DOT GPS Adjacent Band Compatibility Assessment

Space-Based PNT

Advisory Board Meeting

June 28, 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 (six public workshops)
  - 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

EXCOM Letter

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

JAN 1 3 2012

UNITED STATES OF AMERICA

The Honorable Lawrence E. Strickling
Assistant Secretary for Communications and Information
U.S. Department of Commerce
Washington, DC 20230

Dear Assistant Secretary Strickling:

At the request of the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), the nine federal departments and

The EXCOM Agencies continue to strongly support the President's June 28, 2010 Memorandum to make available a total of 500 MHz of spectrum over the next 10 years, suitable for broadband use. We propose to draft new GPS Spectrum interference standards that will help inform future proposals for non-space, commercial uses in the bands adjacent to the GPS signals and ensure that any such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs.

ASHTON B. CARTER
EXCOM Co-Chair
Deputy Secretary of Defense

JOHN D. PORCARI
EXCOM Co-Chair
Deputy Secretary of Transportation

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"... without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs."

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
  - 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

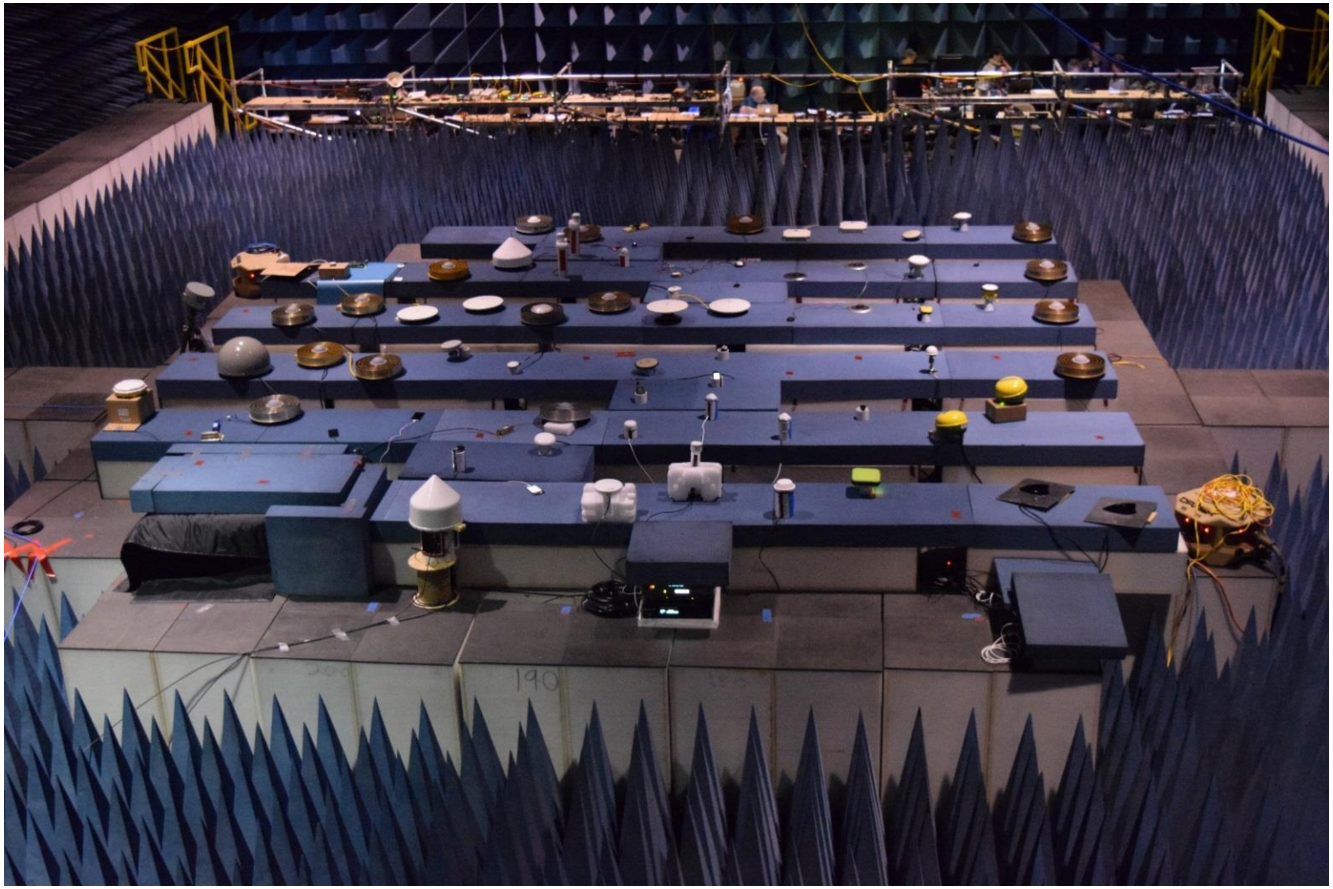
- GNSS receiver testing was carried out April 25-29, 2016 at the Army Research Laboratory's (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF), White Sands Missile Range (WSMR), NM

- 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)

