APEC TPT-WG44

44th Transportation Working Group Meeting

April 25-28, 2017
Chinese Taipei

Subject: U.S. PNT Resiliency Update

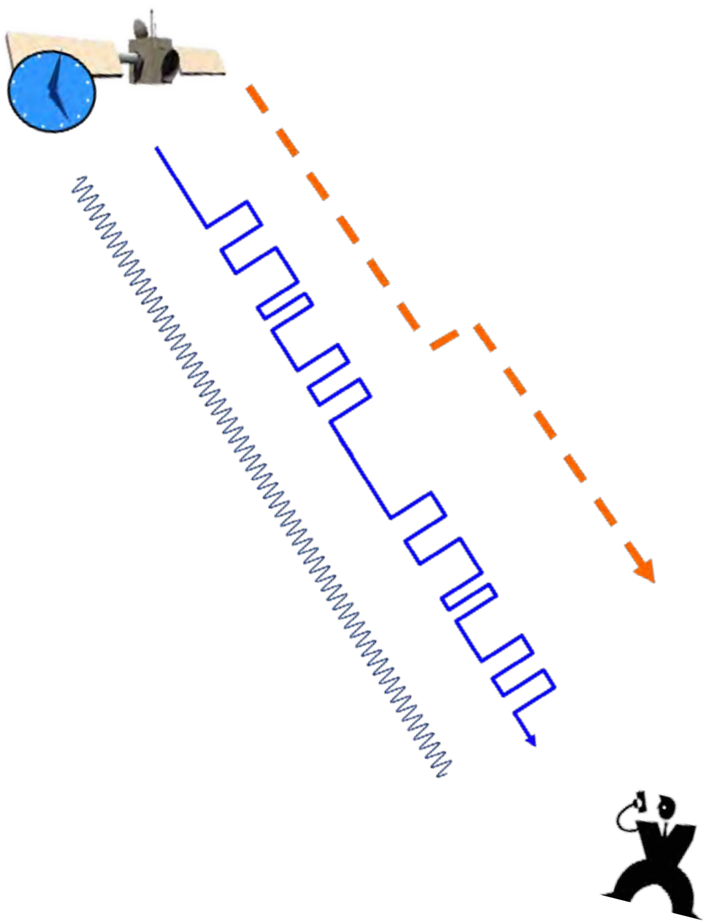
Presenter's Name: Ken Alexander

Economy: United States

Overview: U.S. GNSS Resiliency Update

- GNSS Power Primer
- U.S. Department of Transportation Adjacent-Band Compatibility Assessment
- Department of Homeland Security “Best Practices”
- U.S. Complementary PNT
- FAA Performance-Based Navigation Strategy

GPS/GNSS Power Primer



- **Satellites 23,000km away**
- **Signal is about 30W**
- **Radio waves disperse energy as they propagate**
- **GPS/GNSS signal is reduced**
  - **factor of about Quintillion times (Million x Trillion or 10^{18})**
  - **~ Billion times weaker than other nav signals (DMEs, VORs, ILS, etc.)**
- **Signal is below background radiation noise level**

U.S. DOT GPS Adjacent Band Compatibility Assessment

GPS Adjacent Radiofrequency Band Compatibility Assessment

Objective: Identify adjacent band transmit power levels that can be tolerated by existing GNSS receivers for civil applications

Activities led by DOT/OST-R/Volpe Center:

(Excluding certified aviation applications addressed in a parallel FAA activity)

- 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 with Federal Partners and Industry
- Released public GNSS receiver test plan and developed in-depth GNSS receiver test procedures
- 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

Radiated Testing Overview

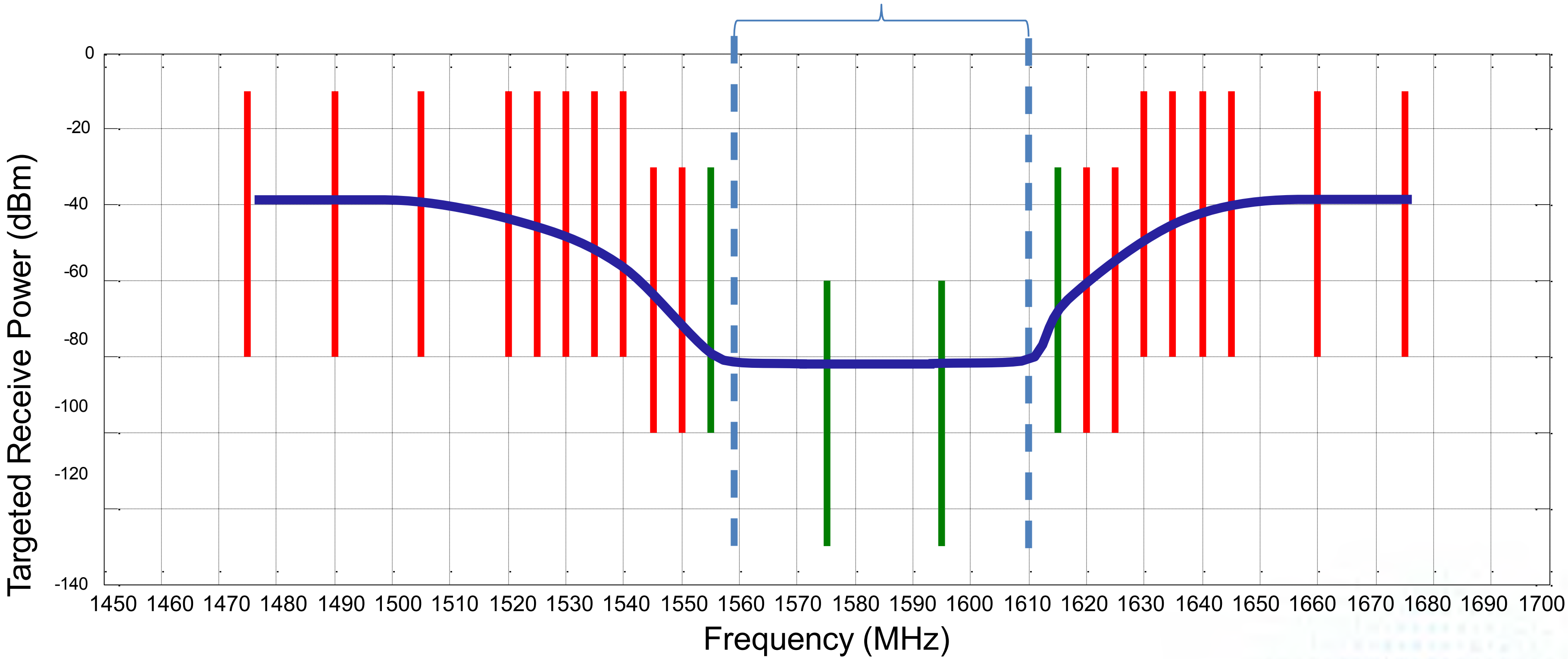
- GNSS receiver testing conducted April 25-29, 2016 at Army Research Laboratory's (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF), White Sands Missile Range (WSMR), NM
- Participation included DOT's Federal partners/Agencies (USCG, NASA, NOAA, USGS, and FAA) and GPS manufacturers
  - Air Force/GPS Directorate conducted testing week of April 18^{th}
- Tests performed in anechoic chamber:
  - Linearity (receivers CNR estimators operating in 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)

Categories GPS/GNSS Receivers Tested

- 80 receivers tested representing six categories of GPS/GNSS receivers:
  - GAV - General Aviation (non certified)
  - GLN - General Location/Navigation
  - HPR - High Precision & Networks
  - TIM - Timing
  - SPB - Space Based
  - CEL - Cellular

