DOT GPS Adjacent Band Compatibility (ABC) Assessment

Space-Based PNT Advisory Board Meeting

Nov. 15, 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:
  - 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 worst cases**: use ***maximum*** **authorized transmitted interference** powers and ***smallest-attenuation*** **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

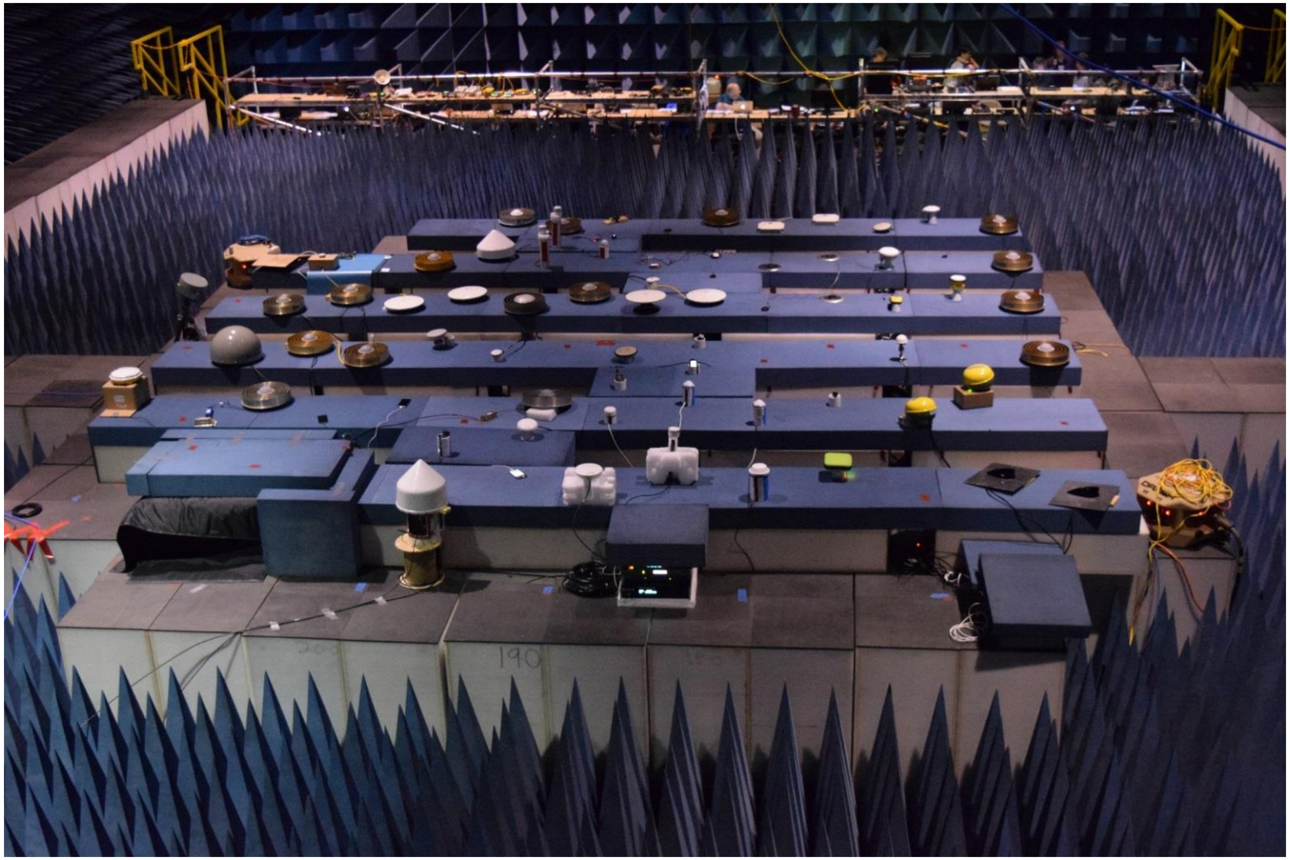
- GNSS receiver testing was carried out April 25-29, 2016 at the Army Research Laboratory's (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF), White Sands Missile Range (WSMR), NM

- 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)

