DOT GPS Adjacent Band Compatibility (ABC) Assessment

International Committee on GNSS (ICG-12)

December 2, 2017

Kyoto, Japan

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:
  - 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

Space-Based PNT Advisory Board View: Minimum Criteria for Testing/Evaluation of GPS Adjacent Band Interference

1. **Accept and strictly apply the 1 dB degradation** Interference Protection Criterion (IPC) for worst case conditions (This is the accepted, world-wide standard for PNT and many other radiocommunication applications)
2. Verify interference for **all classes of GPS receivers** is below criteria, especially precision (Real Time Kinematic - requires both user and reference station to be interference-free) and timing receivers (economically these two classes are the highest payoff applications – many $B/year)
3. Test and **verify interference for receivers** in **all operating modes** is below criteria, particularly **acquisition** and **reacquisition** of GNSS signals under difficult conditions (see attachment of representative interference cases)
4. **Focus analysis on <u>worst cases</u>**: use ***<u>maximum</u>* authorized transmitted interference** powers and ***<u>smallest-attenuation</u>* propagation models** (antennas and space losses) that do not underrepresent the maximum power of the interfering signal (including multiple transmitters)
5. Ensure **interference to emerging Global Navigation Satellite System (GNSS) signals** (particularly wider bandwidth GPS L1C – Galileo, GLONASS), is below criteria
6. All **testing must include GNSS expertise** and be **open to public comment** and scrutiny.