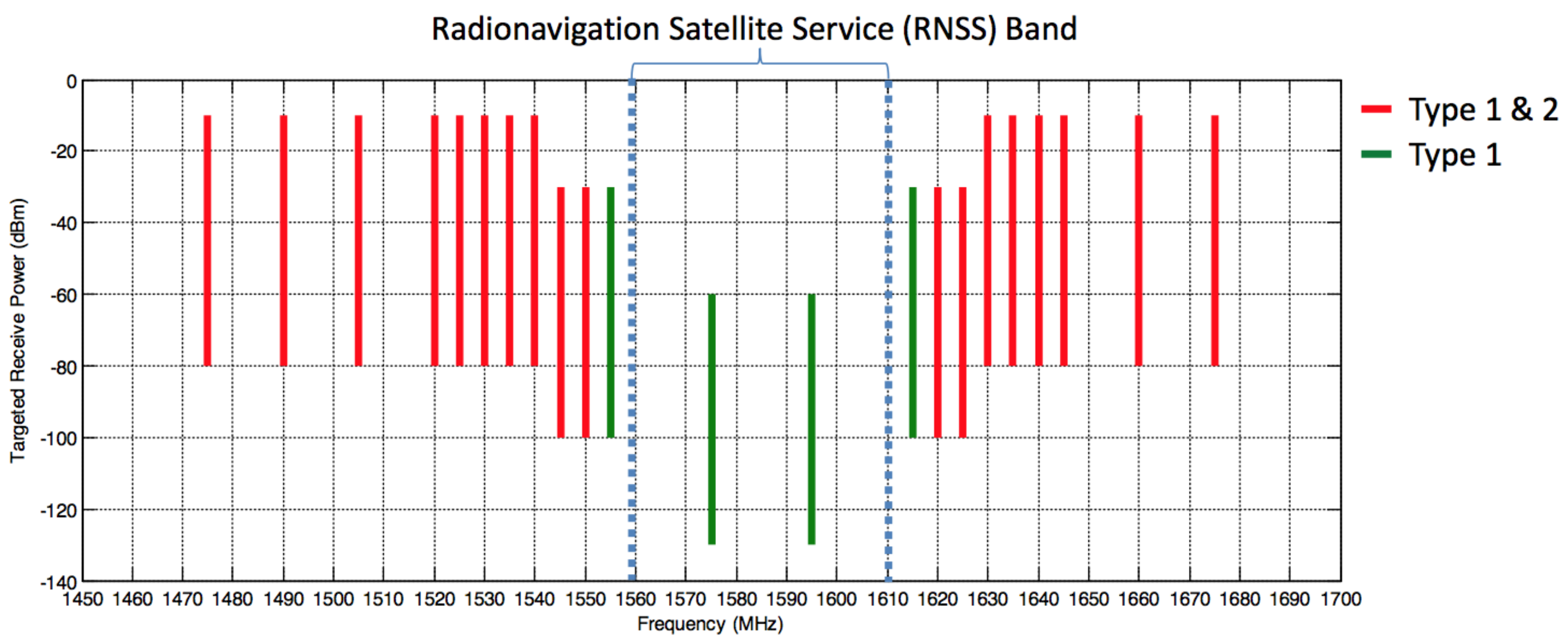
Test Chamber Setup and Tested Signals



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

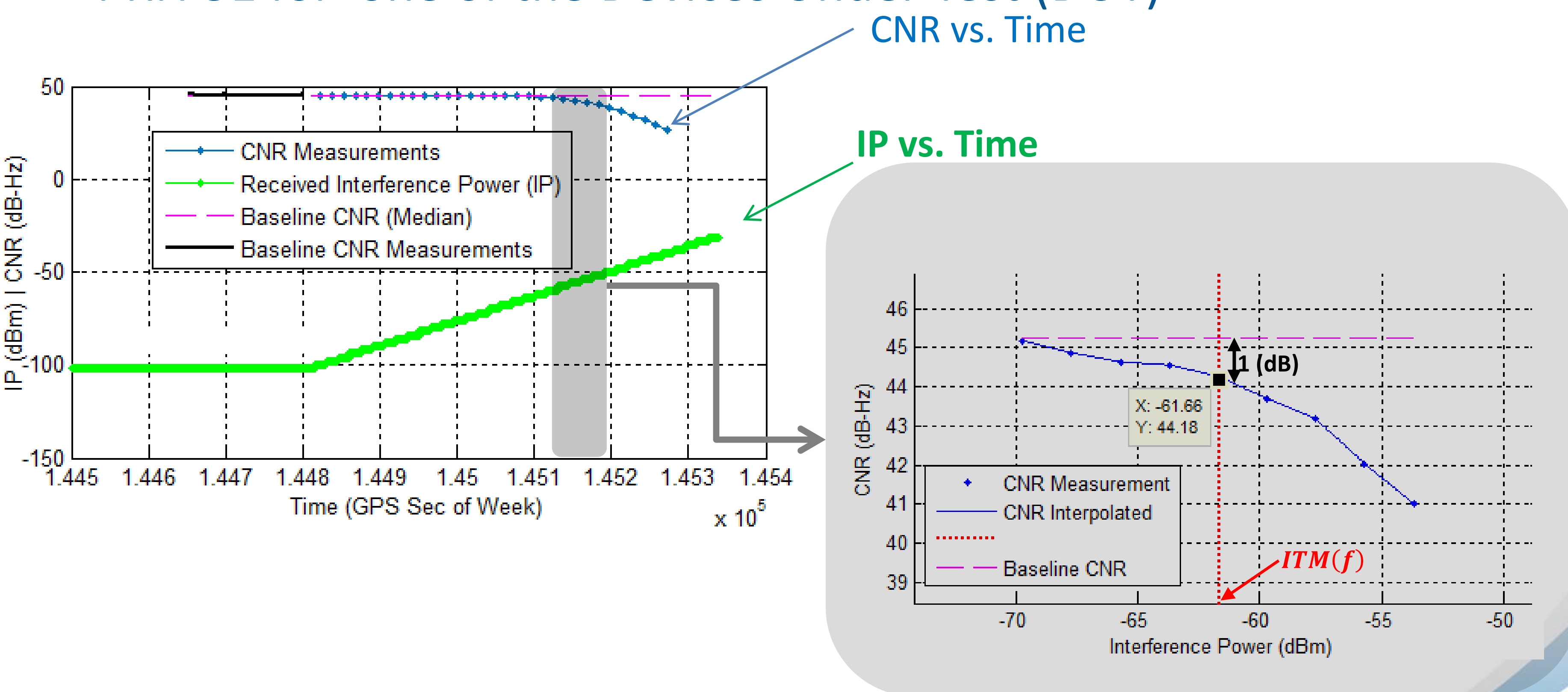
- Data collected to develop Interference Tolerance Mask (ITM) for receivers
  - Carrier signal to noise density ratio (CNR) recorded over varying interference power levels at numerous interference center frequencies