Interference Test Signal Frequencies and Power Profiles

Radionavigation Satellite Service (RNSS) Band



- Type 1 and 2 Signals
- Type 1

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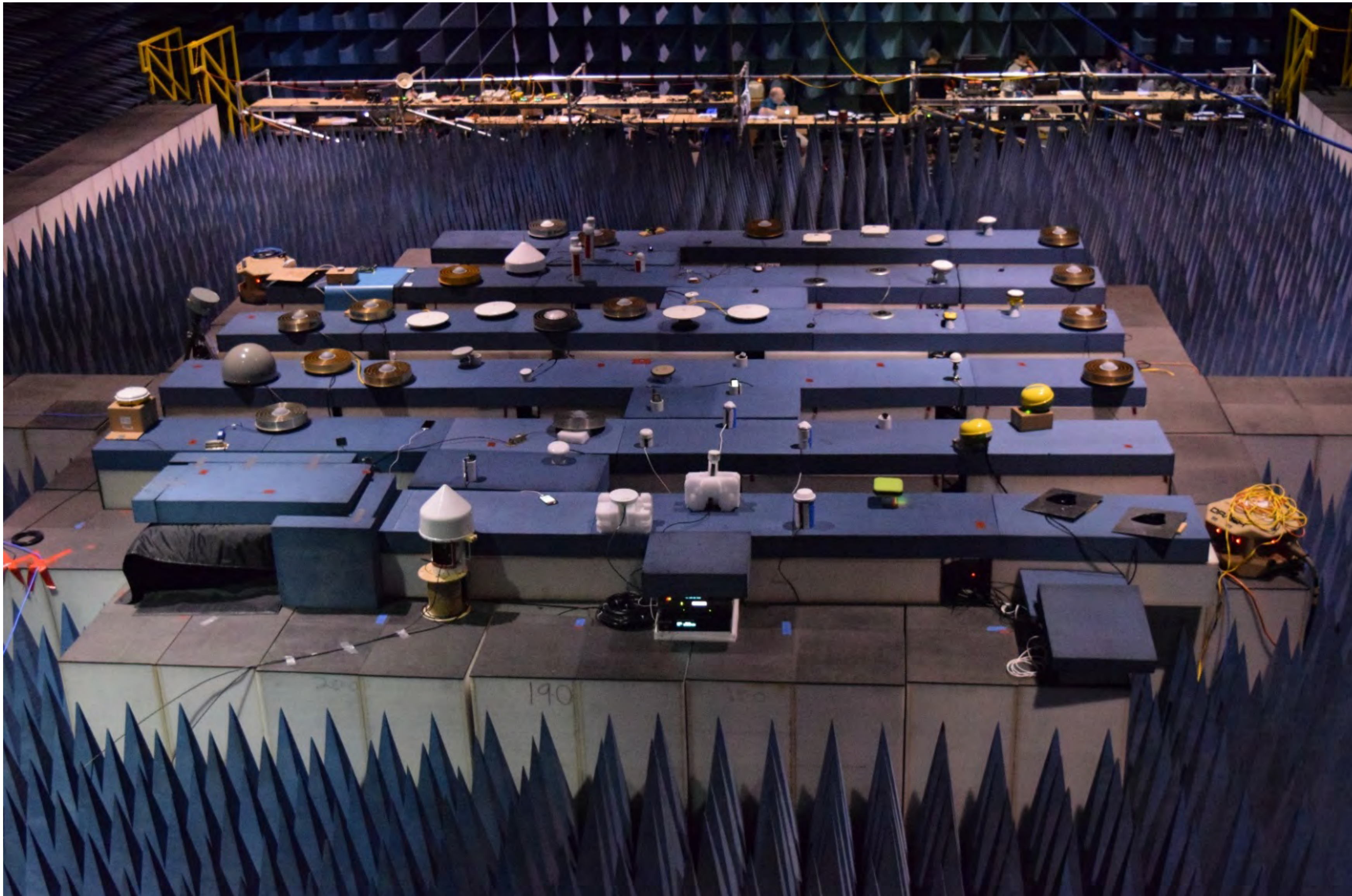
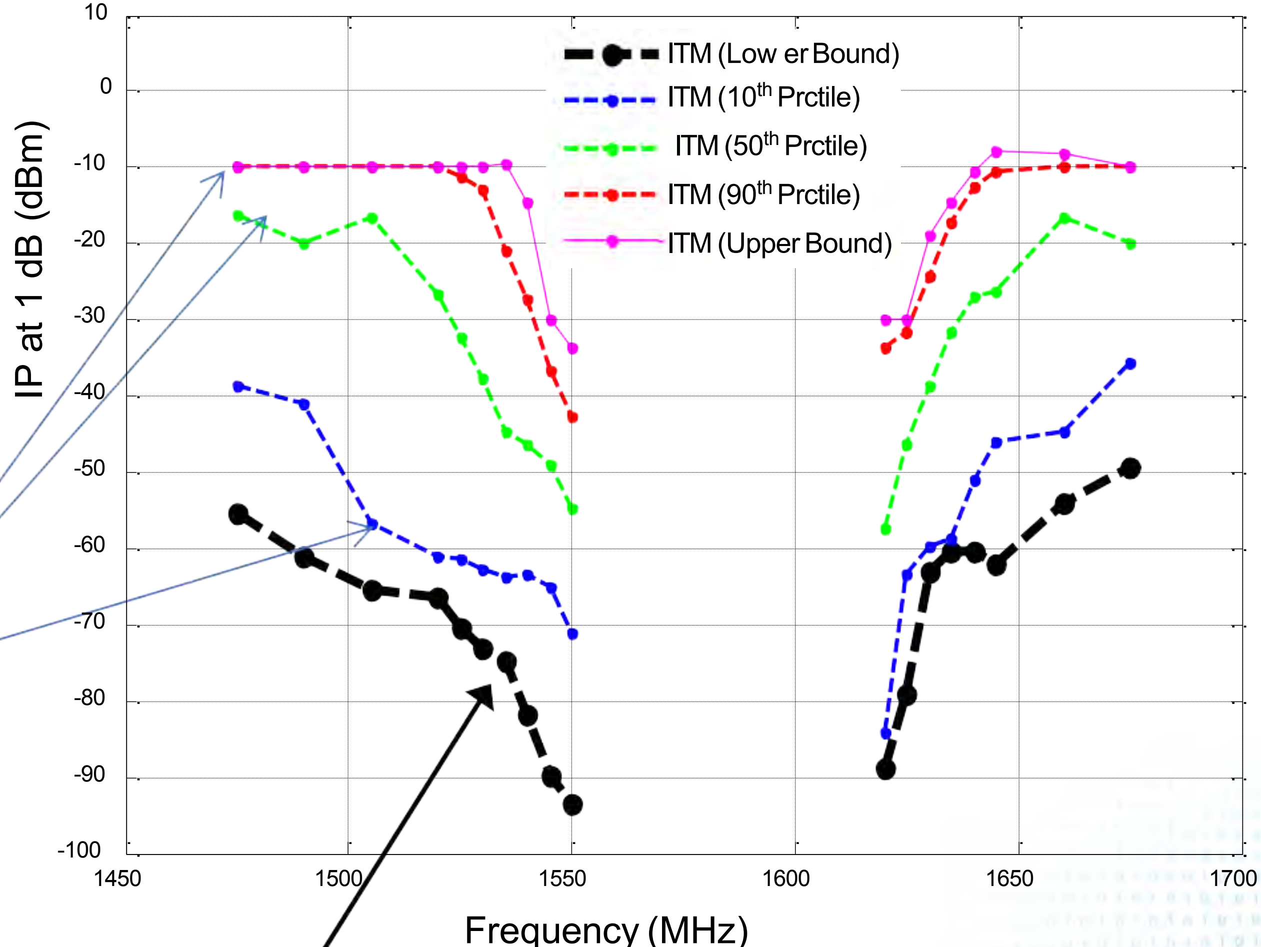
Chamber Test Grid and Setup