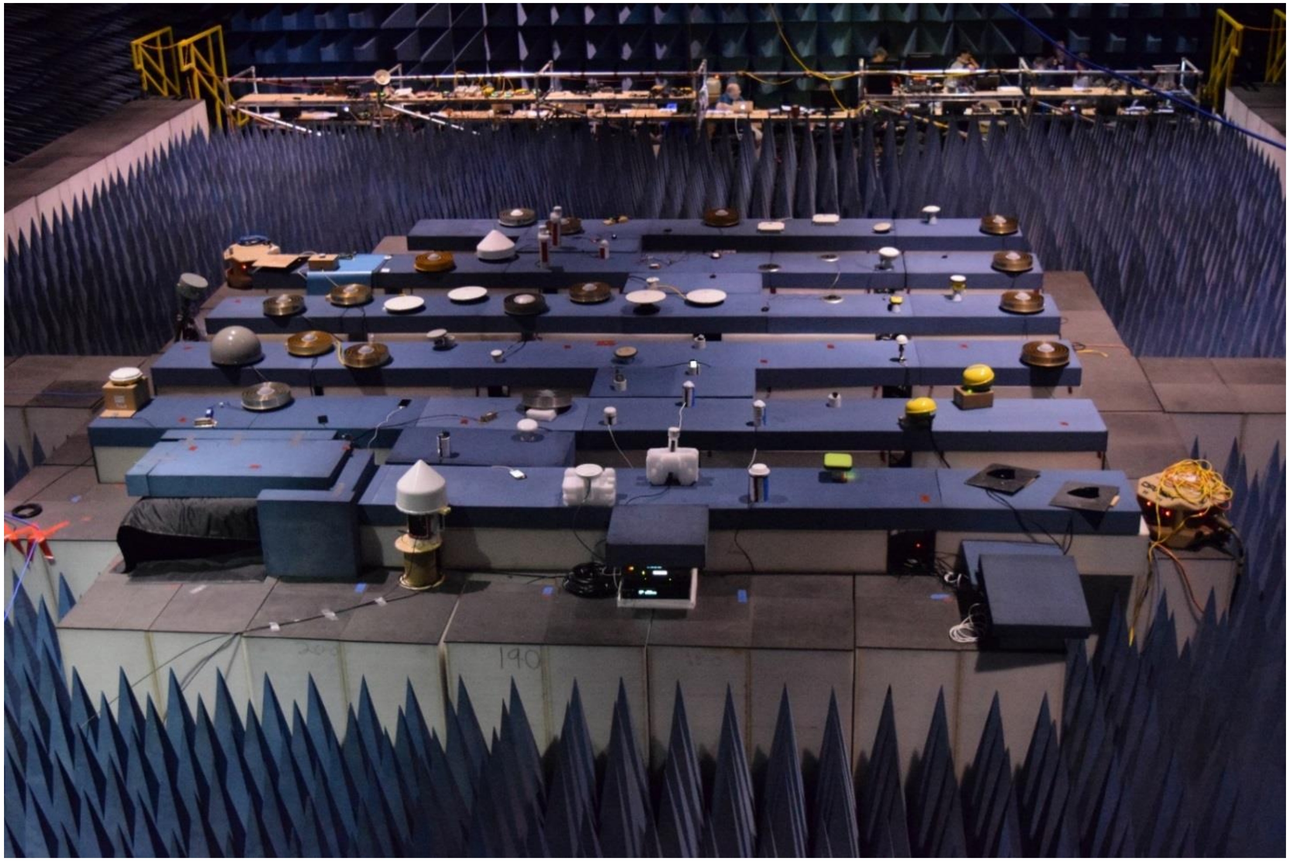
Major Milestones

- 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 [OST-R/Volpe Center]
  - 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]
- Produced 1 dB Interference Tolerance Mask (ITM) results
- Developed Use Case Scenarios and Conducted Inverse Modeling to Determine Power Levels that can be Tolerated
- 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)
- 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, In-Band and Adjacent Band (Type1)
  - 10 MHz Long Term Evolution (LTE) (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