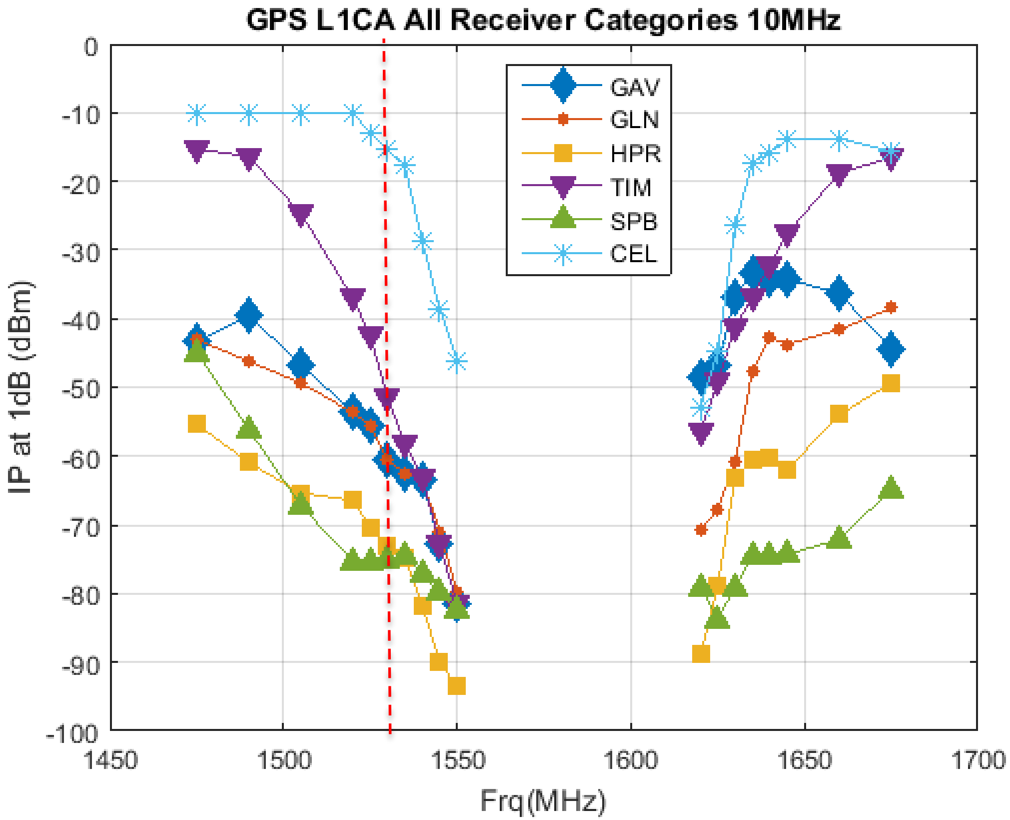
Interference Test Signal Frequencies and Power Profiles

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)