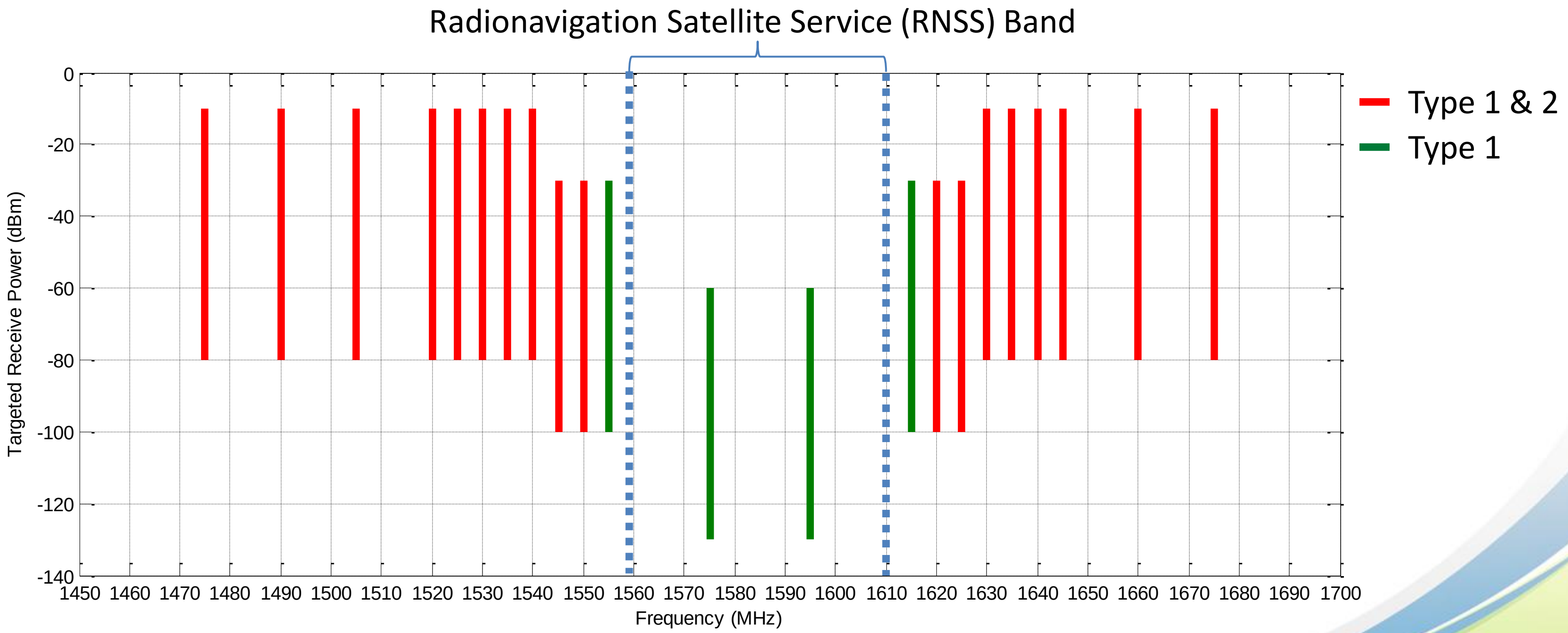
Test Chamber Setup and Tested Signals



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

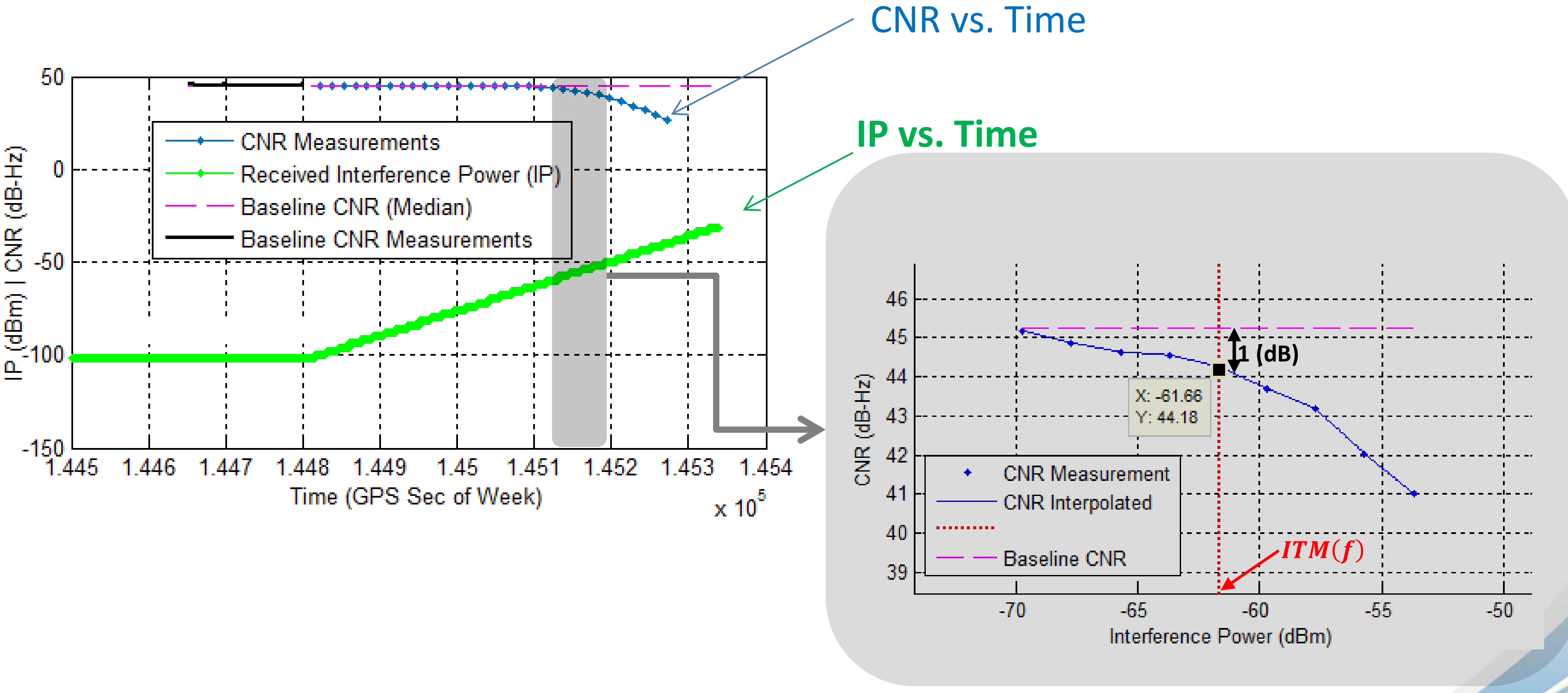
