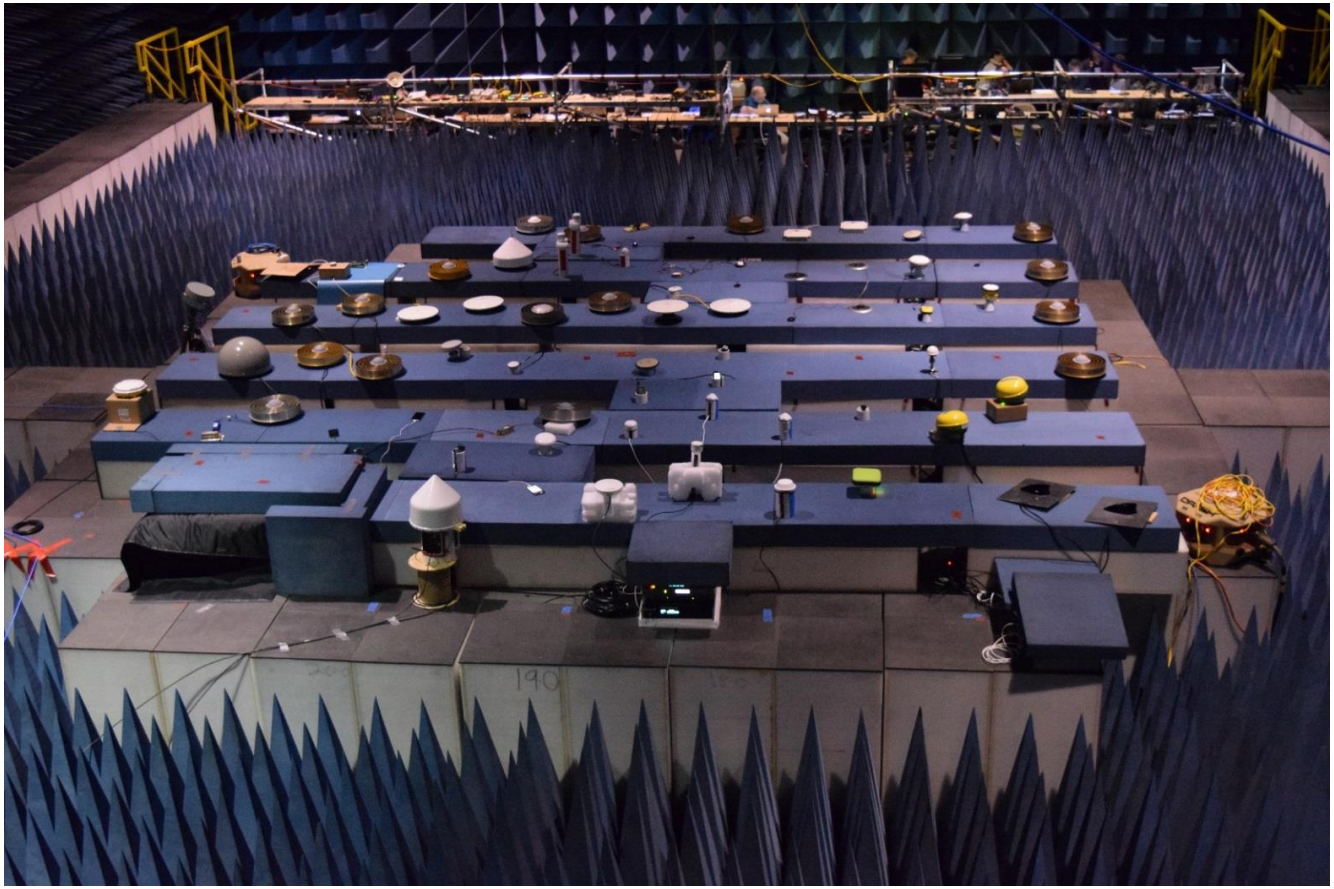
Major Milestones

- Use case data collection effort with Federal Partners and Industry
- Released a public GNSS receiver test plan and developed an in depth GNSS receiver test procedure
- Carried out GNSS testing
  - Radiated test data: collected in an anechoic chamber [White Sands Missile Range (WSMR)]
  - Conducted test data: collected in a laboratory environment [Zeta Associates]
  - Antenna characterization data [The MITRE Corporation]
    - Integrated antennas: collected in an open sky environment
    - External antennas: collected in an anechoic chamber
- Produced 1 dB Interference Tolerance Mask (ITM) results
- Developed use case scenarios and conducted inverse modeling to Determine power levels that can be tolerated
- For more detail see: http://www.gps.gov/spectrum/ABC/

Radiated Testing Overview

- GNSS 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
- Participation included DOT's federal partners/agencies (USCG, NASA, NOAA, USGS, and FAA) and GPS manufacturers (GM, u-blox, NovAtel, Trimble, John Deere, UNAVCO)
  - 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, In-band and adjacent band (Type 1)
  - 10 MHz Long Term Evolution (LTE) (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