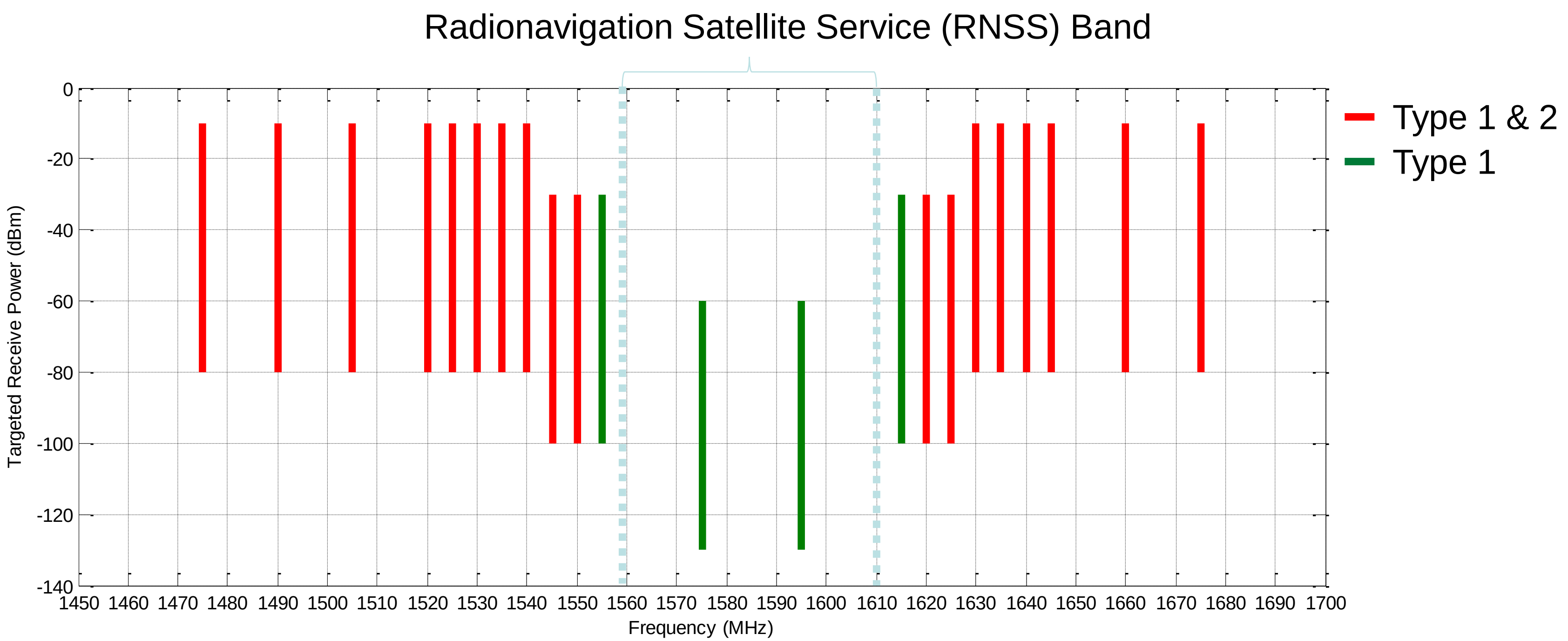
Test Chamber Setup and Tested Signals



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

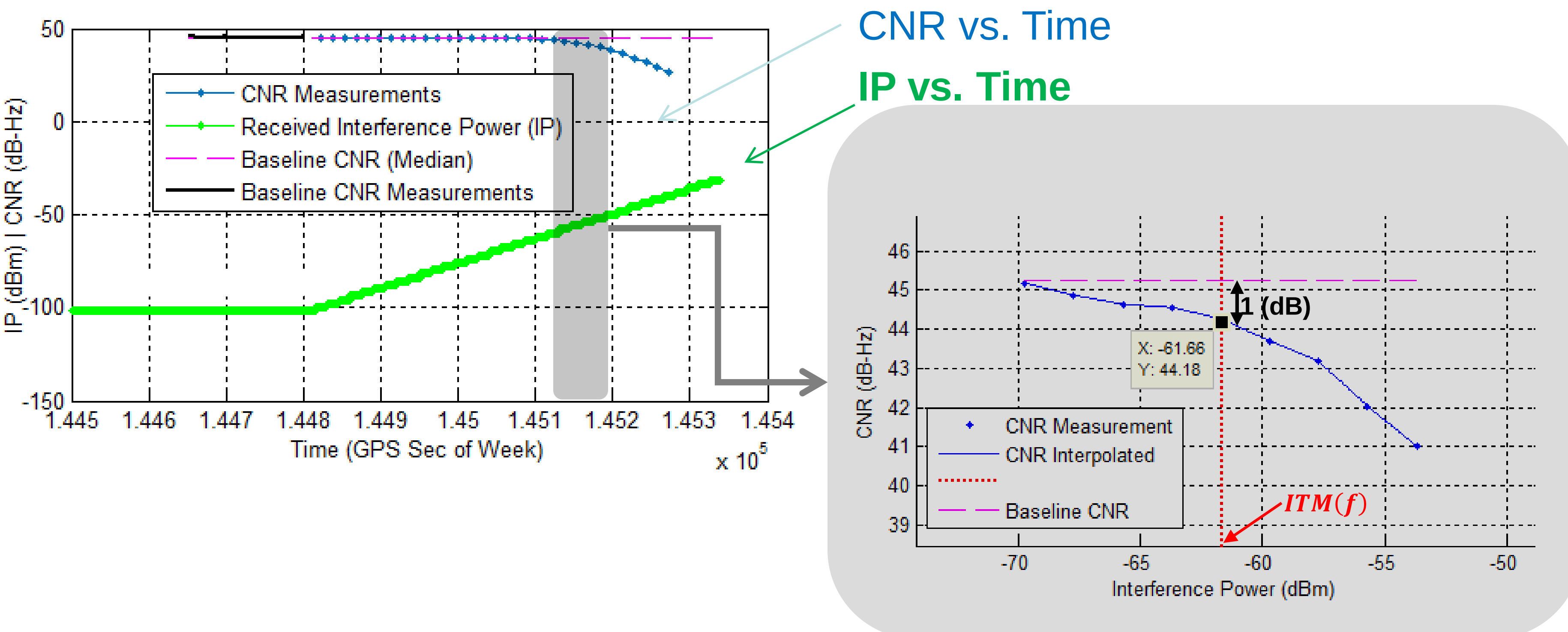
Interference Test Signal Profiles