GNSS Test Signals Used

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

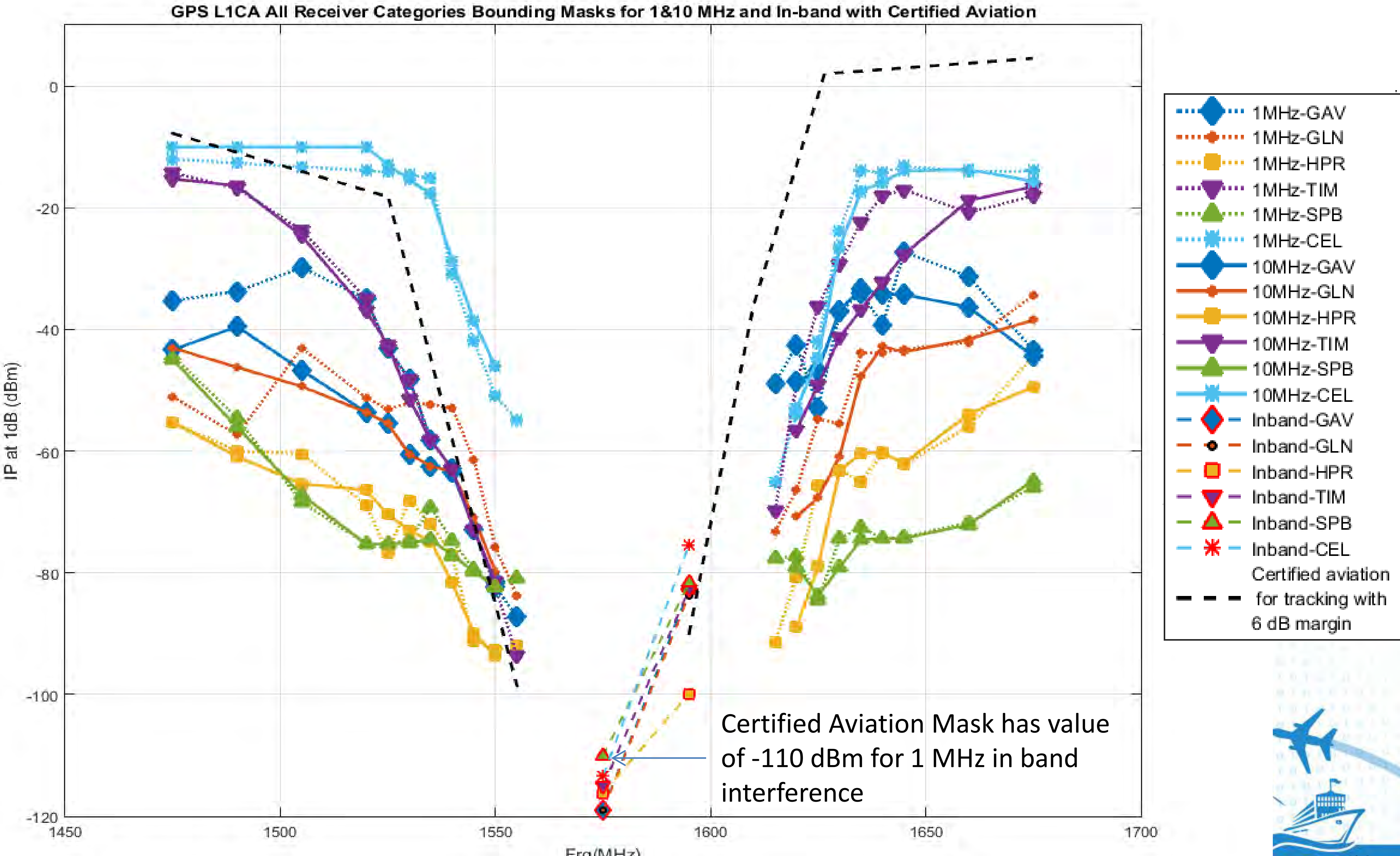
Aggregate Results for L1 C/A High Precision Receiver Category



GPS L1 C/A ITM lower bound and different percentiles corresponding to the HPR category

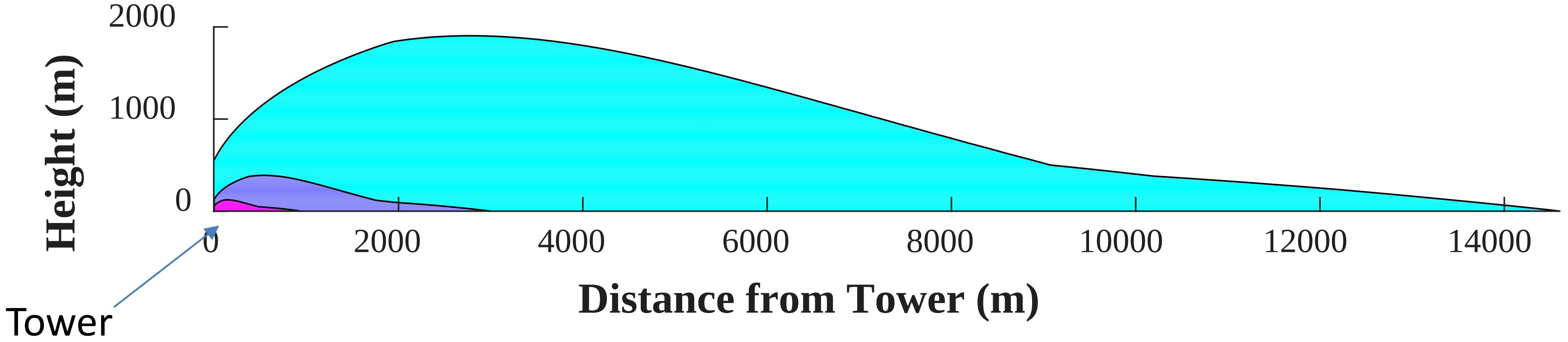
The lower the ITM percentile, the more protection it offers
The bounding ITM (black) protects all tested receivers

Summary of 1&10 MHz and In-band with Certified Aviation Bounding Mask



Macro Urban
High Precision Receiver, 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

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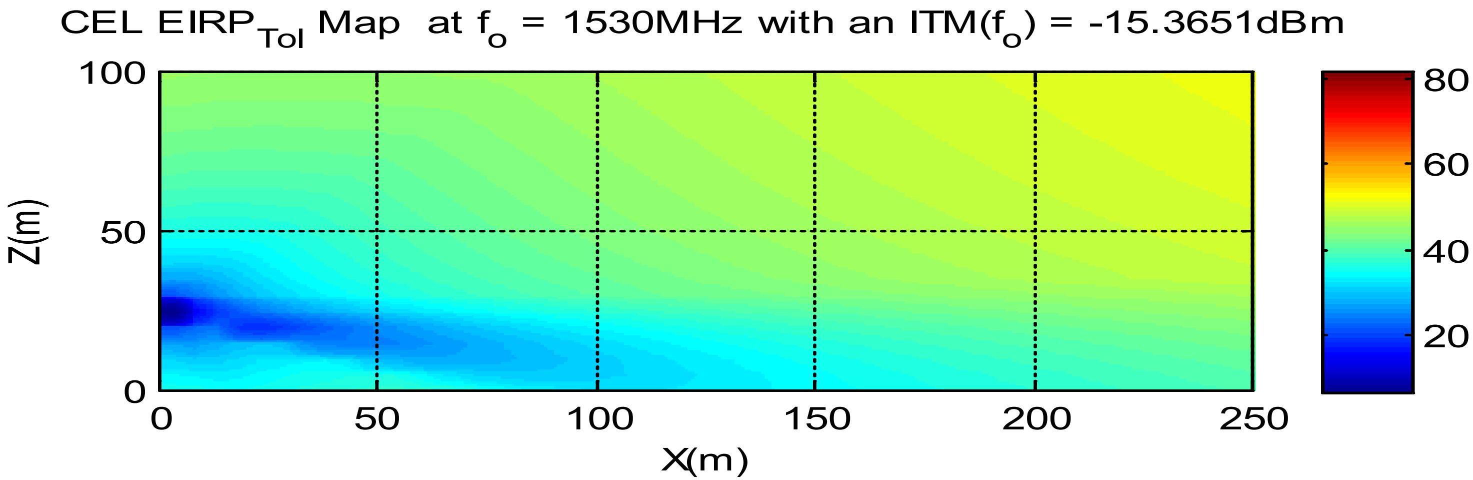
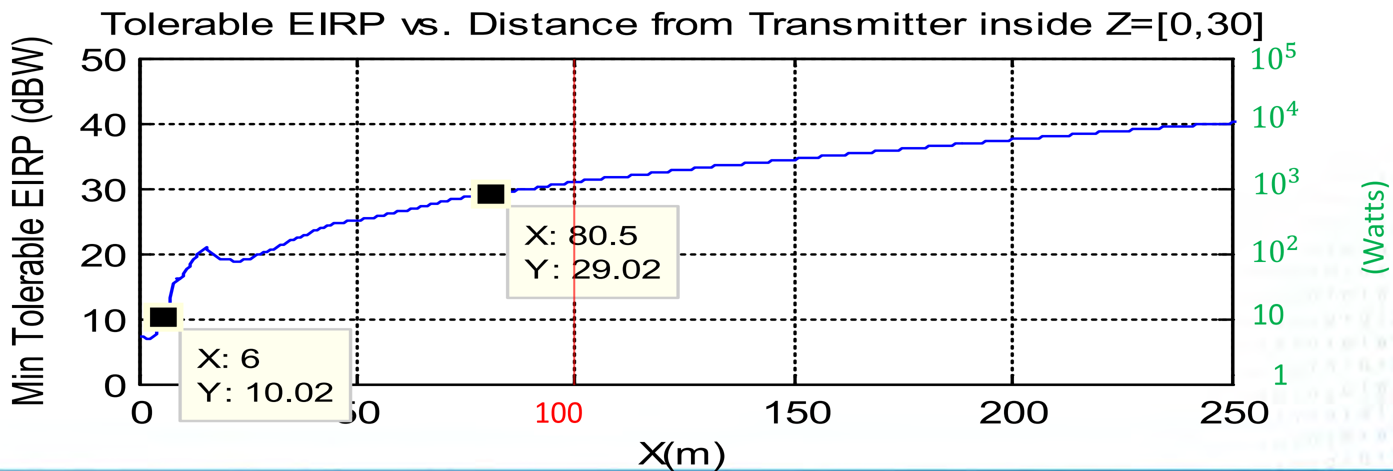
Inverse Modeling:
Cellular (CEL), 1530 MHz