Interference Test Signal Profiles

- 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

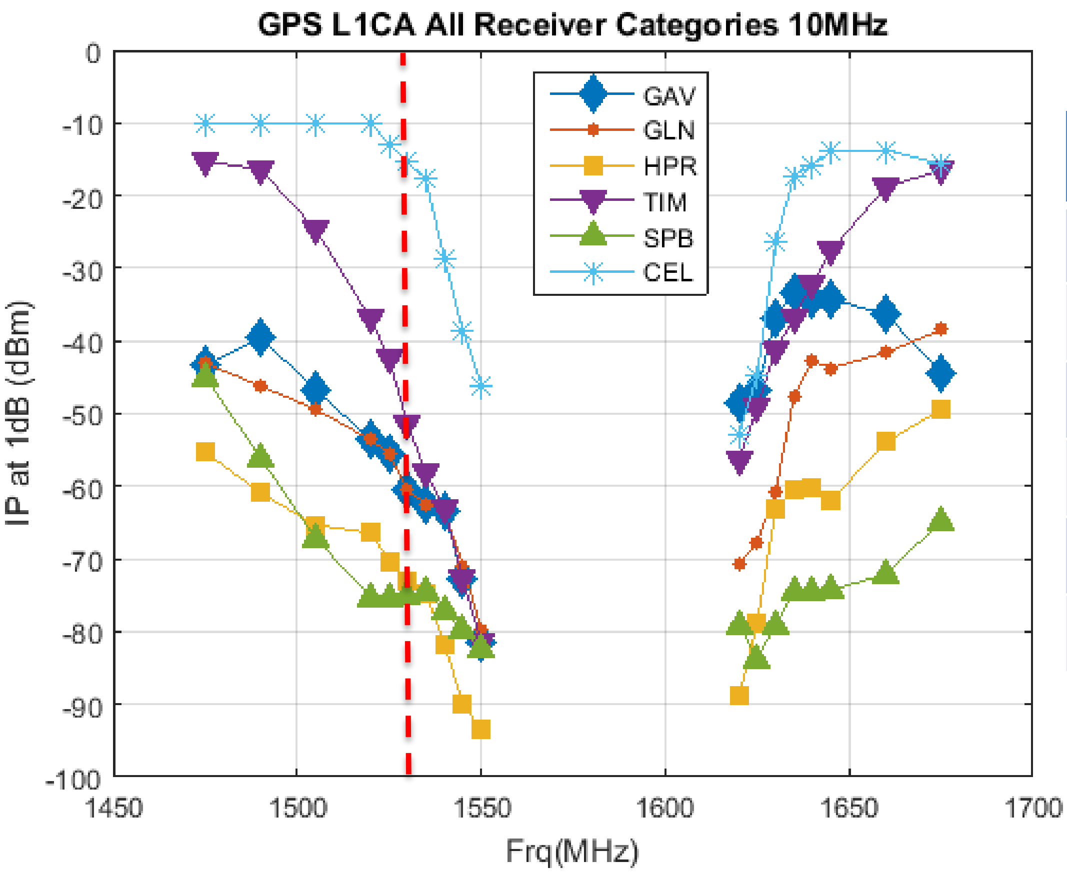


Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