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

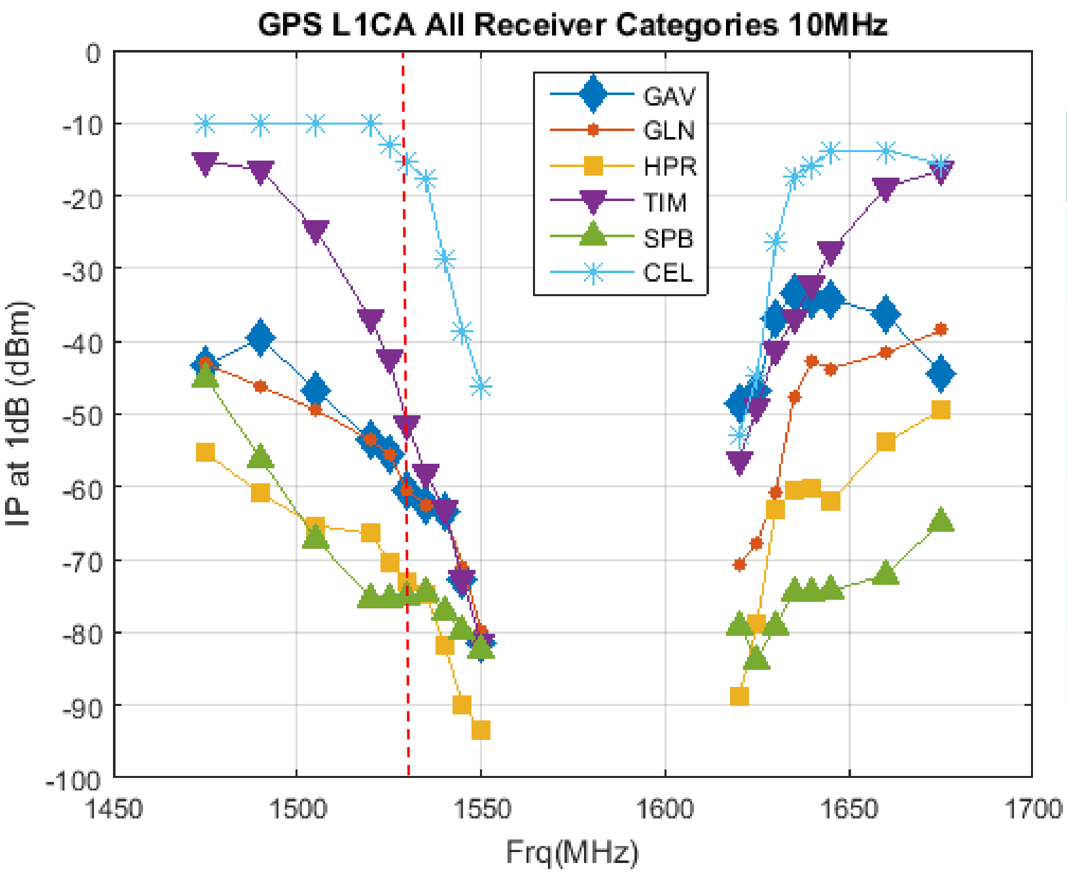


Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

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

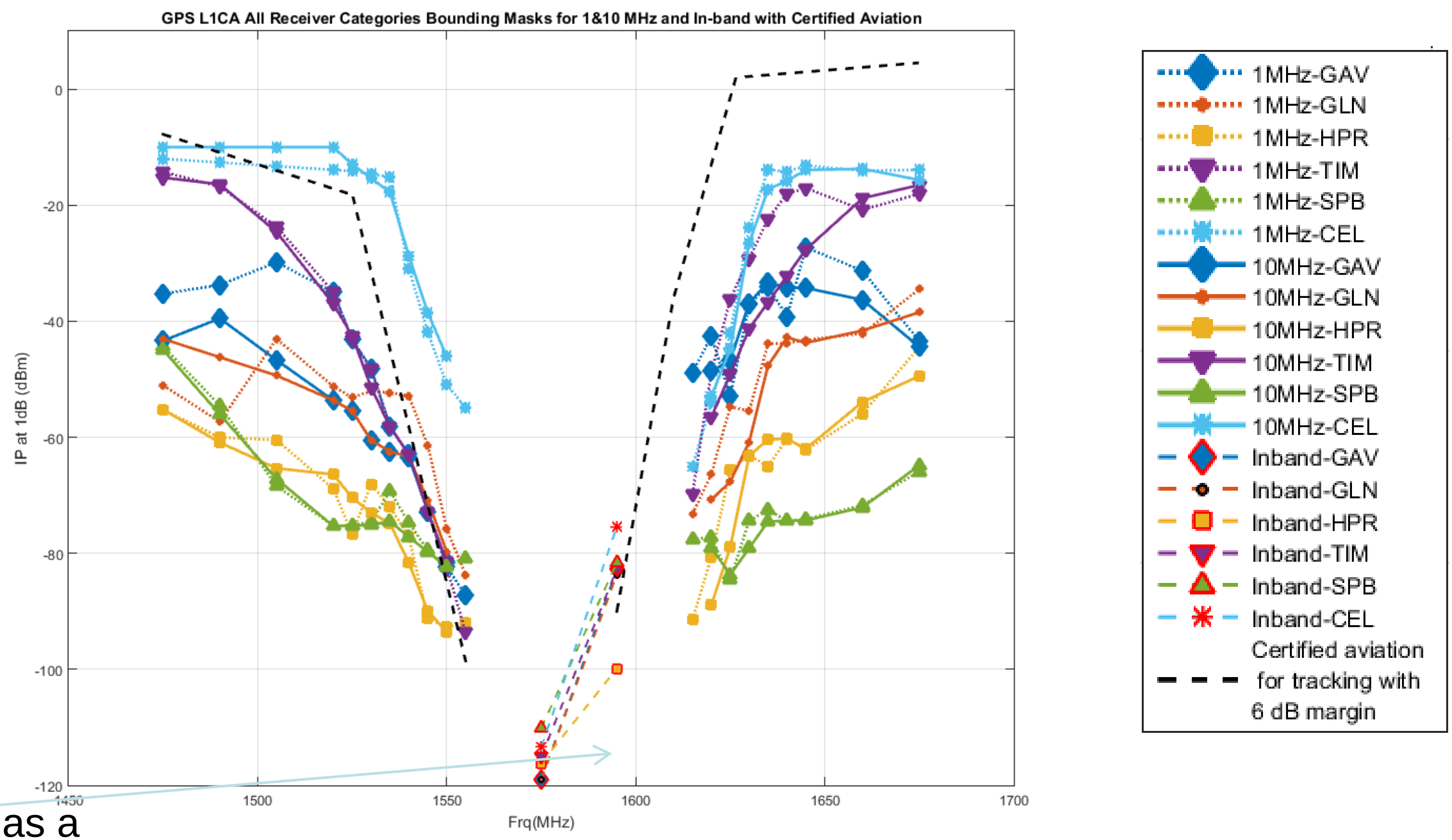