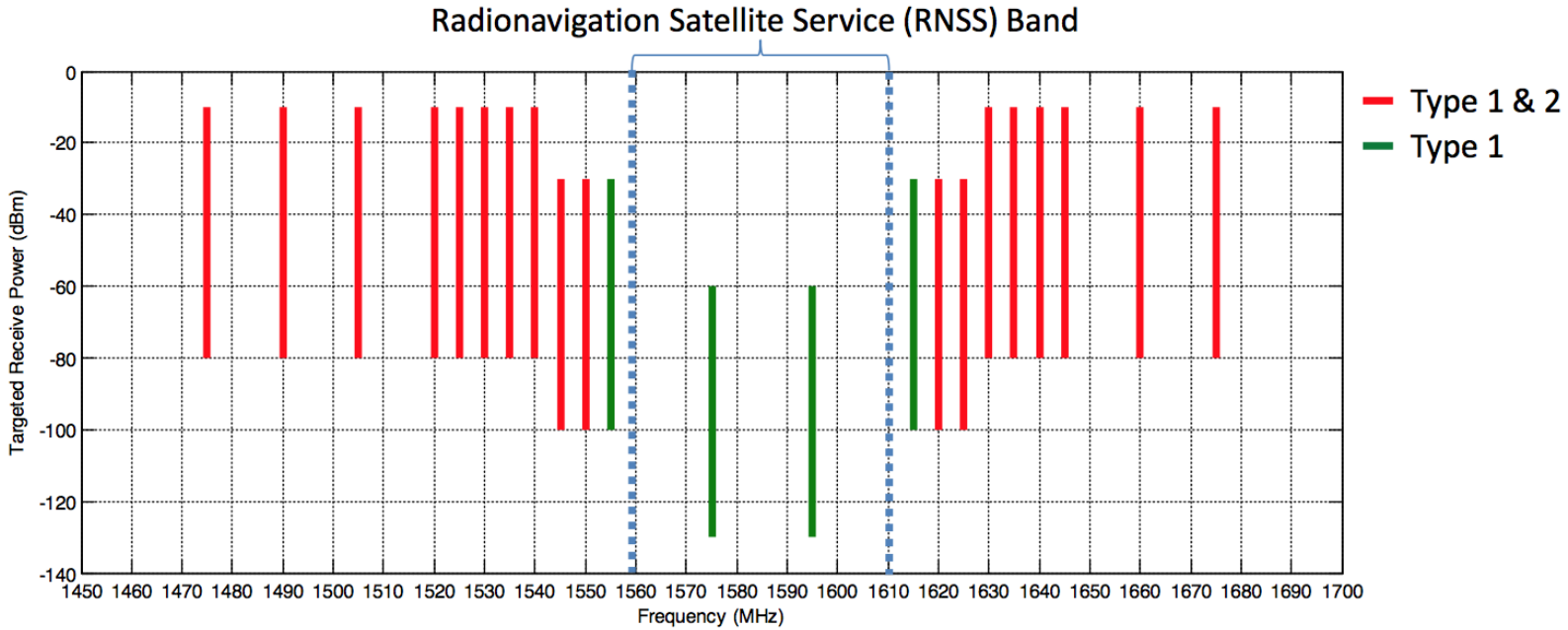
Test Chamber Setup and Tested Signals



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

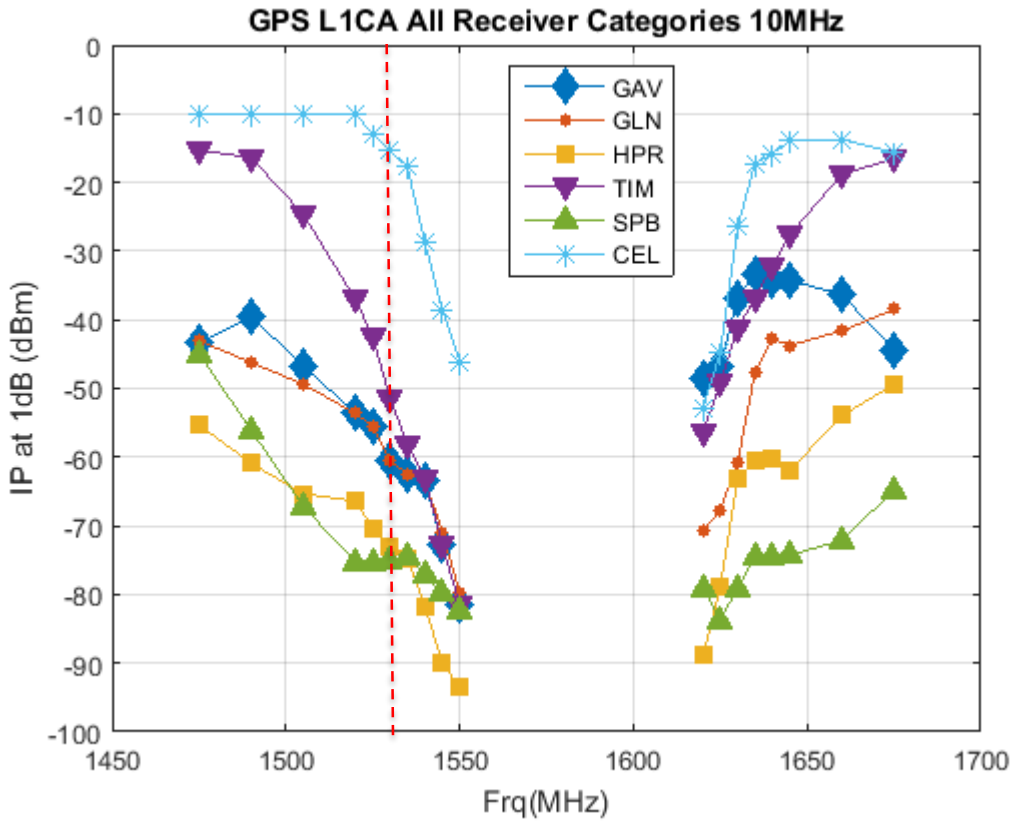
Interference Test Signal Profiles

- Data collected to develop ITM for receivers
  - Carrier signal to noise density ratio (CNR) recorded over varying interference power levels at numerous interference center frequencies
- Data processed to produce ITM