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

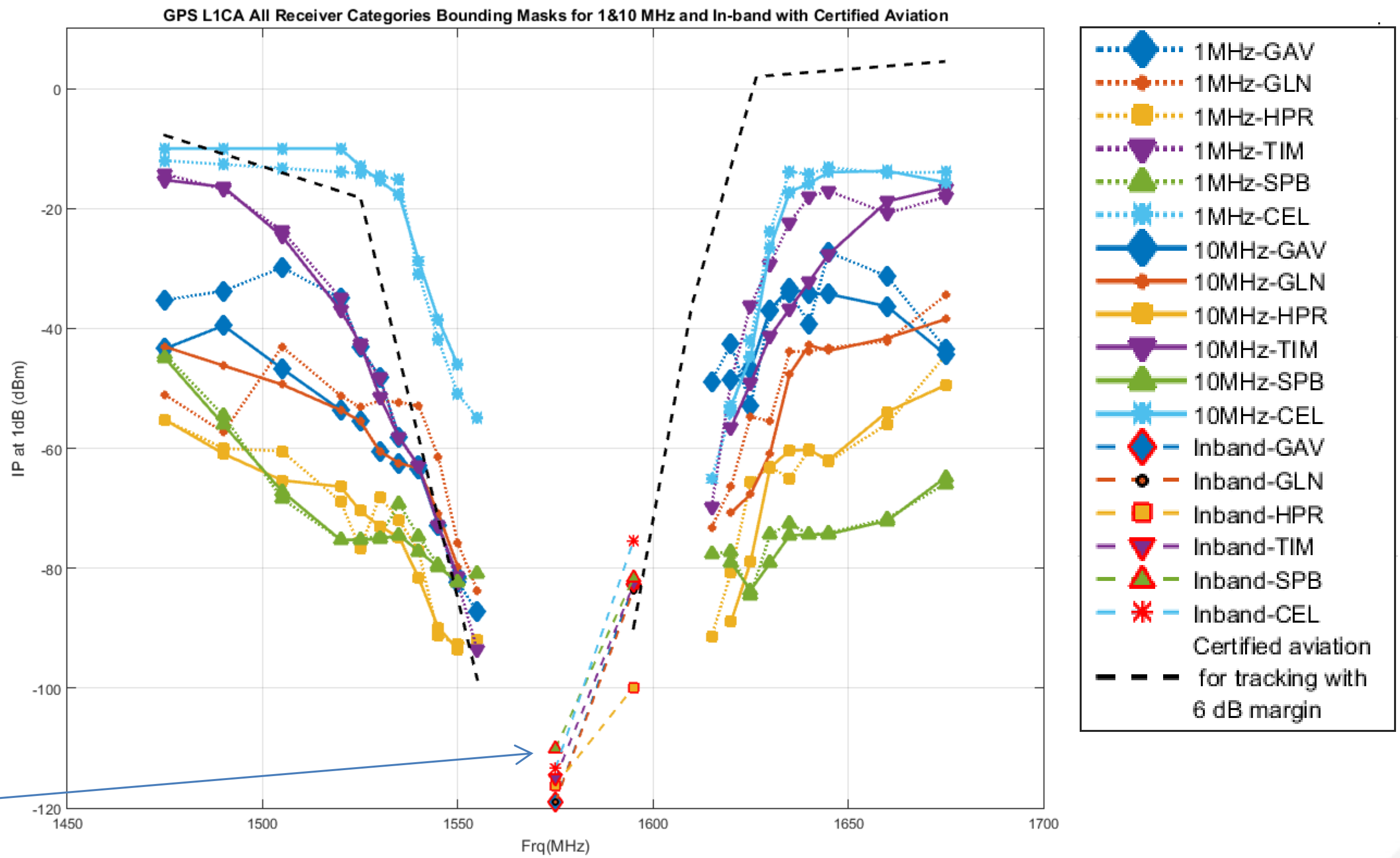


Summary of 10 MHz Bounding Masks GPS L1 C/A