Impact region: 80 m from Transmitter for EIRP of 29 dBW
6 m for EIRP of 10 dBW





Inverse Modeling: General Location Navigation (GLN) 1530 MHz

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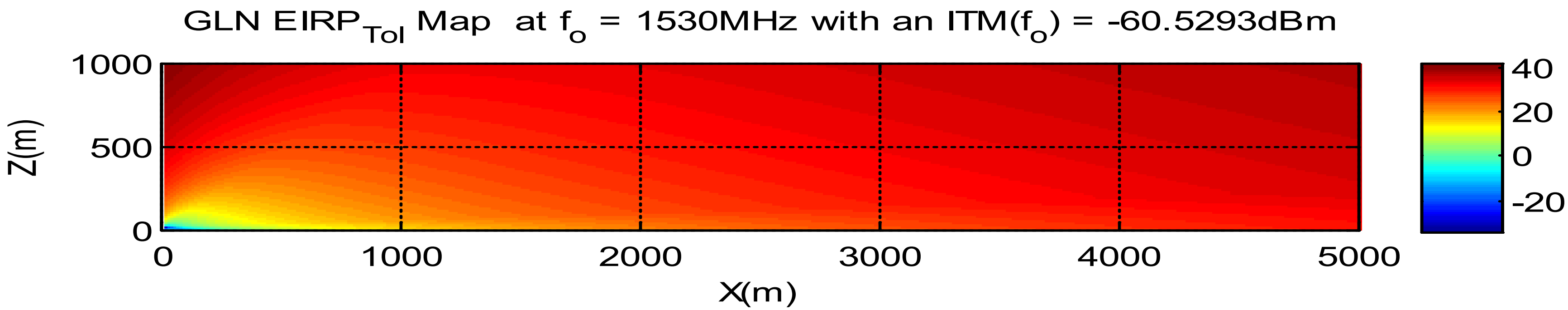
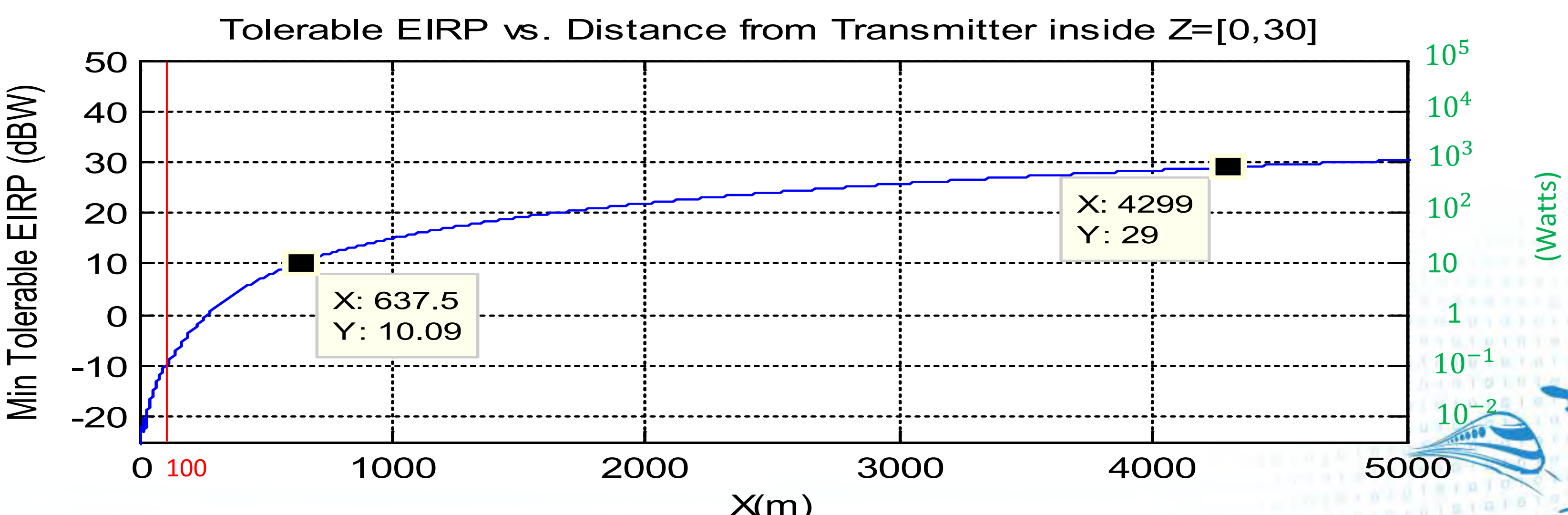
Impact region: 4 to 4.5 km from Transmitter for EIRP of 29 dBW
600 to 650 m for EIRP of 10 dBW