Interference Test Signal Frequencies and Power Profiles

Summary of 10 MHz Bounding Masks GPS L1 C/A



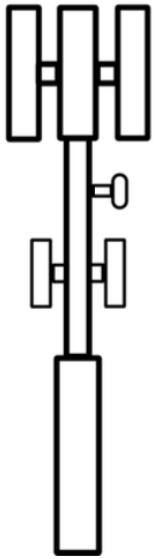
Category	ITM at 1530 MHz (dBm)
GAV - General Aviation (non certified)	-61.0
GLN - General Location/Navigation	-60.5
HPR - High Precision & Networks	-73.0
TIM - Timing	-59.4
SPB - Space Based	-73.5
CEL - Cellular	-15.3

Inverse Modeling/Transmit Power Levels

- Base Station Models
  - Report ITU-R M.2292 – 4G network characteristics for various deployments
  - Recommendation ITU-R F.1336 – antenna characteristics
- Handset/Mobile Device Models
  - 23 dBm EIRP, isotropic transmit antenna, vertical polarization, 2 meter height
- Propagation Loss Models
  - Free-space path loss
  - Two-ray path loss model is expected to show larger impact regions
  - Irregular terrain model will be considered in the future

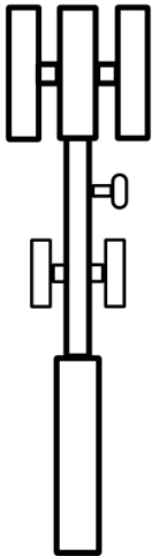
ITU-R: International Telecommunication Union Radiocommunication

ITU-R M.2292 Macro Base Stations



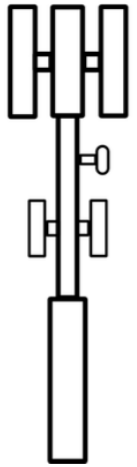
Macro Rural

- 18 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 58/61/61 dBm
- 30 m height
- 3 deg downtilt
- > 3 km cell radius



Macro Suburban

- 16 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 56/59/59 dBm
- 30 m height
- 6 deg downtilt
- 0.5 – 3 km cell radius

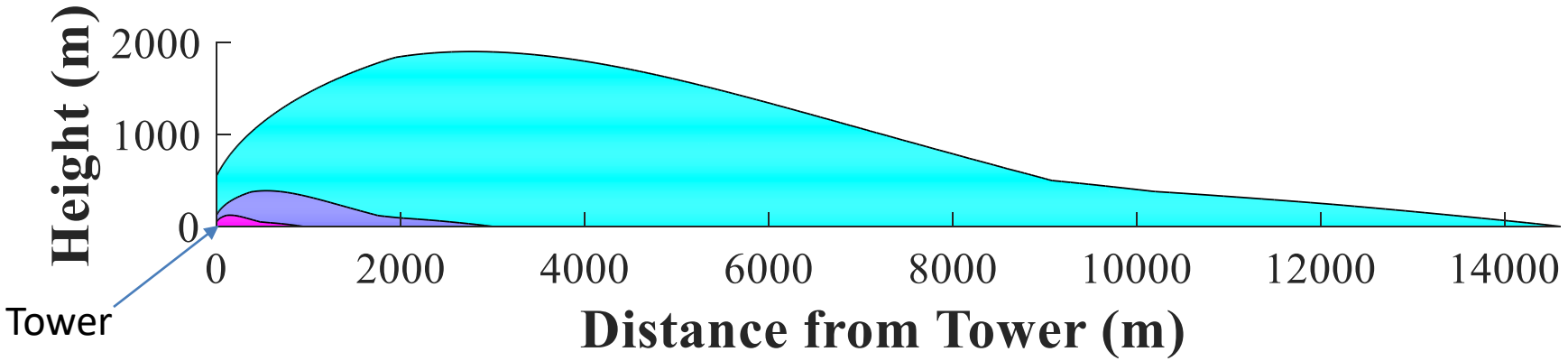


Macro Urban

- 16 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 56/59/59 dBm
- 25 m height
- 10 deg downtilt
- 0.25 – 1 km cell radius

Macro Urban Transmitter*
High Precision Receiver, 1530 MHz

- EIRP = 59 dBm
- Sectors = 3
- Tower height = 25 m (82’)
- Downtilt = 10 degrees
- Frequency = 1530 MHz