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



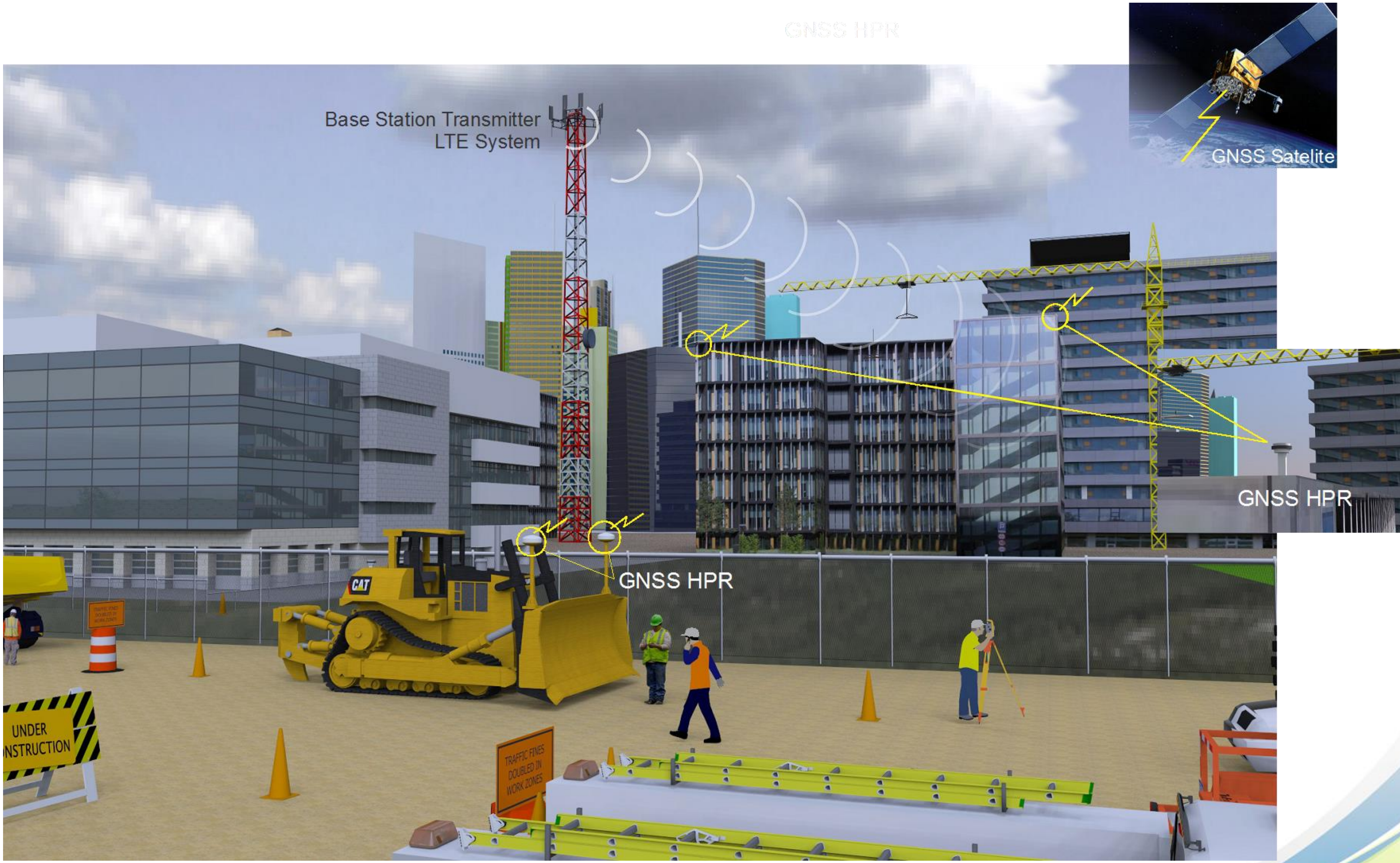
Note: Certified Aviation Mask has a value of -110 dBm for 1 MHz in band interference