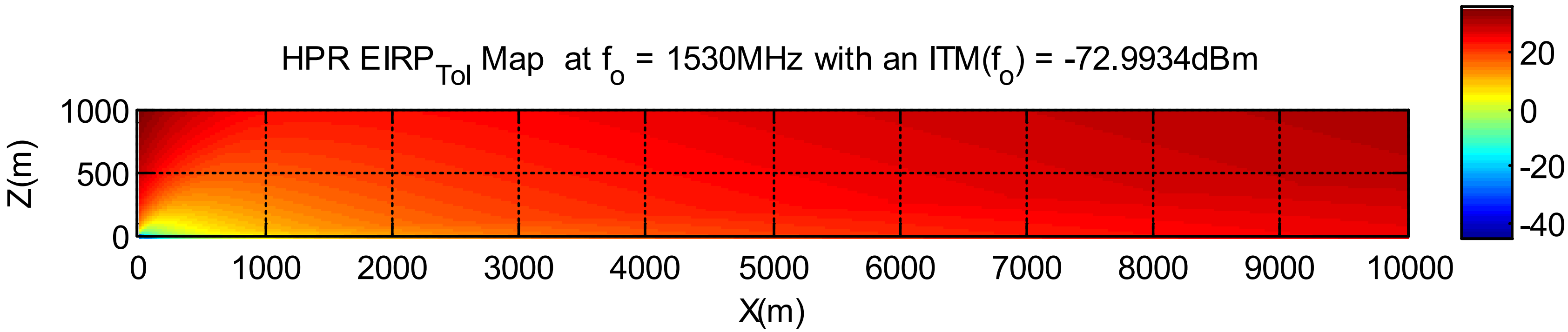


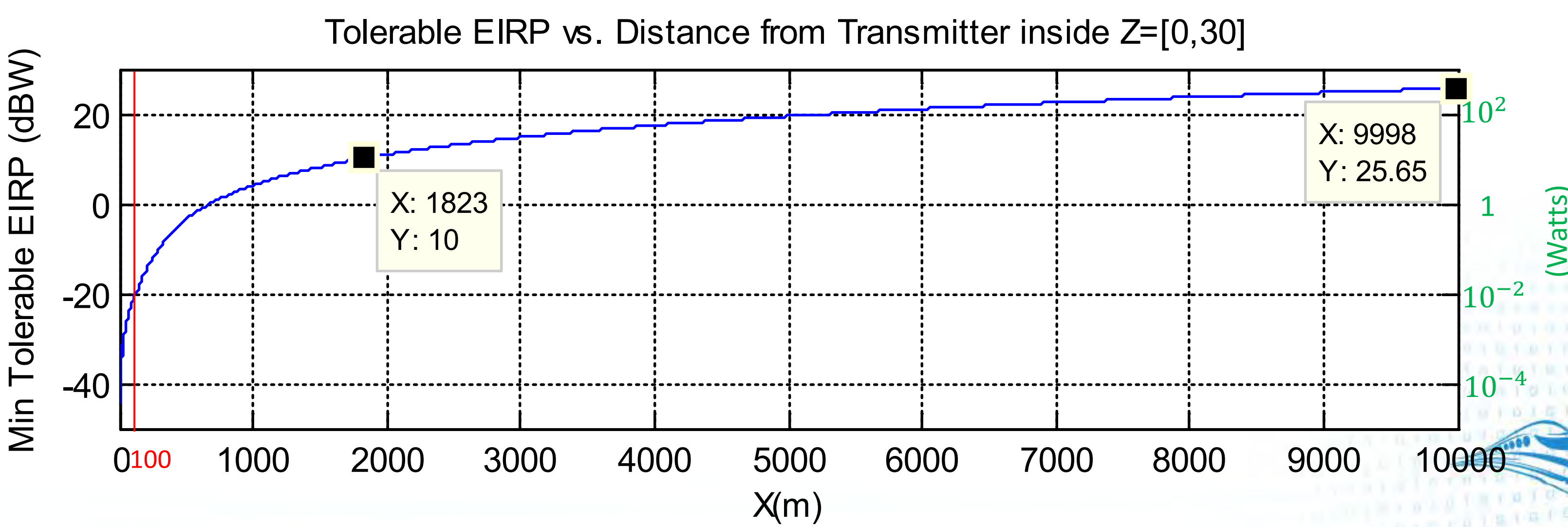


Inverse Modeling: High Precision Receiver HPR, 1530 MHz

Impact region: >10 km from Transmitter for EIRP of 29 dBW

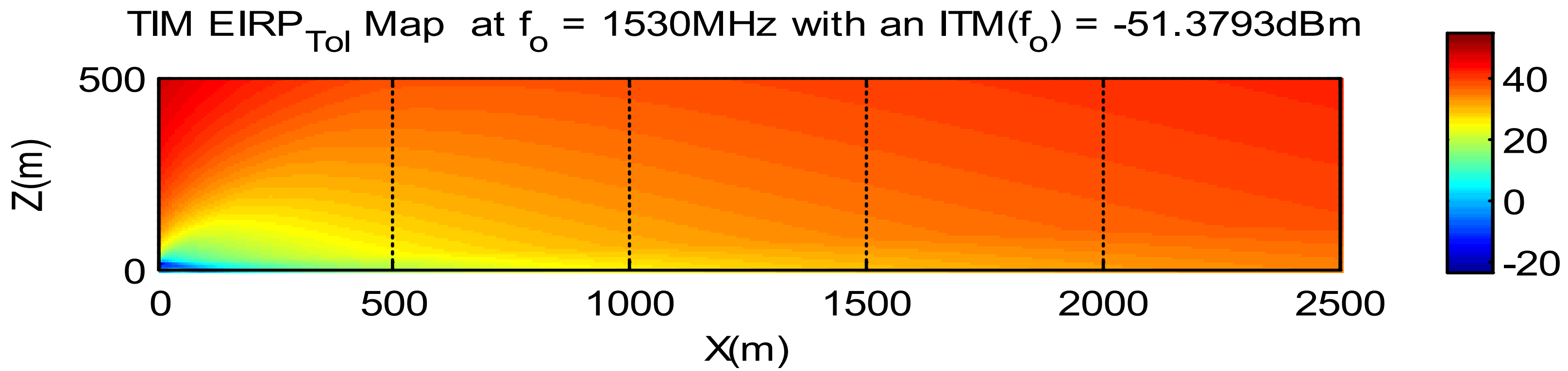
1.5 to 2 km for EIRP of 10 dBW

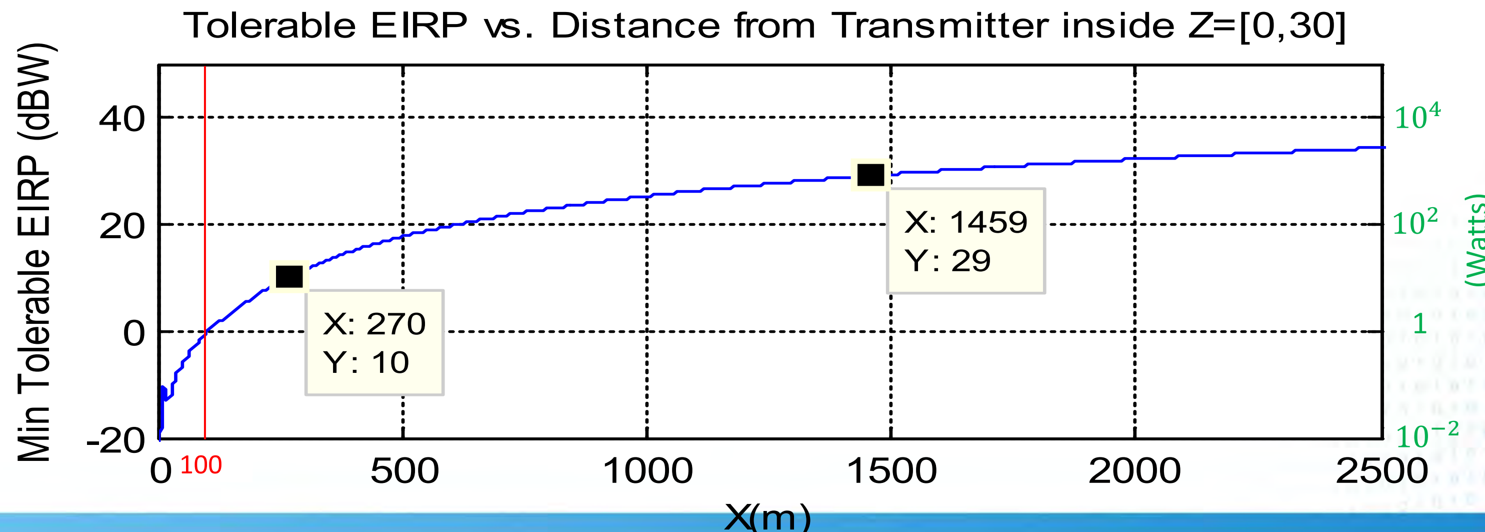




Inverse Modeling: Timing Receivers (TIM), 1530 MHz

Impact region: 1.5 km from transmitter for EIRP of 29 dBW
270 m for EIRP of 10 dBW





Summary: Inverse Modeling Results (Single Base Station)

	Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
			GLN	HPR	TIM	CEL
1475 MHz	Macro Urban	10	-14.4	-24.0	14.6	N/A*
		100	5.6	-4.0	34.6	N/A*
	Micro Urban	10	-13.5	-23.0	14.8	N/A*
		100	6.5	-3.0	34.8	N/A*

	Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
			GLN	HPR	TIM	CEL
1530 MHz	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

*N/A = not applicable; no degradation at maximum power at WSMR.

Summary: Inverse Modeling Results (Single Base Station) in Linear Form

Frequency	Deployment	Stand off distance (m)	Max Tolerable EIRP			
			GLN	HPR	TIM	CEL
1475 MHz	Macro Urban	10	36.3 mW	4 mW	28.8 W	N/A*
		100	3.6 W	0.4 W	2.9 kW	N/A*
	Micro Urban	10	44.7 mW	5 mW	30.2 W	N/A*
		100	4.5 W	0.5 W	3 kW	N/A*

Frequency	Deployment	Stand off distance (m)	Max Tolerable EIRP			
			GLN	HPR	TIM	CEL
1530 MHz	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

*N/A = not applicable; no degradation at maximum power at WSMR.

Next Steps

- Finalize use case analysis based on feedback from March 30th public workshop
- Complete DOT GPS Adjacent Band Compatibility Assessment Final Report
  - Including certified avionics and non certified receivers analysis
- Issue Final Report for Public Review and Comment

DEPARTMENT OF HOMELAND SECURITY "BEST PRACTICES"

DHS NCCIC Released “Best Practices” (BP)

- Guidance and best practices related to GPS equipment can be found in U.S. Department of Homeland Security Jan 6, 2017 public document:

  Improving the Operation and Development of Global Positioning System (GPS) Equipment Used by Critical Infrastructure

  https://ics-cert.us-cert.gov/sites/default/files/documents/Improving_the_Operation_and_Development_of_Global_Positioning_System_(GPS)_Equipment_Used_by_Critical_Infrastructure_S508C.pdf

- IS-GPS-200 Revision H, IRN003, 28 July 2016 identifies data valid ranges
- Best Practices identifies 22 specific recommendations
  - 11 installation & operational strategies for current user equipment
  - 11 developmental opportunities for new products to mitigate spoofing
  - Additionally identifies specific research opportunities


Homeland Security

Improving the Operation and Development of Global Positioning System (GPS) Equipment Used by Critical Infrastructure

FAA SBAS TSOs and LAAS MOPS

Adds Cybersecurity and GPS spoofing mitigation to Section 1 of RTCA/DO-229E (SBAS TSO Appendix 2)