≥ 1 dB C/N_0 degradation

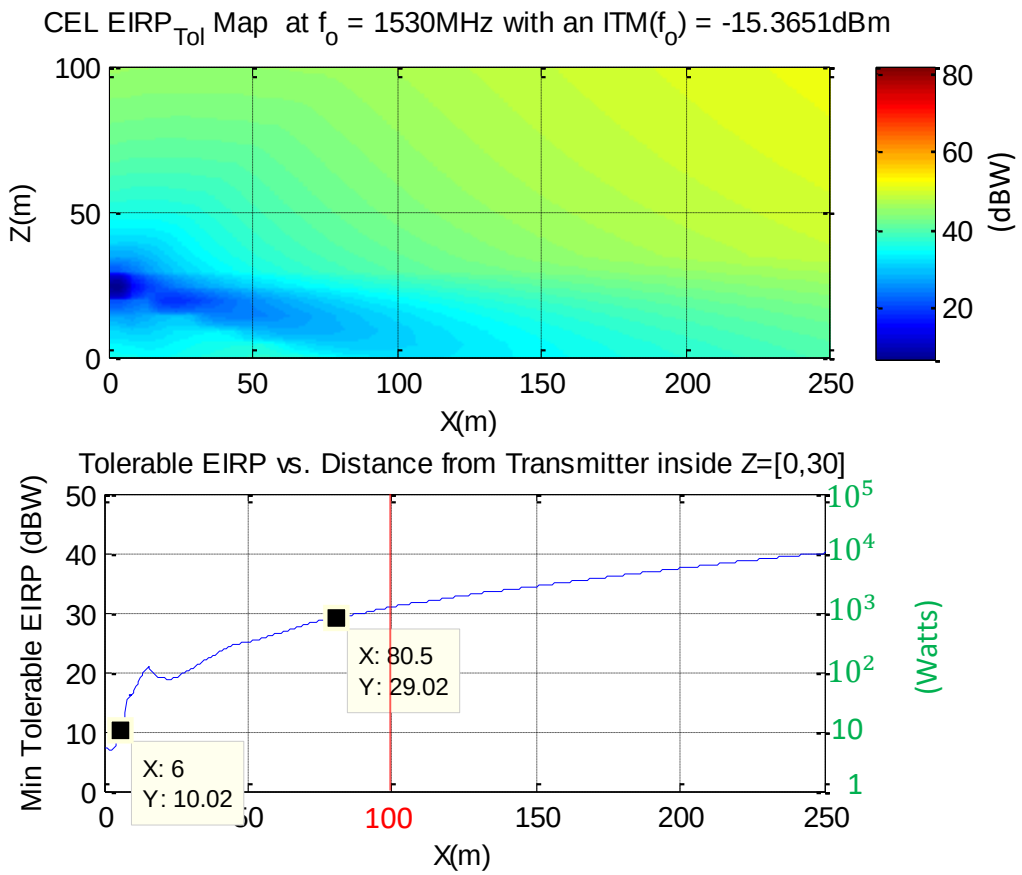
Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

* Based on ITU-R M.2292

Inverse Modeling: CEL, 1530 MHz

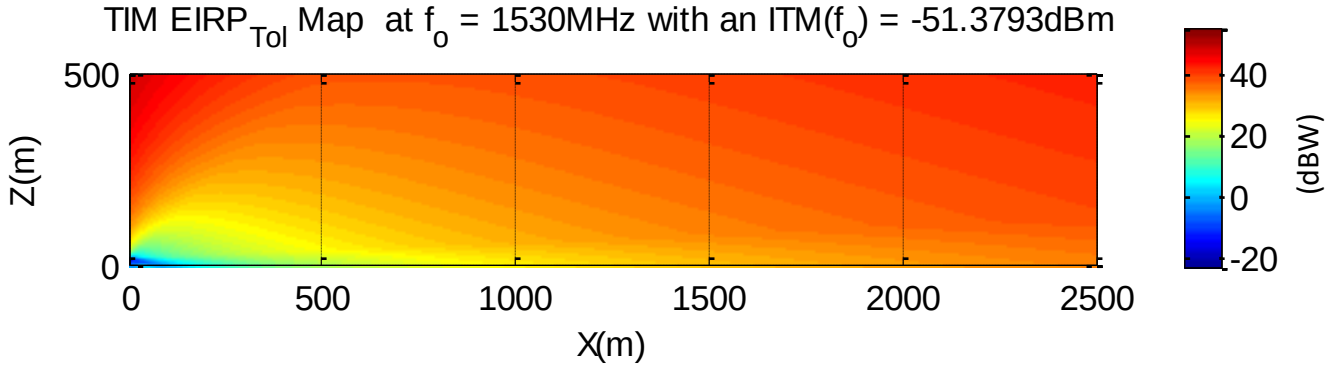
- Extent of the impact region: 80 m from Transmitter for EIRP of 29 dBW
  6 m for EIRP of 10 dBW