Summary of 10 MHz Bounding Masks GPS L1 C/A



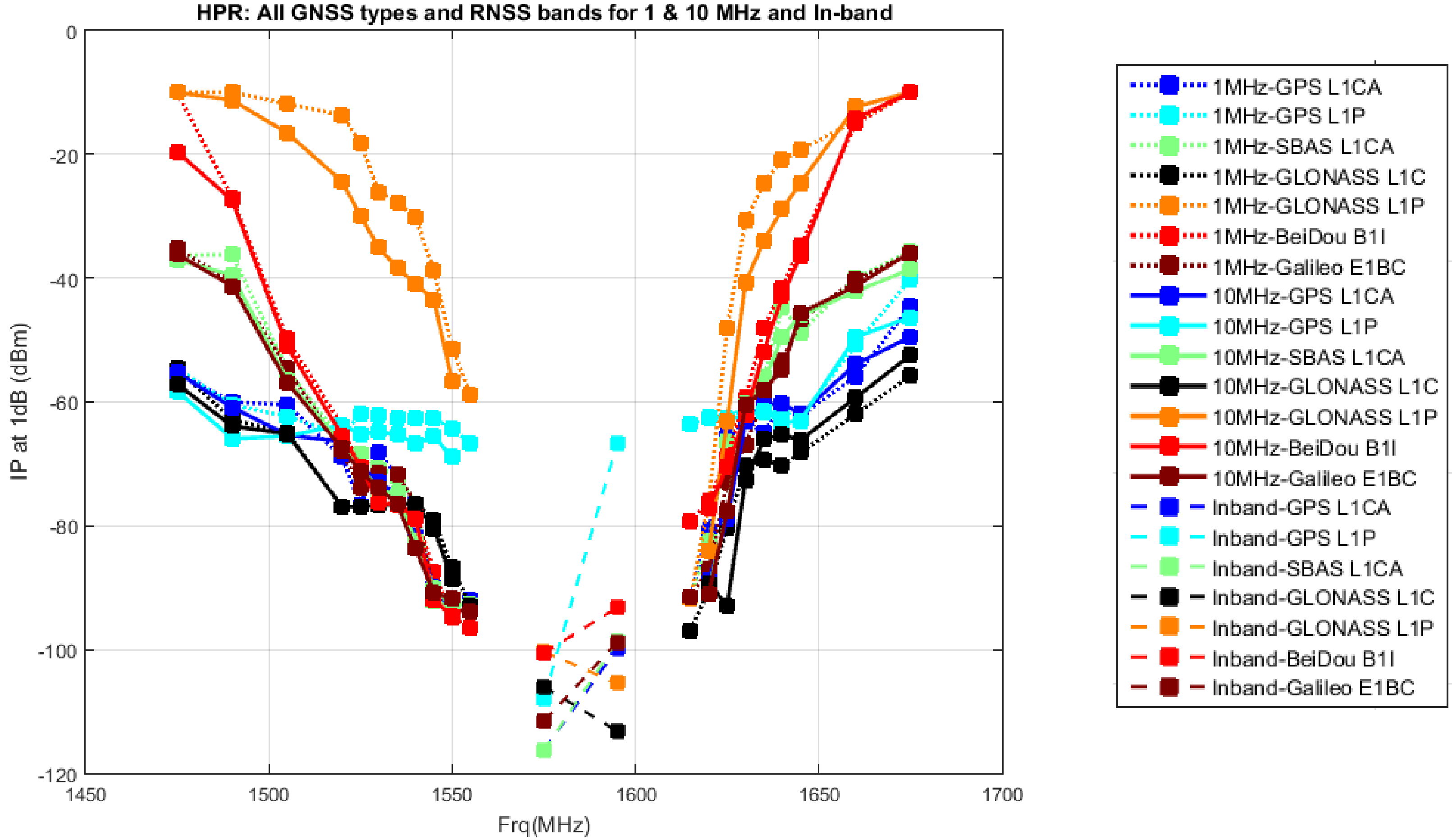
Category	ITM at 1530 MHz (dBm)
GAV - General Aviation (non certified)	-61.0
GLN - General Location/Navigation	-60.5
HPR - High Precision & Networks	-73.0
TIM - Timing	-59.4
SPB - Space Based	-73.5
CEL - Cellular	-15.3

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

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



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)