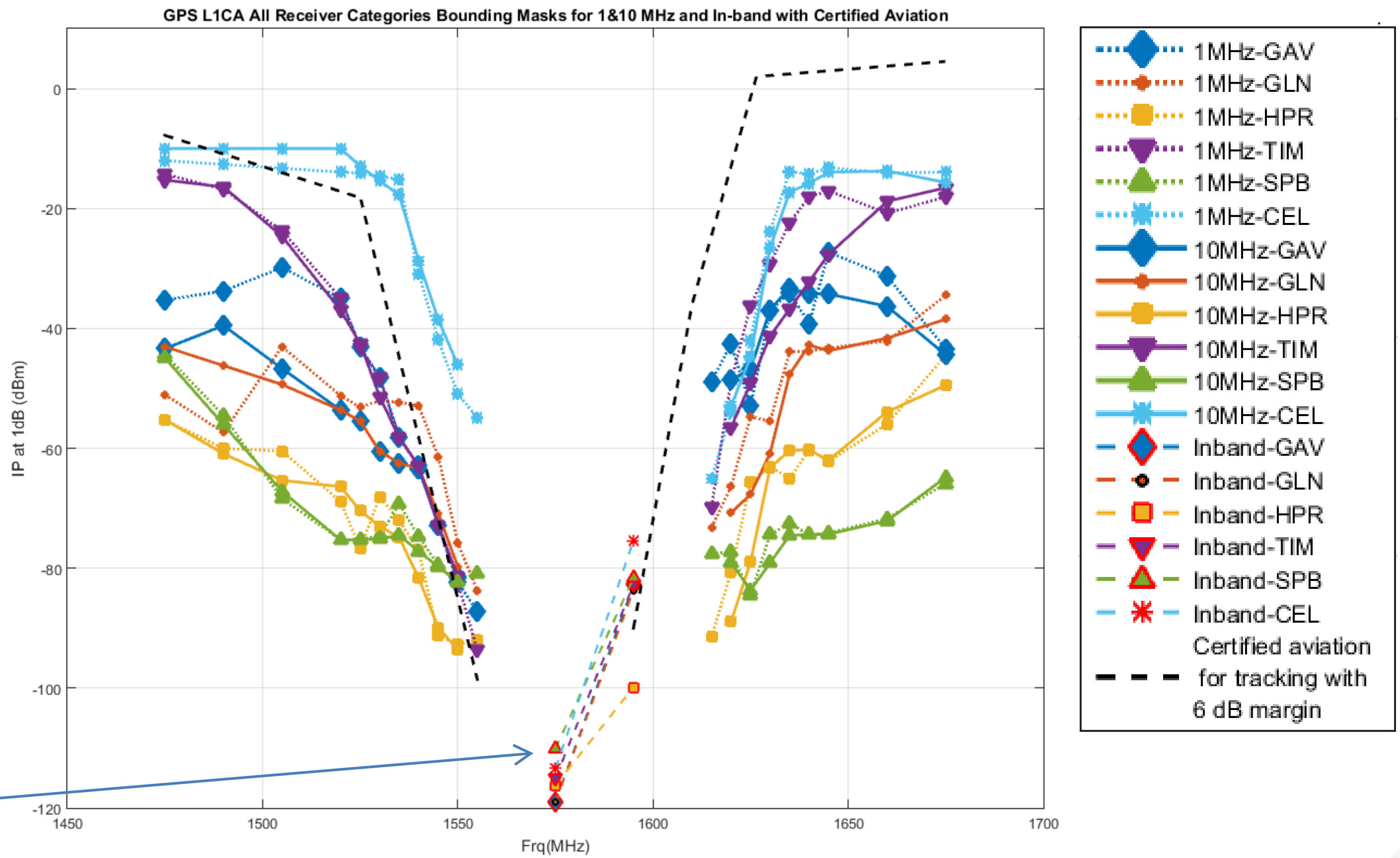


Summary of 10 MHz Bounding Masks GPS L1 C/A



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

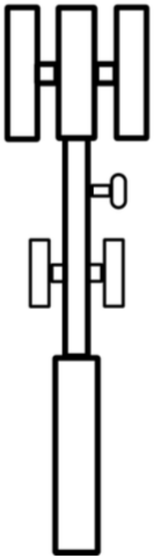
- In-band interference 1-dB degradation levels are consistent with expectation (-110 to -120 dBm/MHz for the L1C/A ITMs)

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

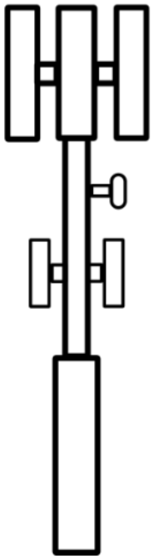
ITU-R: International Telecommunication Union Radiocommunication

ITU-R M.2292 Macro Base Stations



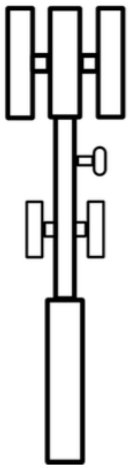
Macro Rural

- 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

Emergency Services Scenarios

Photo courtesy Tiero/ThinkStock

Drone/Emergency Response/Disasters

Photo courtesy StockSolutions/ThinkStock

Ankle Bracelet Monitoring

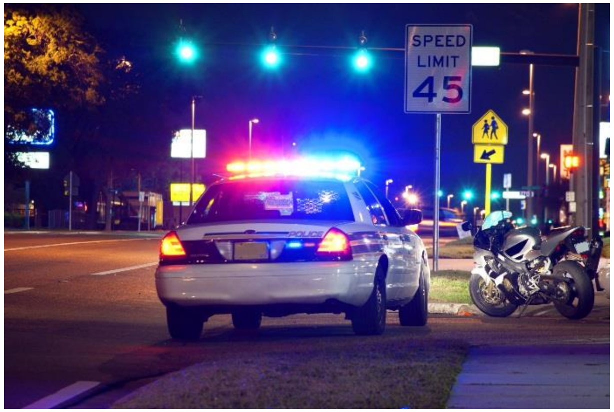


Photo courtesy Mokee81/ThinkStock

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

Why HPR as an Important Use Case?

- EXCOM Priorities
  - Focus on existing uses ✓
  - Vital Needs:
    - Economic ✓
    - Public Safety ✓
    - Scientific ✓
    - National Security ✓