Summary of Radiated Test Results

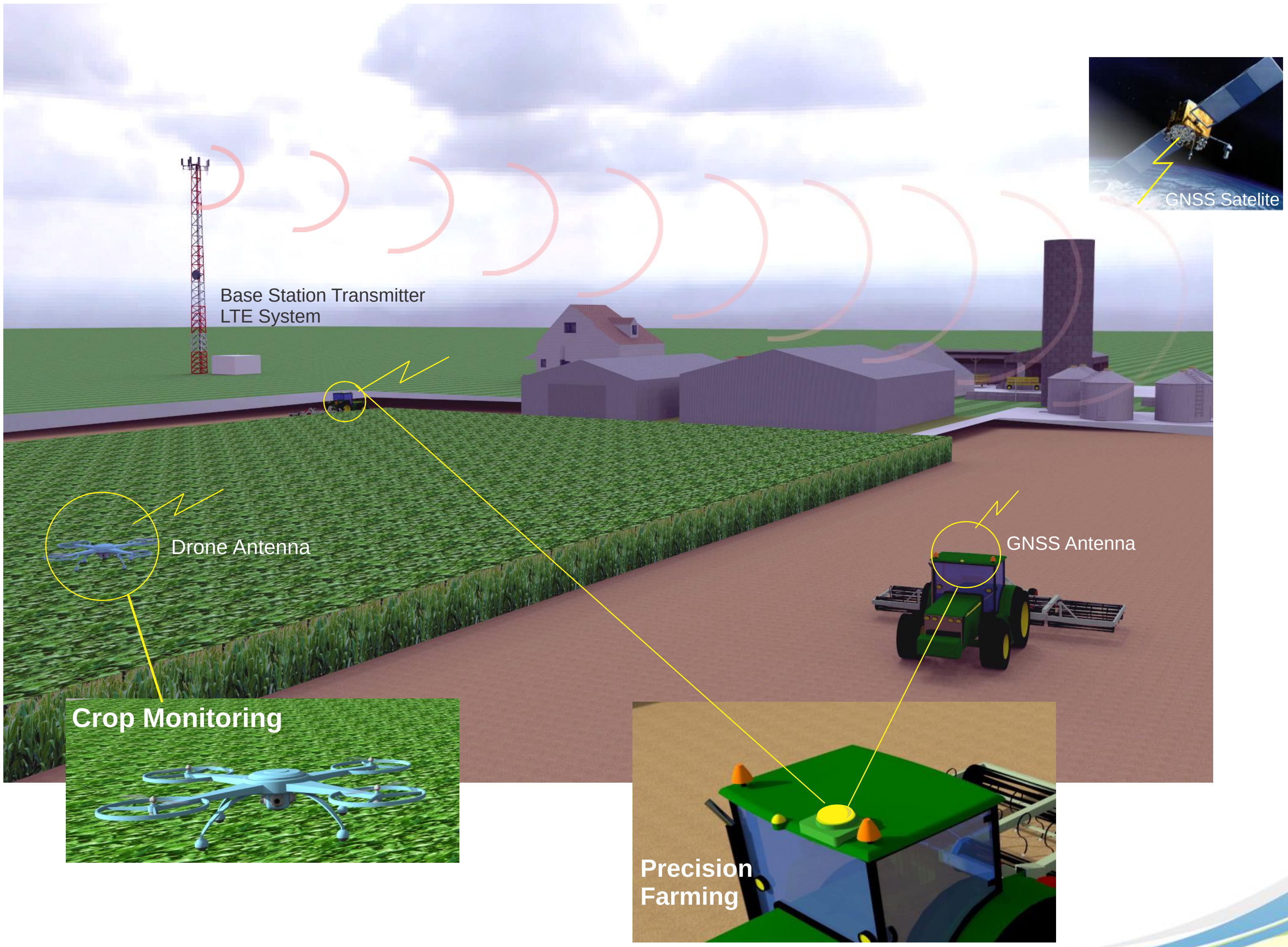
- 1 MHz AWGN and 10 MHz LTE interference signals ITM bounds have been produced for all emulated GNSS signals
- Most bounding ITMs show little sensitivity to interference signal types (AWGN (1 MHz) and LTE (10 MHz))
- Certified aviation receiver mask does not bound the masks of the 6 civil receiver categories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