Emergency Services Scenarios

Photo courtesy Tiero/ThinkStock

Drone/Emergency Response/Disasters

Photo courtesy StockSolutions/ThinkStock

Ankle Bracelet Monitoring

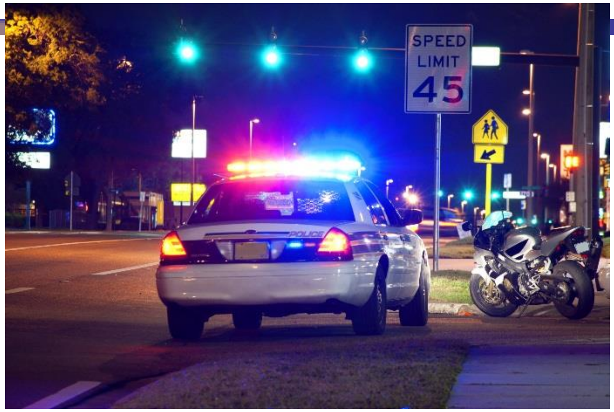


Photo courtesy Mokee81/ThinkStock

Police/Emergency Response/Resource Tracking

Photo courtesy Mrdoomits/ThinkStock

Emergency Response/ Resource Tracking

Photo courtesy ThinkStock

Drone/Emergency Response/Disasters

Construction/Infrastructure Scenarios

Photo courtesy of WSP Canada Inc

GPS HPR receiver used in construction/surveying

Photo courtesy of WSP Canada Inc

GPS HPR receiver used in construction/surveying

Photo courtesy ThinkStock

GPS HPR receiver used in construction guidance

Photo courtesy Medvedkov/ThinkStock

Construction/Surveying

Agriculture/Farming Scenario

Photo courtesy Valio84sl/ThinkStock

Drone/Crop Monitoring

Photo courtesy of John Deere

GPS Guidance System

Photo courtesy of John Deere

High Precision Farming

Photo courtesy of John Deere

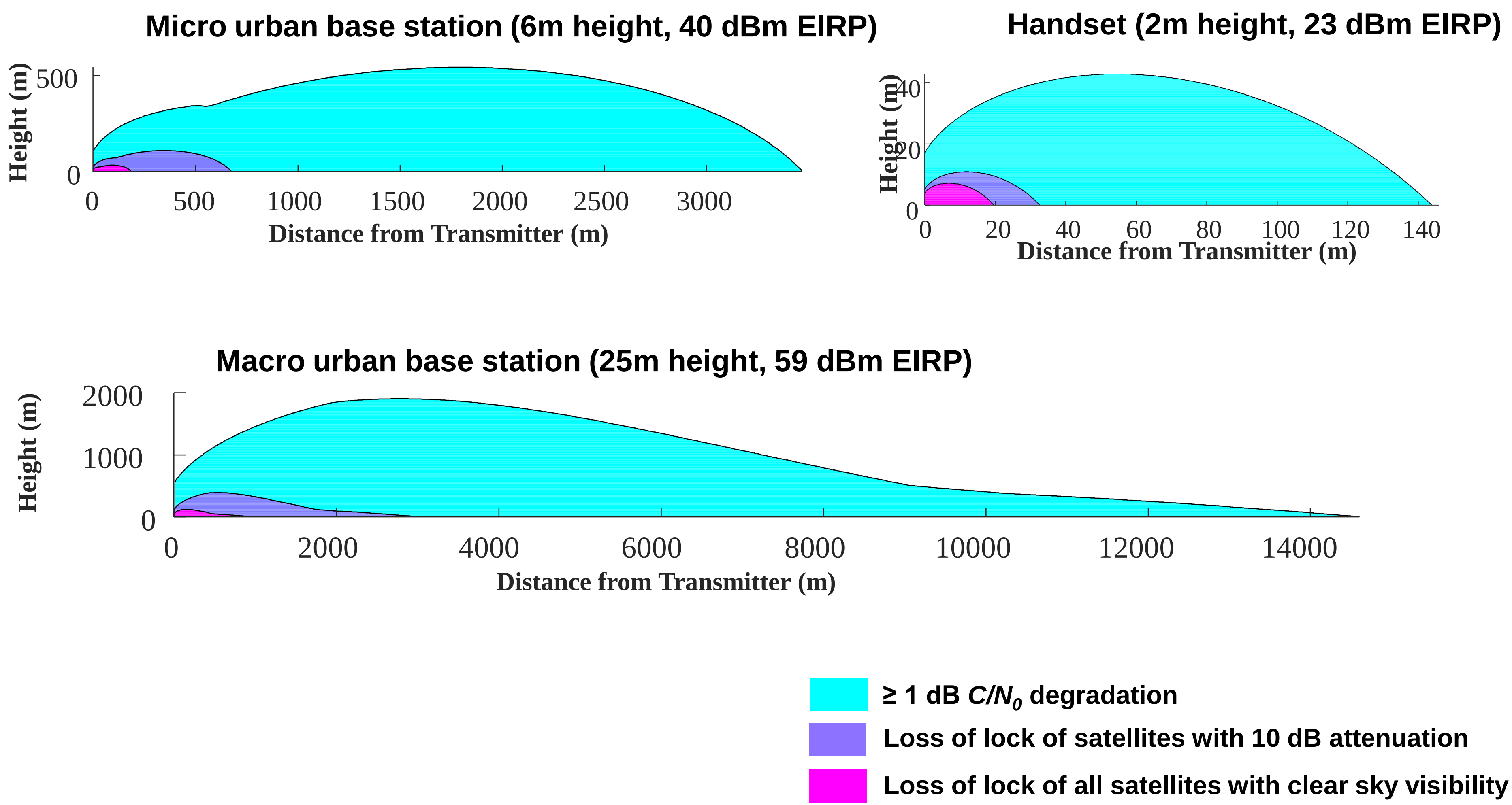
High Precision Farming

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

ITU-R: International Telecommunication Union Radiocommunication

Results: Region of Impact for ITU Recommended Power Levels (1530 MHz)