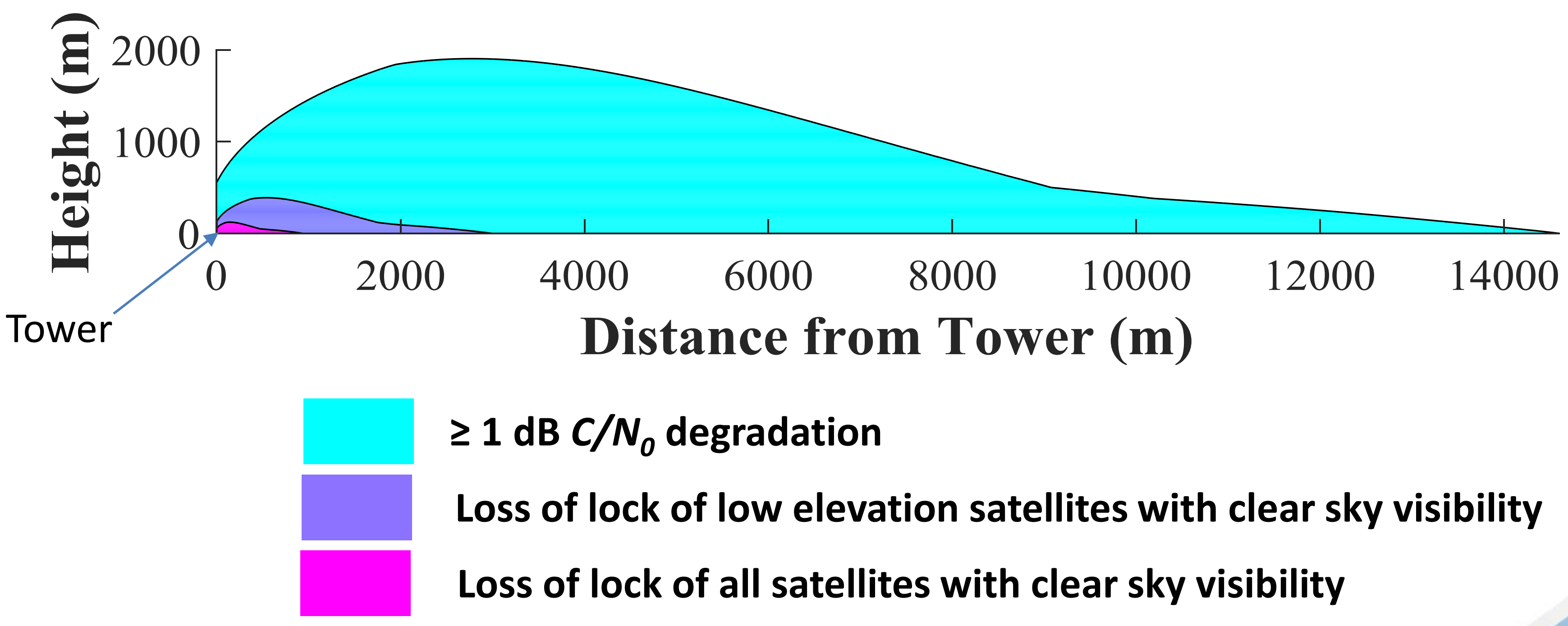
❑ PNT Advisory Board Priorities

- Focus on HPR and TIM ✓
- Focus analysis on most sensitive case ✓
- Apply the 1 dB degradation ✓
- Include GNSS ✓

Category	Existing Uses	Vital Needs				Most Sensitive ITM
		Economic	Public Safety	Scientific	National Security	
GAV	✓	✓	✓	✓	✓	
GLN	✓	✓	✓	✓	✓	
HPR	✓	✓	✓	✓	✓	✓
TIM	✓	✓	✓	✓	✓	
CEL	✓	✓	✓	✓		
SPB	✓	✓	✓	✓	✓	✓

Macro Urban Transmitter*
High Precision Receiver, 1530 MHz

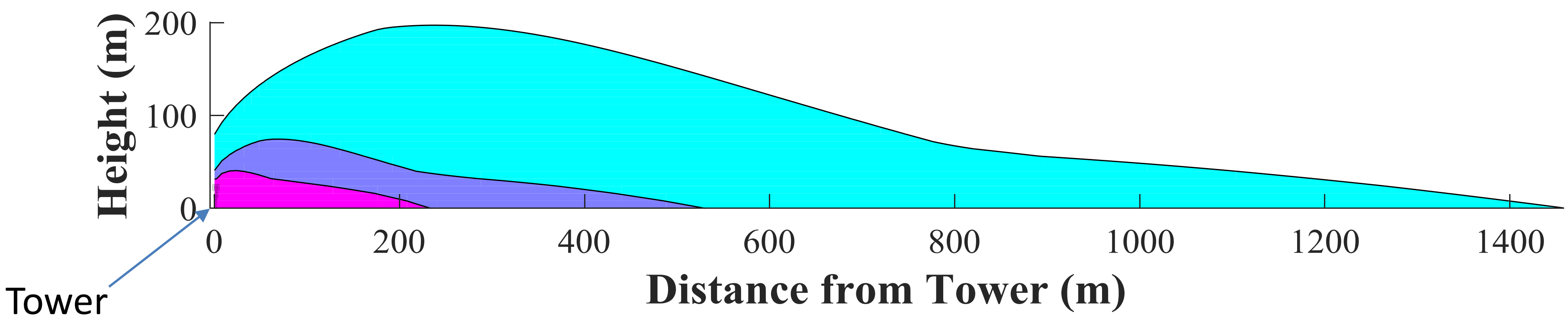
- EIRP = 59 dBm
- Sectors = 3
- Tower height = 25 m (82’)
- Downtilt = 10 degrees
- Frequency = 1530 MHz



* Based on ITU-R M.2292

Macro Urban, TIM, 1530 MHz

- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m (82')
- Downtilt = 10 degrees
- Frequency = 1530 MHz