- Consistent with RTCA DO-253D (LAAS) Standard (Pending)
- Cross-checks of GNSS sensor data against:
  - Independent position sources and/or
  - Other detection monitors using GNSS signal metrics or
  - Data checks implemented in antenna, receiver, and/or
  - Through integration with other systems at aircraft level
- Data validity checks to recognize and reject measurement and data spoofing consistent with:
  - DHS Best Practices document and
  - IS-GPS-200 Revision H, IRN003, 28 July 2016

SBAS TSOs & LAAS MOPS (continued)

- Addresses aircraft equipment cybersecurity information security vulnerability mitigation techniques
- Physical isolation for security of avionics should not be assumed adequate
  - Recommends a layered approach to aircraft information security risk mitigation that includes both technical (e.g., software, signal filtering) and physical strategies
  - Addresses supply chain risk management (for example, if a manufacturer is outsourcing software code development, is the contractor and its staff properly vetted?)
- Requires the applicant to consider how vulnerability could propagate to downstream systems
- Public comment closed April 17, 2017
  https://www.faa.gov/aircraft/draft_docs/tso/

U.S. COMPLEMENTARY PNT

Complementary PNT

- EXCOM reaffirmed need for PNT complement(s) to GPS
- Recent Activities:
  - Assessment update considered many factors -- policy to technology
  - U.S. coverage in event of GPS/GNSS outage (natural or man-made events)
  - Identified and assessed alternatives including a broad mix of terrestrial RF and autonomous PNT technologies
  - Federal Cooperative Research and Development Agreement established with Industry
- Public stakeholder input obtained by Federal Register Notice
- Federal Register Notice issued to identify Timing requirements

Complementary PNT Service for National Critical Infrastructure Resiliency

- 2016 Timing RFI Focus Areas
  - Nationwide CI Timing Application Coverage for a GPS Backup
  - Regional/Local CI Timing Application Coverage for a GPS Backup
  - Nationwide or Regional/Local CI Timing Application Coverage Additional to GPS Capabilities
  - POC: Karen L. Van Dyke, Director, Positioning, Navigation, and Timing & Spectrum Management, DOT
  - Response Timeline: January 30, 2017

  https://www.federalregister.gov/documents/2016/11/30/2016-28805/positioning-navigation-and-timing-pnt-service-for-national-critical-infrastructure-resiliency
- 2016 National Defense Authorization Act (NDAA)

  Tasks "Covered" Secretaries (DoD, DHS, & DOT) to: Jointly conduct a study to assess and identify technology-neutral requirements to backup and complement the PNT capabilities of the Global Positioning System for national security and critical infrastructure

CPNT Validation

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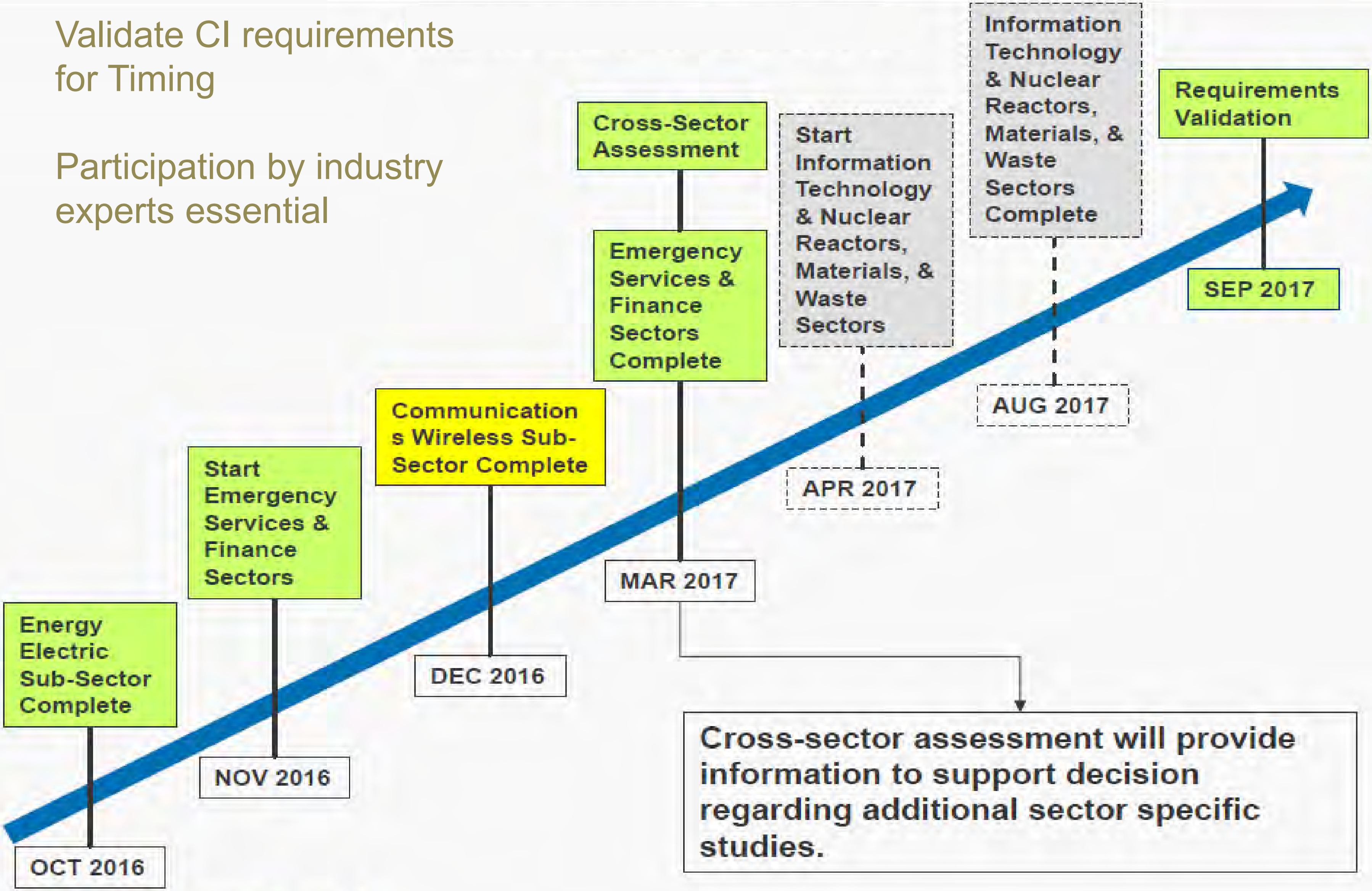
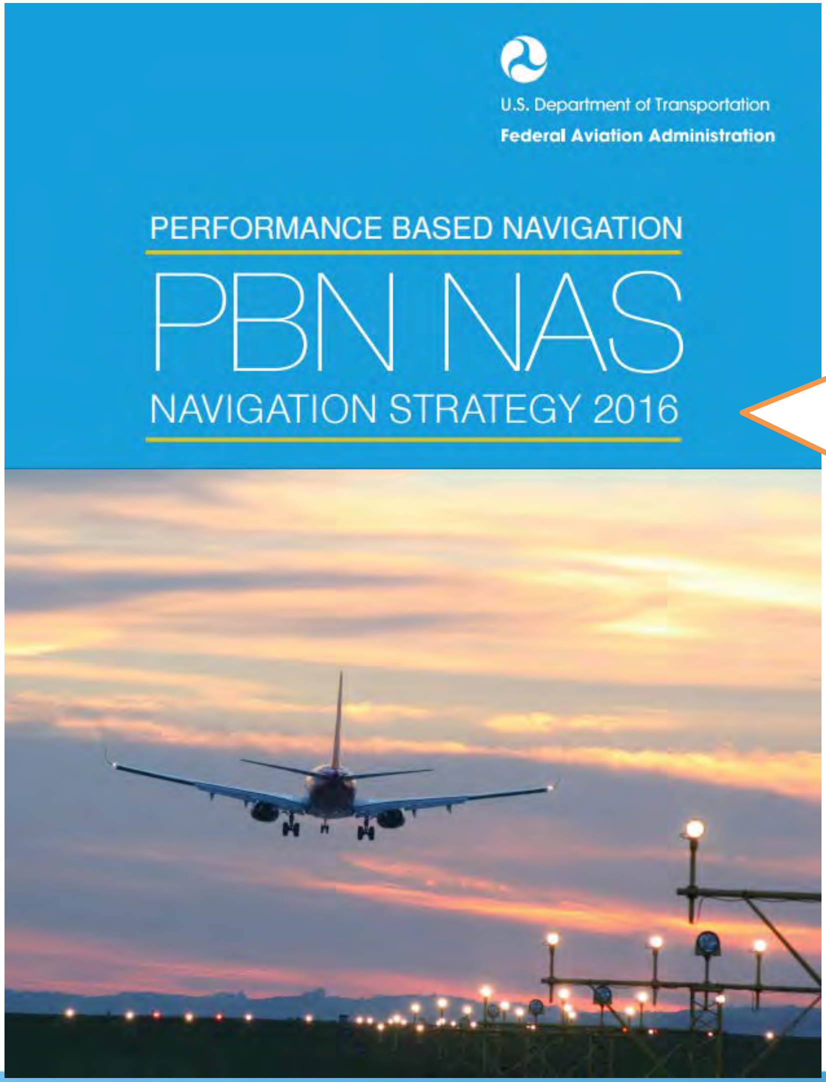
Validate CI requirements for Timing