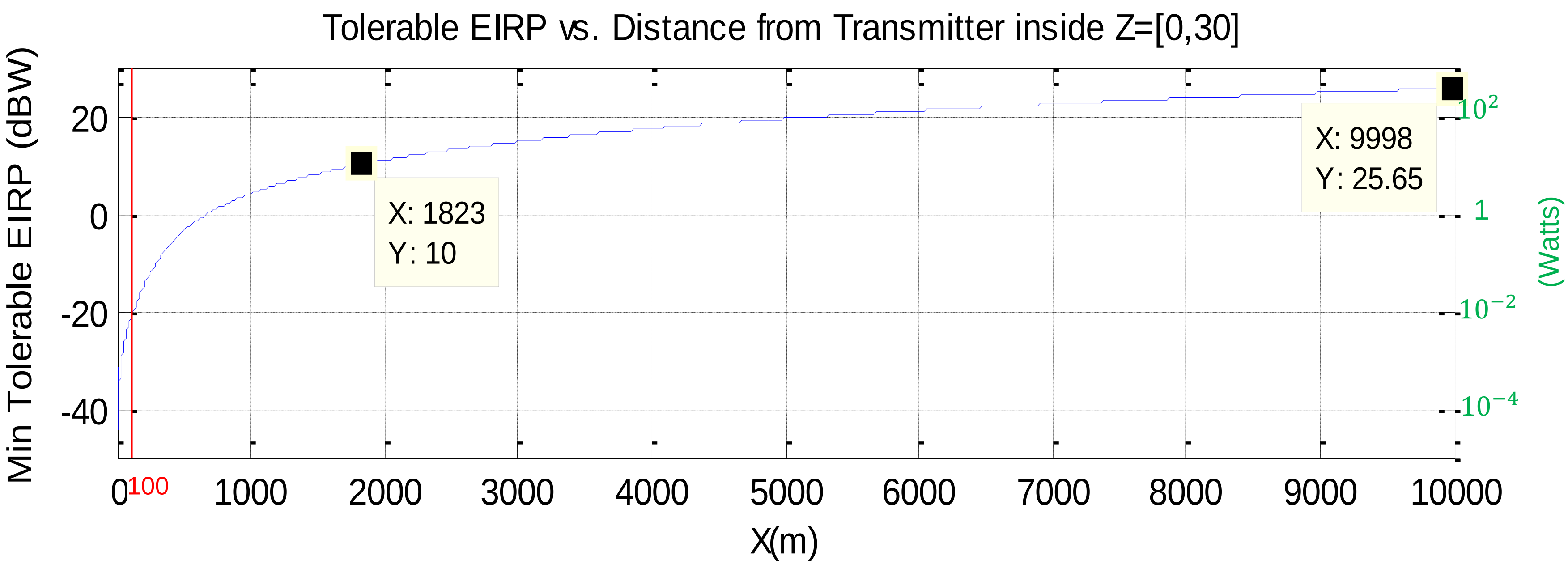


Inverse Modeling: HPR, 1530 MHz

Extent of the impact region:

>10 km from Transmitter for EIRP of 29 dBW

1.5 to 2 km for EIRP of 10 dBW



Maximum Tolerable Power Level for GPS/GNSS Receivers at 1530 MHz

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

Maximum Tolerable Power Level for Space-Based Receivers at 1530 MHz

Deployment Scenario	Number of Base Stations	Max Tolerable Power	
		dBW	EIRP
Macro Cell	184,500	11	12.6 W
Macro Cell	67,240	16	39.8 W
Macro Cell	44,850	17	50.1 W
Macro Cell	24,140	21	125.9 W
Macro + Micro Cell	282,186	8	6.3 W
Macro + Micro Cell	102,841	12	15.8 W
Macro + Micro Cell	69,477	14	25.1 W
Macro + Micro Cell	39,695	16	39.8 W

Next Steps

- Coordinate DOT GPS Adjacent Band Compatibility Assessment Final Report within U.S. Government
  - Includes certified avionics and non certified receivers
- Issue Final Public Report

Thank You