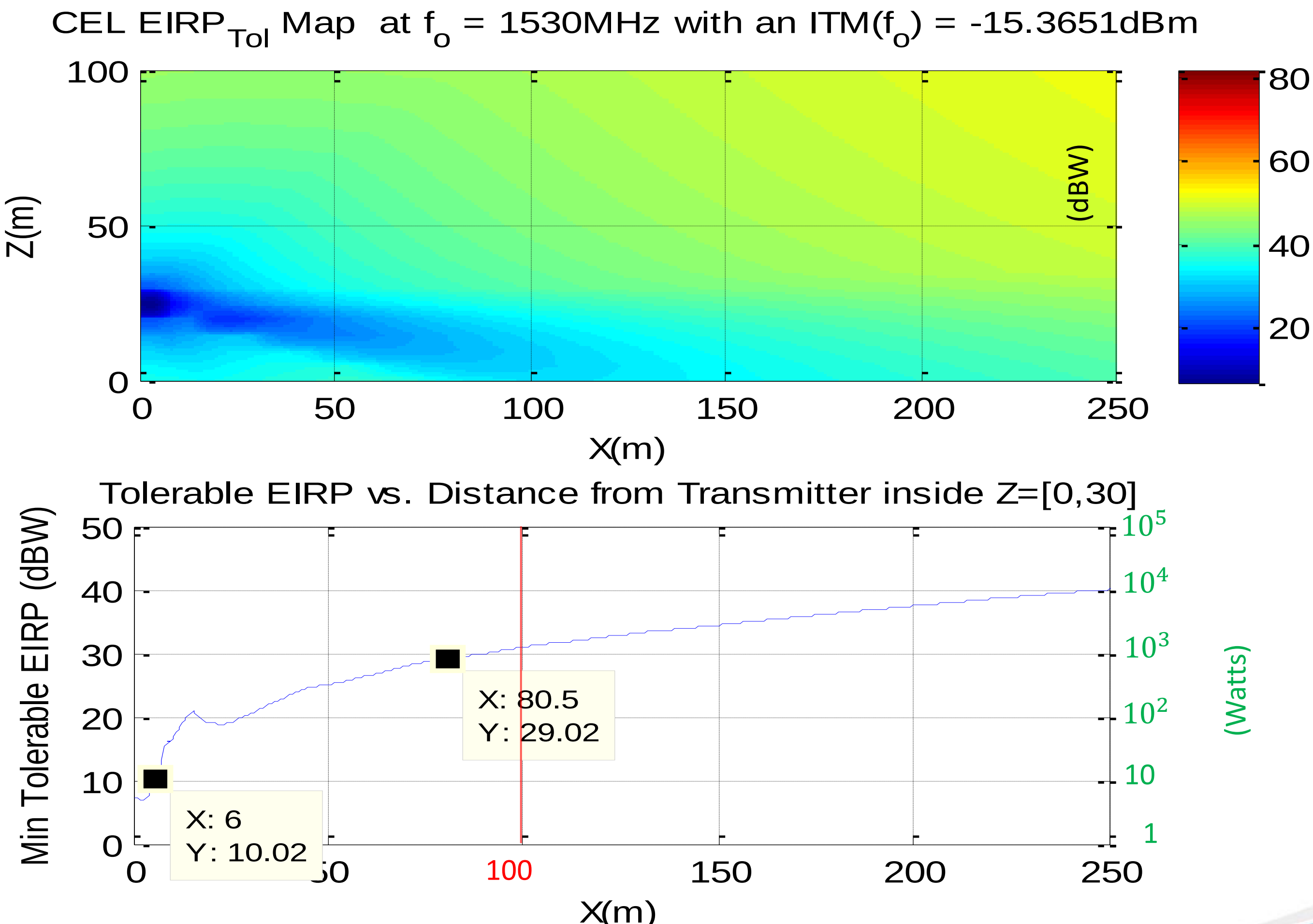
≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Inverse Modeling: CEL, 1530 MHz

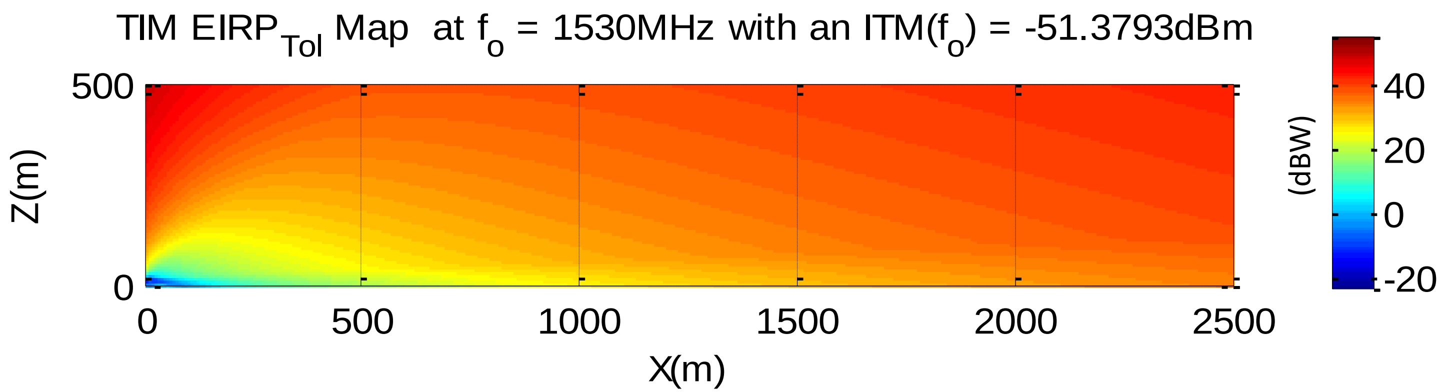
- Extent of the impact region: 80 m from Transmitter for EIRP of 29 dBW
  6 m for EIRP of 10 dBW