Participation by industry experts essential



FAA Performance Based Navigation (PBN) Strategy



Signed by the Administrator in October 2016, defining the next 15 years of PBN Implementation for the agency.
Download Here

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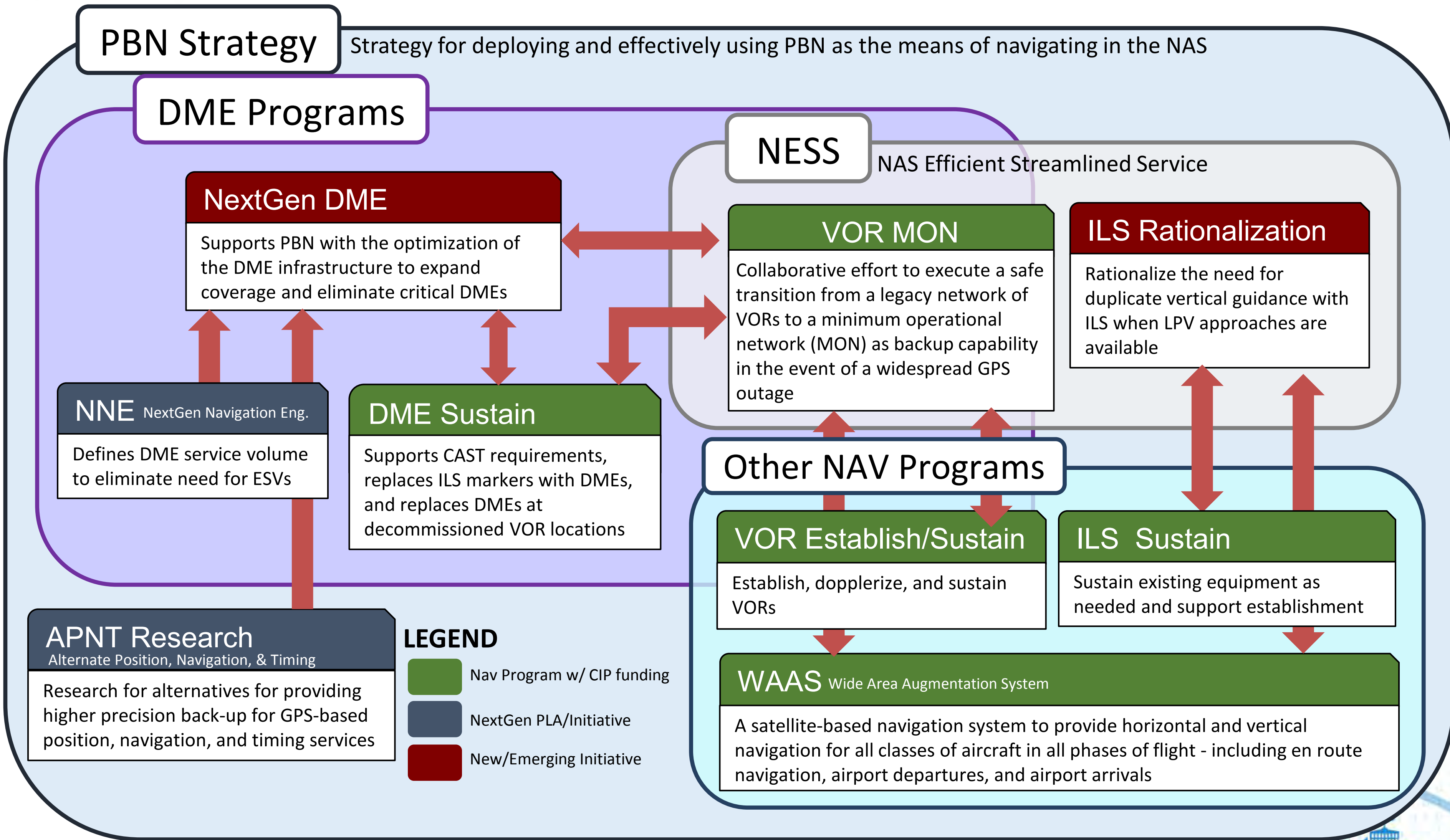
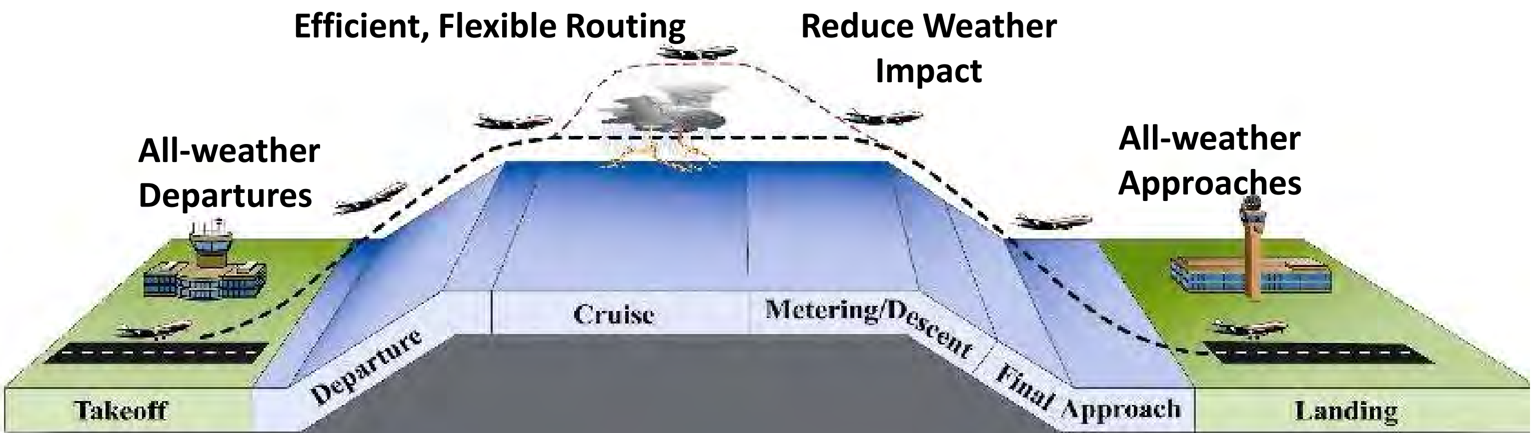
PBN Strategy Goals by Benefit Area

	Near-Term (2016-2020)	Mid-Term (2021-2025)	Far-Term (2026-2030)
Improved predictability		• Key airports transitioned to time and speed-based management	• NAS transitioned to time and speed-based management
More cost effective & agile service delivery	• Shorten development and implementation time for new ATS routes by removing rulemaking requirement • **Begin ILS Rationalization at NSG 4-5 airports**	• Develop integrated procedure design tools • Digital delivery of navigation chart data • Develop automation for periodic review of procedures • **Continue ILS Rationalization at NSG 4-5 airports**	• **ILS rationalization complete at NSG 4 and 5 airports** • **ILS rationalization analysis for NSG 1, 2, and 3 airports**
Increased access	• Update regulations to allow SVGS for qualifying approaches • Update regulations to allow EFVS operations to touchdown • **Criteria for SA CATI/1800 RVR and SA CATII for LPV**		
Improved resiliency	• **DME/DME coverage expanded for NSG 1 and 2 airports based on site-specific evaluations** • **Class A airspace is covered by DME/DME (IRU not required) redundancy** • **Discontinue 70 VORs by end of near-term**	• **DME/DME coverage expanded for NSG 1 and 2 airports based on site-specific evaluations** • **Approx. 200 more VORs will be discontinued by end of mid-term**	• **Re-evaluation of need for remaining VOR facilities**