Emergency Response Scenario

Construction/Infrastructure Scenario



Agriculture/Farming Scenario

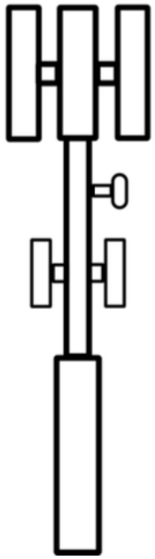


Inverse Modeling / Transmit Power Levels

- 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

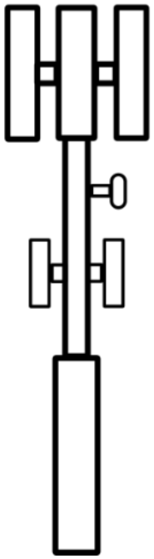
ITU-R: International Telecommunication Union Radiocommunication

ITU-R M.2292 Macro Base Stations



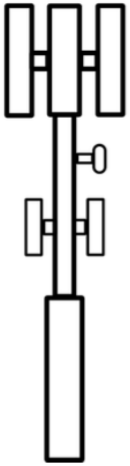
Macro Rural

- 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

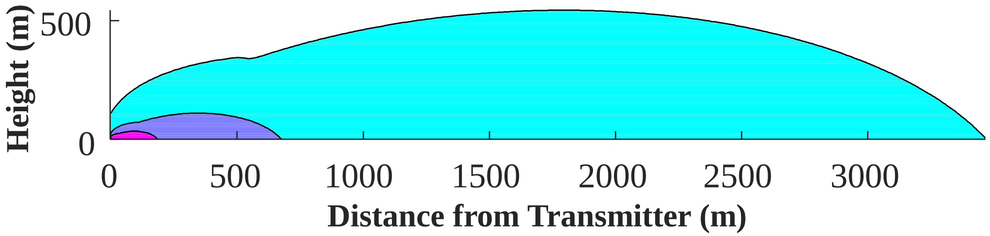


Macro Urban

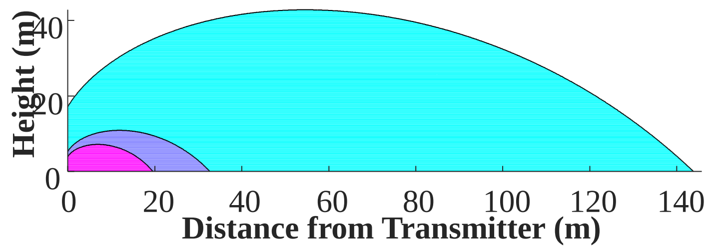
- 16 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 56/59/59 dBm
- 25 m height
- 10 deg downtilt
- 0.25 – 1 km cell radius