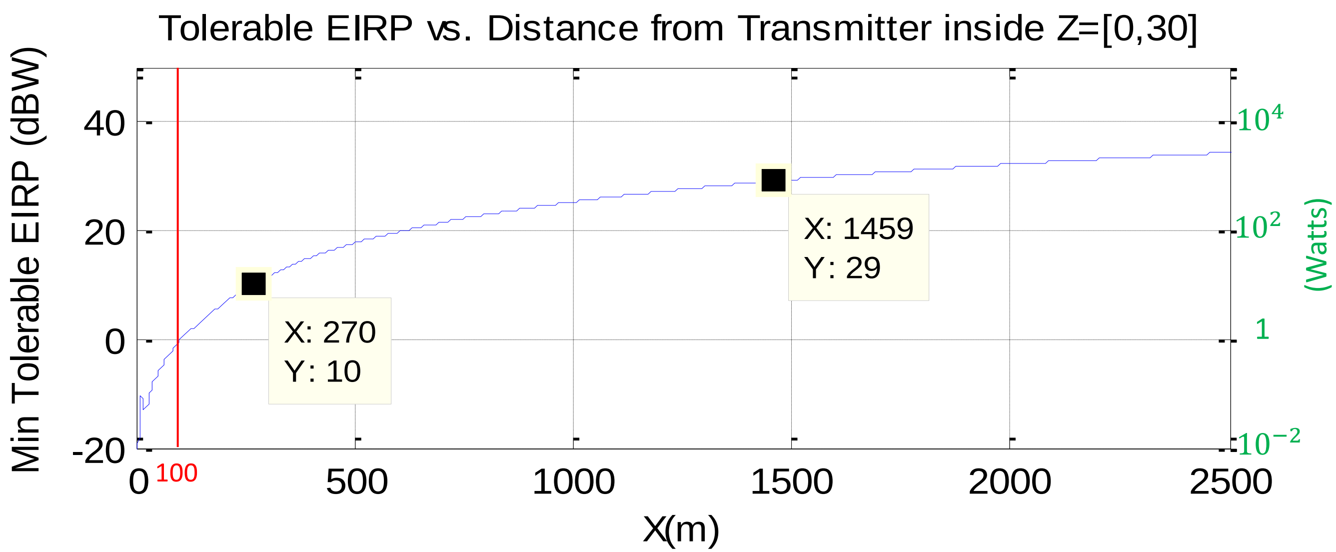


Inverse Modeling: TIM, 1530 MHz

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

  270 m for EIRP of 10 dBW

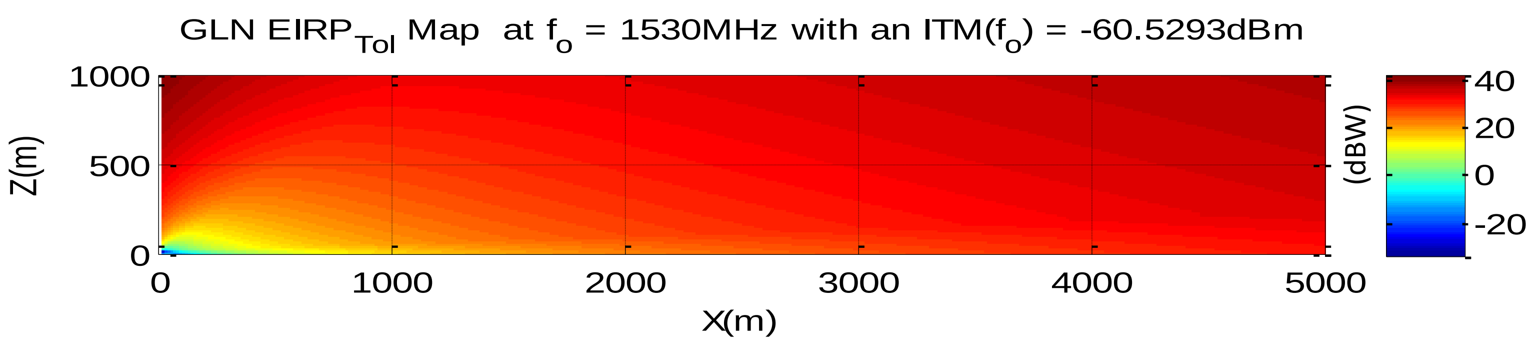


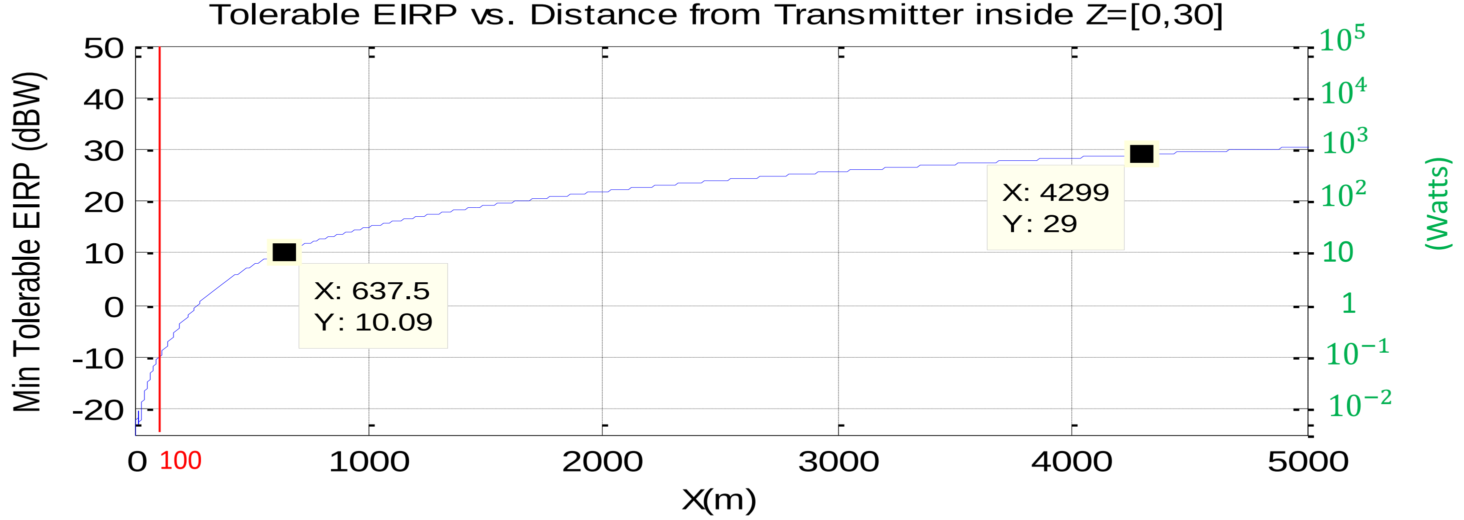


Inverse Modeling: GLN, 1530 MHz