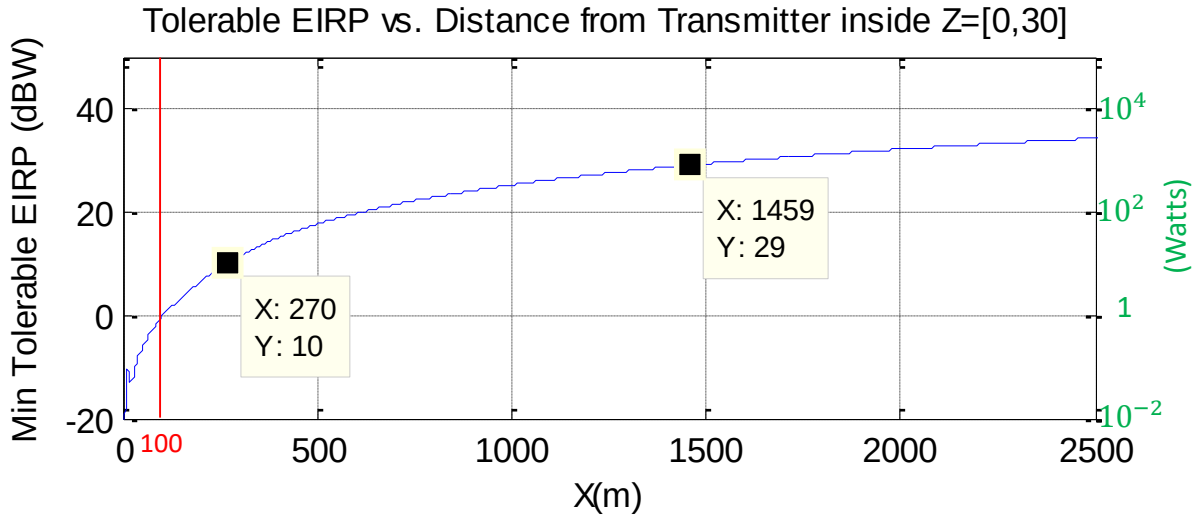


Inverse Modeling: TIM, 1530 MHz

- Extent of the impact region: 1.5 km from transmitter for EIRP of 29 dBW

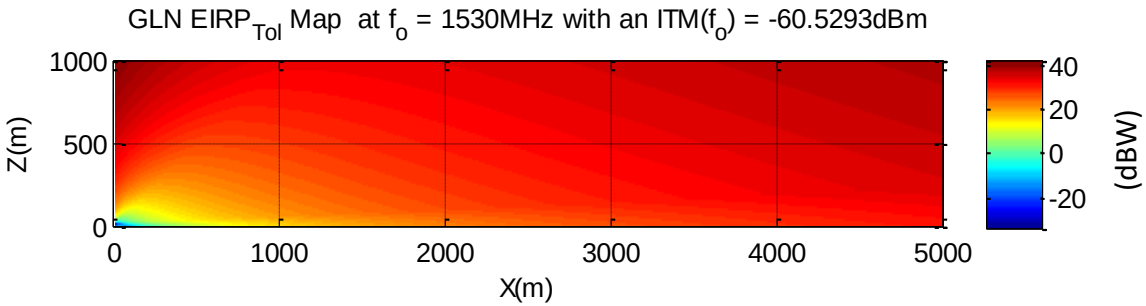
  270 m for EIRP of 10 dBW

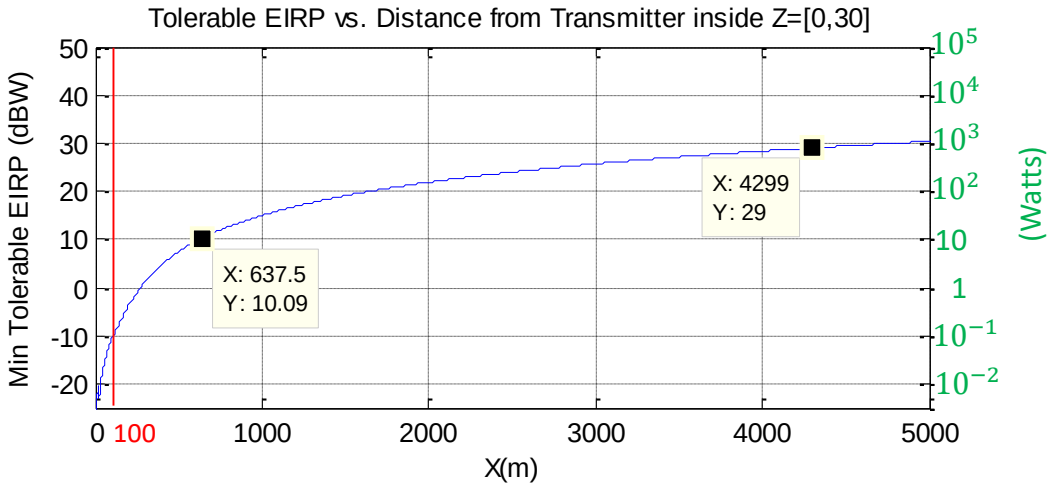




Inverse Modeling: GLN, 1530 MHz

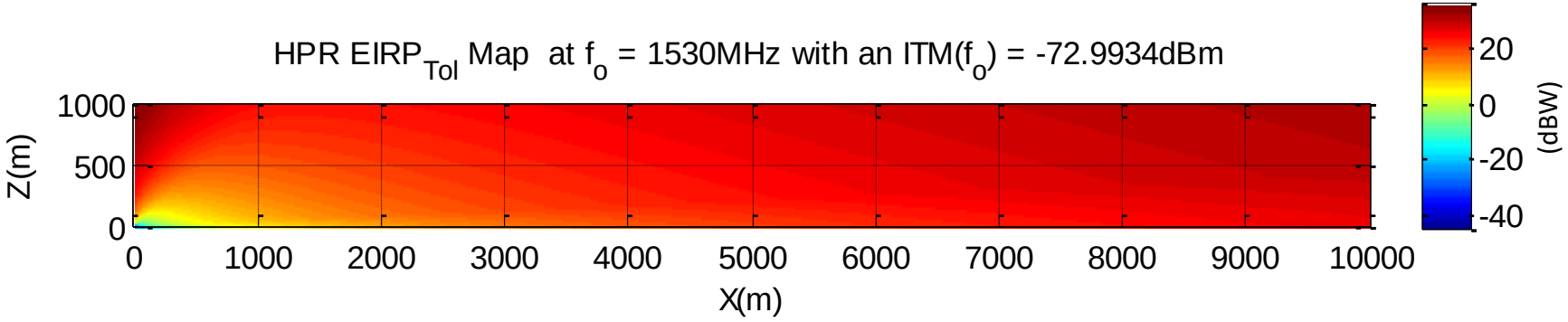
- Extent of the impact region: 4 to 4.5 km from Transmitter for EIRP of 29 dBW
  600 to 650 m for EIRP of 10 dBW