Results: Region of Impact for ITU Recommended Power Levels

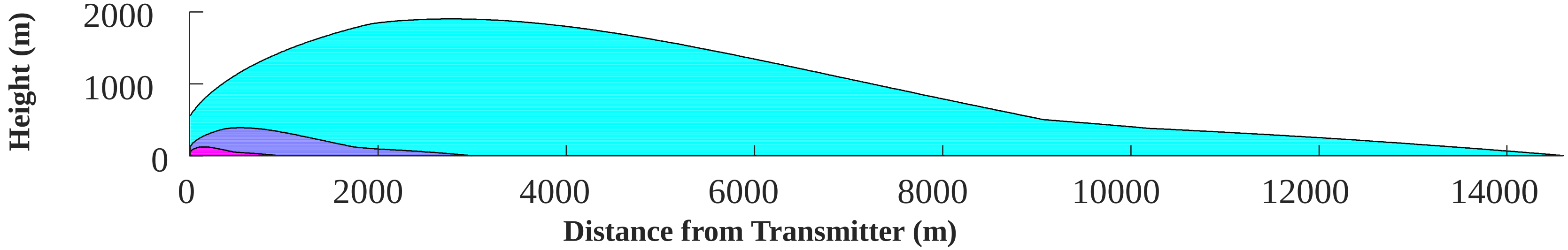
Micro urban base station (6m height, 40 dBm EIRP)



Handset (2m height, 23 dBm EIRP)



Macro urban base station (25m height, 59 dBm EIRP)

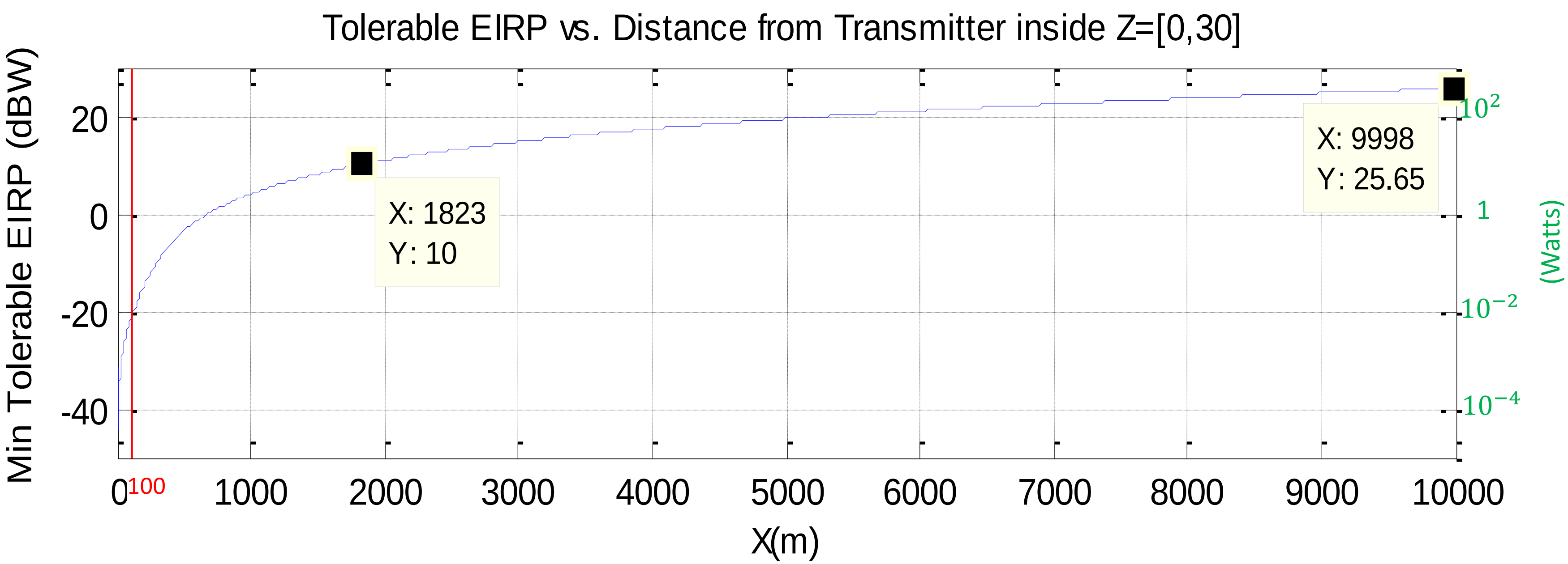


- ≥ 1 dB C/N_0 degradation
- Loss of lock of satellites with 10 dB attenuation
- Loss of lock of all satellites with clear sky visibility

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