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

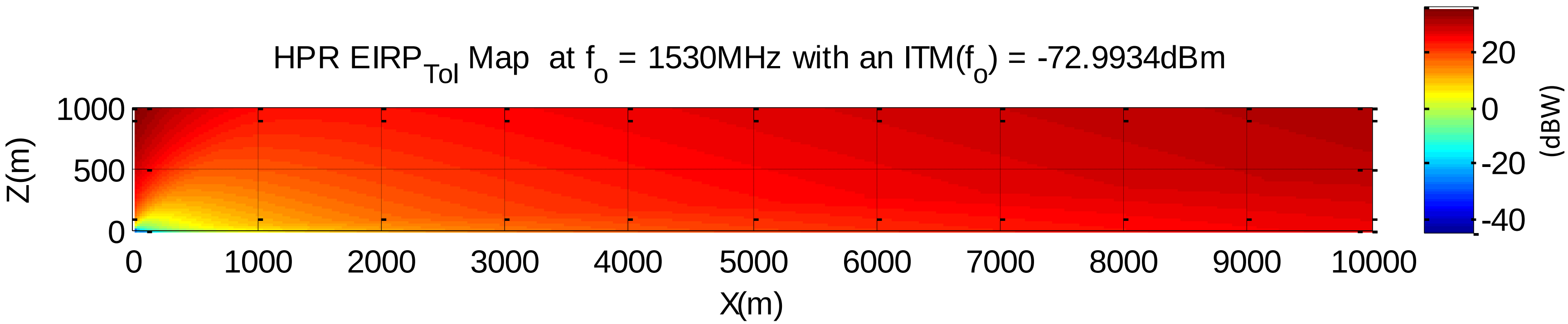
  600 to 650 m for EIRP of 10 dBW

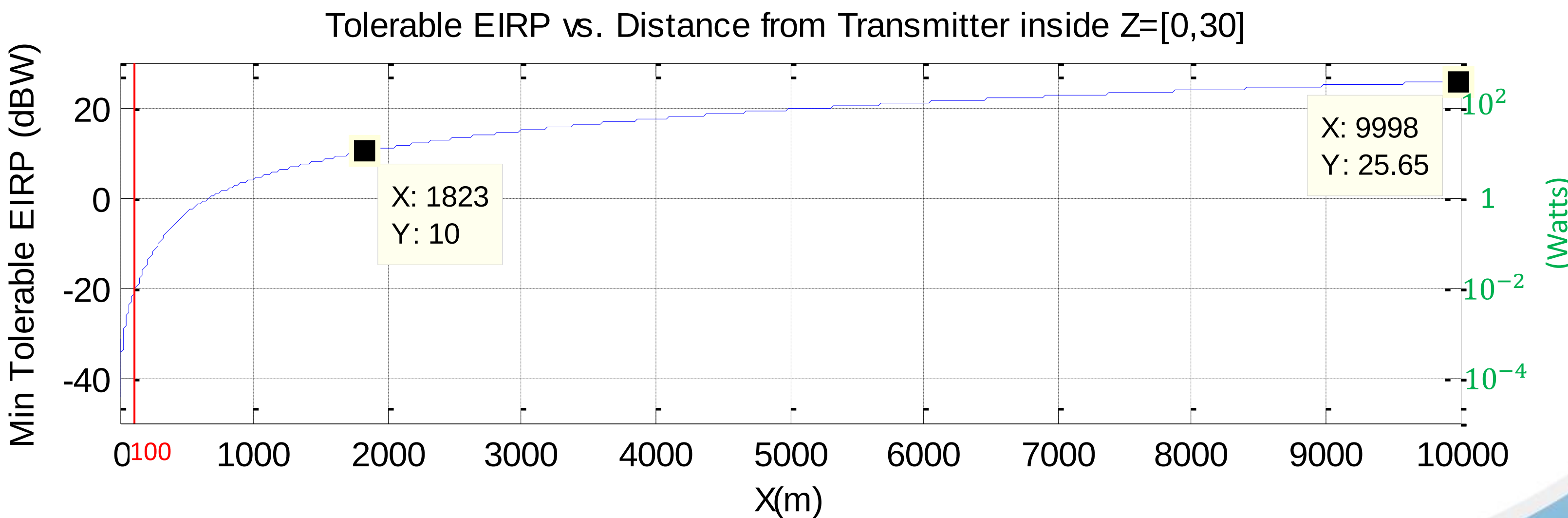




Inverse Modeling: HPR, 1530 MHz

- 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

- 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