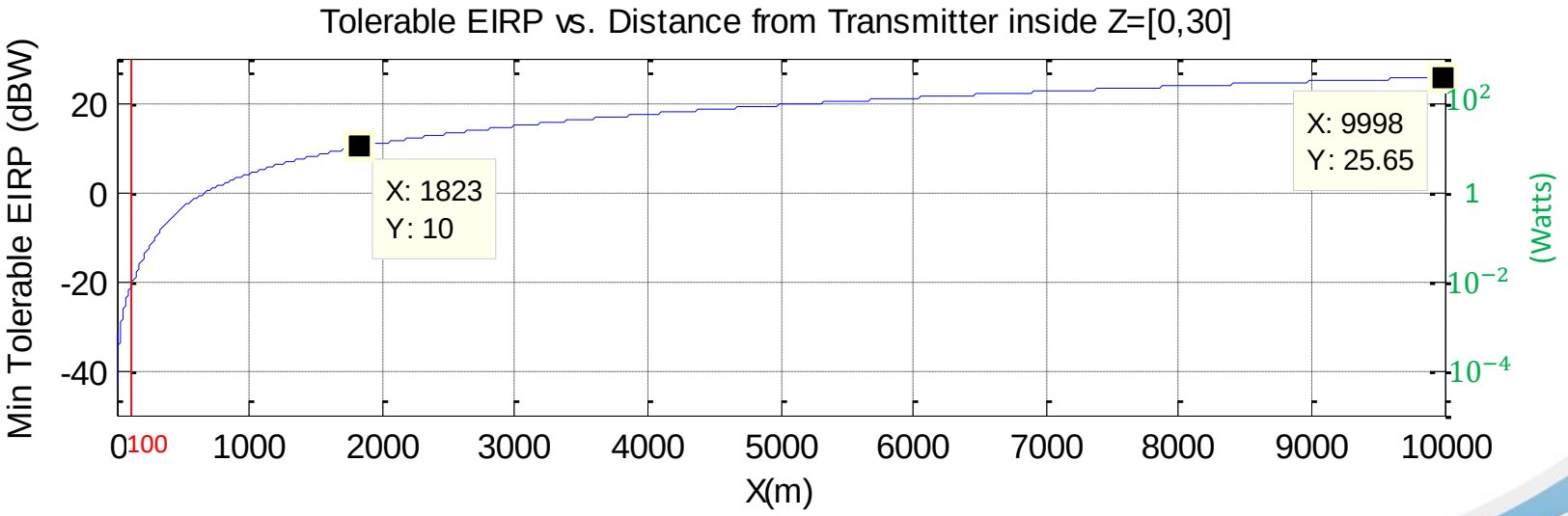




Inverse Modeling: HPR, 1530 MHz

- Extent of the impact region: >10 km from Transmitter for EIRP of 29 dBW
  1.5 to 2 km for EIRP of 10 dBW





Summary Inverse Modeling – 1530 MHz Results (Single Base Station)

Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
		GLN	HPR	TIM	CEL
Macro Urban	10	-31.0	-41.9	-20.6	10.9
	100	-11.0	-21.9	-0.6	31
Micro Urban	10	-29.8	-41.2	-20.1	10.7
	100	-9.8	-21.1	-0.1	30.8

Deployment	Stand off distance (m)	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Macro Urban	10	0.8 mW	64 μW	8.7 mW	12.3 W
	100	79.4 mW	6.5 mW	0.9 W	1.26 kW
Micro Urban	10	1 mW	76 μW	9.8 mW	11.7 W
	100	104 mW	7.8 mW	1 W	1.2 kW