Navigation Programs Strategic Alignment



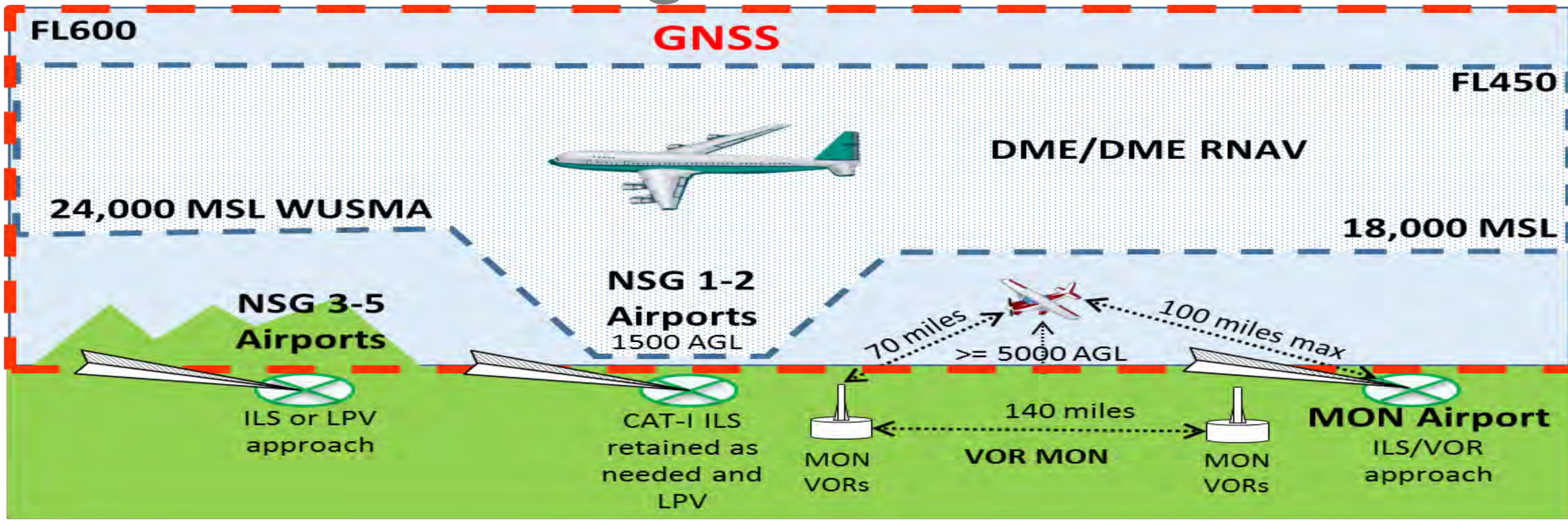
FAA Navigation Systems Portfolio



Legacy Navigation Infrastructure	LOC RVR GNSS	VOR TACAN DME GNSS	VOR TACAN DME NDB GNSS	VOR TACAN DME NDB GNSS	ILS/LOC RVR VOR / DME / TACAN / NDB GNSS MALSR ALSF-2 REIL PAPI/VASI
Future Navigation Infrastructure	GNSS LOC RVR	GNSS DME / TACAN VOR	GNSS DME / TACAN VOR	GNSS DME / TACAN VOR	GNSS ILS/LOC RVR DME / TACAN VOR MALSR ALSF-2 REIL PAPI

Note: NavAid system listed first in each cell is preferred navigation service

Resilient Navigation Services



- GNSS is primary enabler for all PBN (RNAV and RNP) and ADS-B accuracy and integrity for surveillance separation
- Realign DME infrastructure to enable RNAV without need for Inertial systems
- VOR MON can be used by aircraft that are not DME/DME RNAV equipped
- Most CAT-I ILSs retained to enable safe recovery and operations in event of GNSS outage
- All CAT-III ILS retained

En Route and Terminal Strategy

- New DMEs will be procured/installed to enable DME/DME RNAV (without IRU) in Class A airspace and NSG 1-2 Airports
  - DME network will be optimized by removing unneeded facilities
  - Perform an engineering study and acquisition management activities to develop and award a DME procurement contract by 2019
- PBN Route Structure (PBNRS) will provide structure where needed and direct point-to-point navigation will be used where structure is not necessary
  - Most Jet Routes and Victor Airways (outside WUSMA) will be removed and replaced with RNAV Q/T Routes, where needed
- VORs will remain in the NAS for the foreseeable future
  - VORs will be discontinued to a Minimum Operational Network (MON)
  - Select VORs will be Dopplerized or relocated to relieve encroachment issues
  - Perform an engineering study and acquisition management activities to develop a VOR sustainment strategy

Instrument Approach Strategy

- Existing CAT-II/III ILS will be retained to provide access for commercial aircraft in low/zero visibility
- Localizer Performance with Vertical guidance (LPVs) published on RNAV(GPS) charts will fulfill all new needs for CAT-I vertically guided approach service
  - LPV or LP approaches will be provided to all qualifying runways
  - AFS will assess elimination of the Glideslope Qualification Surface (GQS) for LPV Terminal Instrument Procedures (TERPs) to qualify additional runways for approaches
- RNP approach procedures will be implemented by the Metroplex and Single-Site PBN programs
- VOR, ILS and LOC approaches will be retained at MON airports to provide a backup to GNSS outages
- NDB and Non-MON VOR approaches will be cancelled
- CAT-I ILSs will be assessed to identify systems that can be discontinued
  - Initial criteria approved by FAA JRC with a delay to program implementation

FAA Navigation and Positioning Goals

- Enable navigation and surveillance modernization
  - 2016 Performance-Based Navigation Strategy and
  - Automatic Dependent Services-Broadcast (ADS-B)
- Conventional NavAids provide resiliency to ensure safety, capacity, and efficiency
- Procure NextGen Distance Measuring Equipment (DME) as an RNAV backup for Class A airspace and larger airports during GNSS outages
- Implement VOR Minimum Operational Network (MON)
- DME/DME provides an alternative RNAV capability
- Procure systems to sustain retained infrastructure
- Innovate navigation services to enable new capabilities

Resiliency Summary

- GNSS is vulnerable to intentional interference/spoofing
- Threat and capability of spoofing is likely to increase
- Intentional Interference and Spoofing are Cyber Attacks
- Backup systems and mitigations allow continued safe operation at reduced levels of efficiency and capacity
- Additional mitigations available and necessary
  - Focus on detection/awareness to transition to use of other means of navigation (vs. fly-through)
  - Many spoofing detection methods identified; testing and evaluation essential for civil aviation environment

Asia-Pacific Economic Cooperation

GPS Information, Presentations, etc.

GPS BULLETIN

Information for Policymakers from the National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT)

May 3, 2016

Space Bill Addresses PNT

On April 14, Rep. Jim Bridenstine (R-OK) introduced the American Space Renaissance Act.

Section 103 of the bill is titled "Positioning, Navigation, and Timing." According to the Congressman, the provision "Expresses a sense of Congress on the importance of positioning, navigation, and timing (PNT) for national security and economic prosperity. Requires the Secretary of Defense to provide a strategy to ensure DOD PNT leverages the best available signals from alternative PNT systems. The strategy will address issues associated with monitoring and verifying accuracy, integrity, availability, security, and reliability of foreign PNT signals."

Section 104 cites the National Executive Committee for Space-Based PNT as a model for establishing a new National Executive Committee on Weather.

Learn more at GPS.gov

DHS Demonstrates Precision Timing Technology at NYSE

On April 20, DHS announced the successful demonstration of Enhanced LORAN (eLoran), a precision timing technology, for financial transactions at the New York Stock Exchange (NYSE). Recognizing the challenges of space-based signals and the importance of having multiple timing sources, eLoran is one technology being considered to provide a complementary timing solution to existing GPS technology.

Precise and synchronized timing of financial transactions is critical to markets worldwide and is mandated by regulation in the European Union and is increasingly required in the United States. Today, precision timing capabilities are provided primarily by GPS. However, GPS's space-based signals are low-power and susceptible to possible disruptions. GPS signals are also difficult to receive indoors and in urban canyons.

The live demonstration at the NYSE was hosted by Juniper Networks, Harris Corporation, and UrsaNav, under a cooperative agreement with DHS. Over 60 industry and government representatives attended, including senior officials from DHS, DOT, DOD, Treasury, and DOE. The ensuing discussion highlighted the over-reliance upon GPS for precise timing, the threat of a loss of civil GPS services, possible impacts to the U.S. critical infrastructure and the economy, and a common interest in developing resilient timing solutions for our nation's critical infrastructure.

View press release at DHS.gov

Federal GPS site: www.gps.gov

- "GPS Bulletin" Newsletter published by NCO
  - Anyone can subscribe or get back issues

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