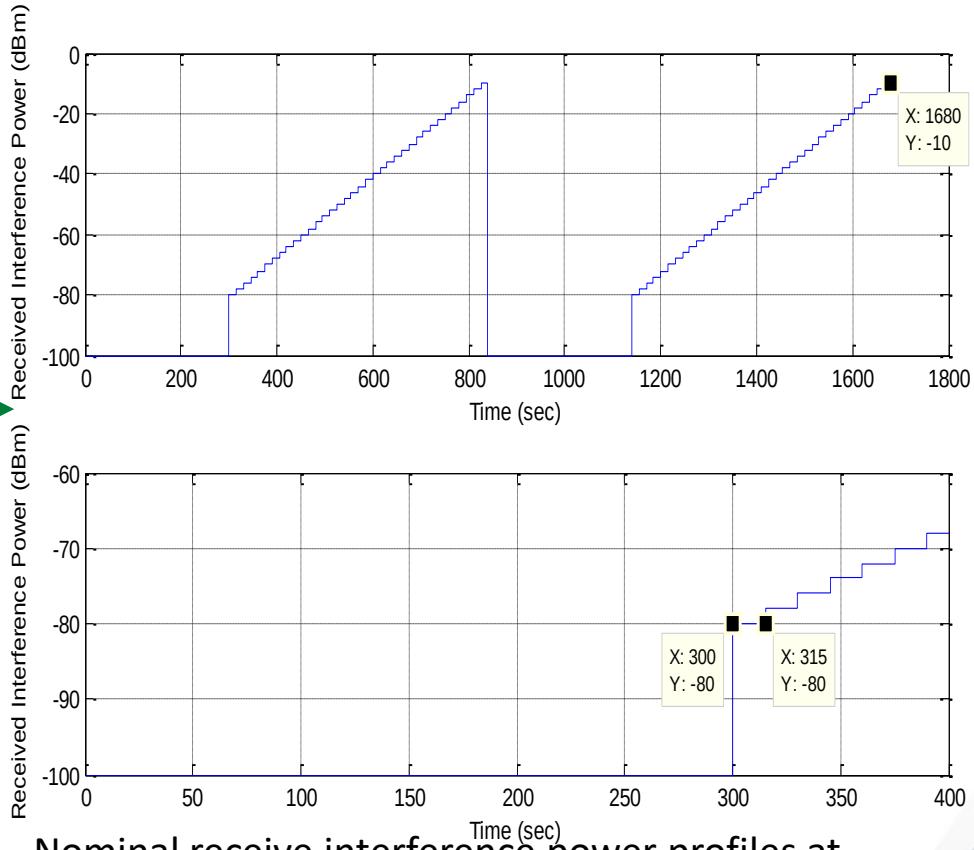
Next Steps

- Finalize Use Case Analysis Based on Feedback from March 30th Workshop
- Complete DOT GPS Adjacent Band Compatibility Assessment Final Report
  - Will include certified avionics and non certified receivers
- Issue Final Report for Public Review and Comment

Backup Slides

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

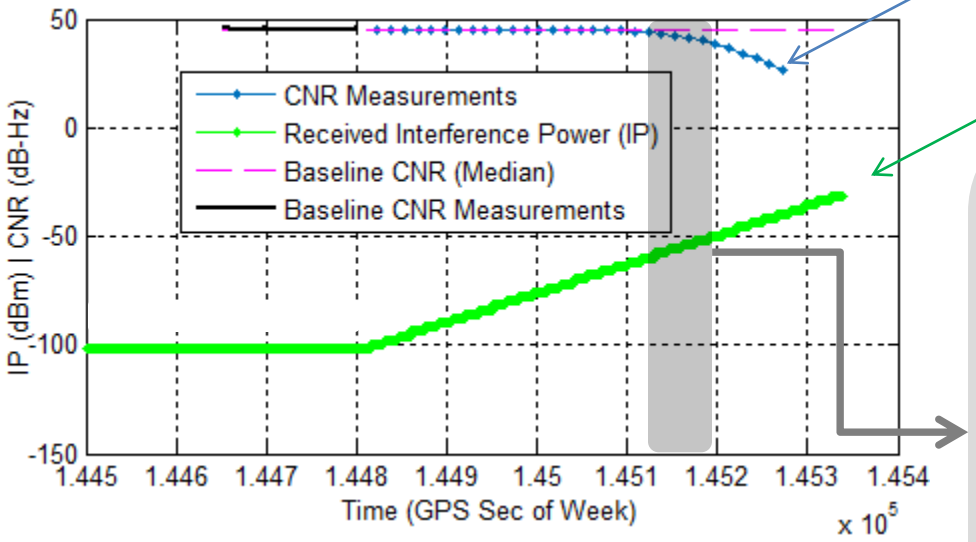


Nominal receive interference power profiles at GNSS antenna location for the (1475 to 1540 MHz) and (1630 to 1675 MHz) frequency ranges.

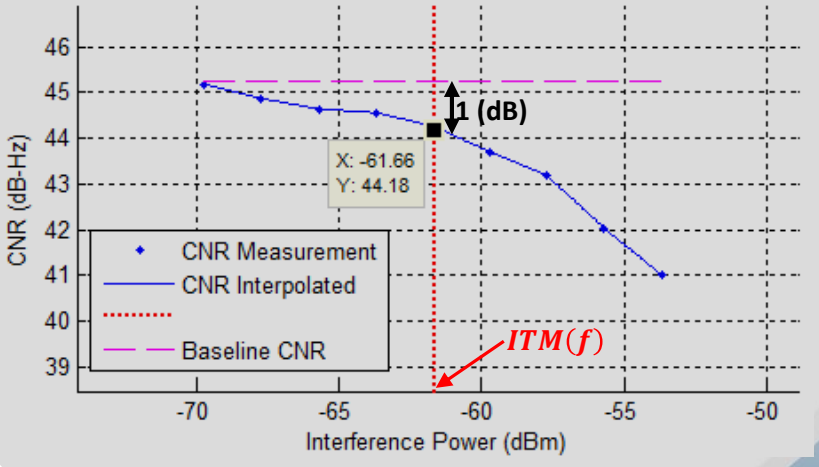
Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

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

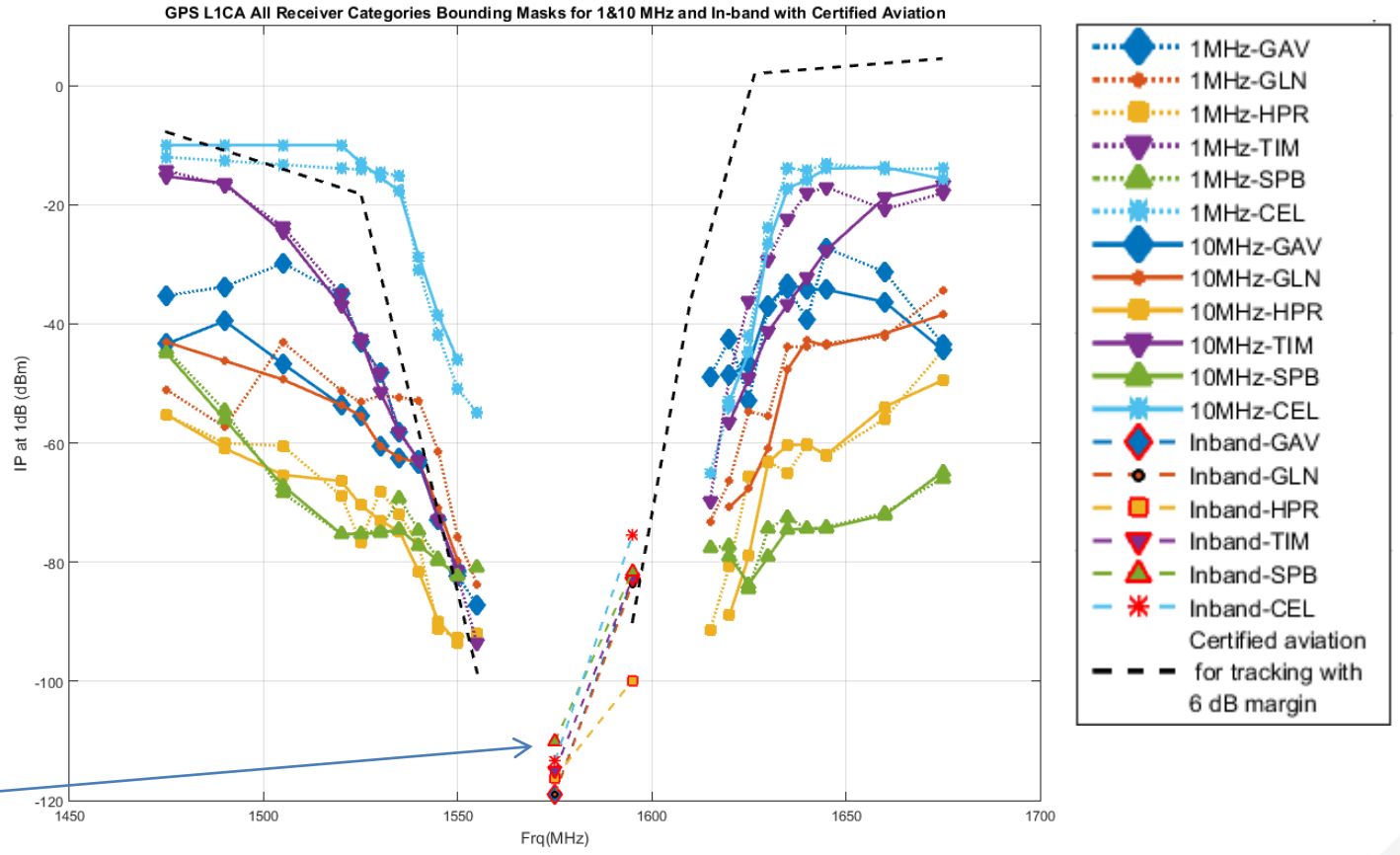
CNR vs. Time



IP vs. Time



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

Wired Test Overview

- Test objectives:
  - Receiver/antenna comparison with chamber results
  - OOBE interference at prescribed and proposed levels w/LTE uplink and downlink signals
  - GNSS signal re-acquisition characterizations
- Tests executed week of 25 July with 14 GNSS receivers
  - Representative set of equipment from chamber testing from each receiver category (except space)
  - Receivers tested were USG provided
- Same test instrumentation for wired as with radiated tests
  - GNSS playback (MITRE)
  - Interference system with modifications to support OOBE and re-acquisition test requirements

Antenna Characterization Overview

- Such characterization is needed to:
  - Compare radiated and conducted (wired) test results
  - Apply interference tolerance masks (ITMs) to use cases where adjacent band transmitters are seen by GPS/GNSS receiver antennas at any direction besides zenith (antenna boresight)

- Antennas relative gain patterns were measured for the purpose of linking ITMs to tolerable transmit power for the case of off-bore sight incident interference power:
  - For Right-hand/left-hand circular polarization (RHCP/LHCP), vertical (V), and horizontal (H) polarizations
  - at 22 frequencies: 1475, 1490, 1495, 1505, 1520, 1530, 1535, 1540, 1545, 1550, 1555, 1575, 1595, 1615, 1620, 1625, 1630, 1635, 1640, 1645, 1660, and 1675 MHz