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
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 18th
- 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

Frequency (MHz)

Targeted Receive Power (dBm)

-140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140

1450 1460 1470 1480 1490 1500 1510 1520 1530 1540 1550 1560 1570 1580 1590 1600 1610 1620 1630 1640 1650 1660 1670 1680 1690 1700

Type 1 and 2 Signals

Type 1

Type 1
Chamber Test Grid and Setup
### GNSS Test Signals Used

<table>
<thead>
<tr>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS L1 C/A-code</td>
</tr>
<tr>
<td>GPS L1 P-code</td>
</tr>
<tr>
<td>GPS L1C</td>
</tr>
<tr>
<td>GPS L1 M-code</td>
</tr>
<tr>
<td>GPS L2 P-code</td>
</tr>
<tr>
<td>GPS SBAS L1</td>
</tr>
<tr>
<td>GLONASS L1 C</td>
</tr>
<tr>
<td>GLONASS L1 P</td>
</tr>
<tr>
<td>BeiDou B1I</td>
</tr>
<tr>
<td>Galileo E1 B/C</td>
</tr>
</tbody>
</table>
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

Certified Aviation Mask has value of -110 dBm for 1 MHz in band interference.
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
Inverse Modeling: Cellular (CEL), 1530 MHz

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

CEL EIRP$_{\text{Tol}}$ Map at $f_0 = 1530$ MHz with an ITM($f_0$) = -15.3651 dBm

Tolerable EIRP vs. Distance from Transmitter inside $Z=[0,30]$
Inverse Modeling: General Location Navigation (GLN) 1530 MHz

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

GLN EIRP$_{Tol}$ Map at $f_0 = 1530$MHz with an ITM($f_0$) = -60.5293dBm
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

HPR EIRP_{Tol} Map at f_0 = 1530MHz with an ITM(f_0) = -72.9934dBm

Tolerable EIRP vs. Distance from Transmitter inside Z=[0,30]
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

TIM EIRP\textsubscript{Tol} Map at $f_o = 1530$MHz with an ITM($f_o$) = -51.3793dBm

Tolerable EIRP vs. Distance from Transmitter inside Z=[0,30]
### Summary: Inverse Modeling Results (Single Base Station)

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Stand off distance (m)</th>
<th>Max Tolerable EIRP (dBW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GLN</td>
</tr>
<tr>
<td><strong>1475 MHz</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macro Urban</td>
<td>10</td>
<td>-14.4</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>5.6</td>
</tr>
<tr>
<td>Micro Urban</td>
<td>10</td>
<td>-13.5</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>6.5</td>
</tr>
</tbody>
</table>

| **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

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Stand off distance (m)</th>
<th>Max Tolerable EIRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GLN</td>
</tr>
<tr>
<td>Macro Urban</td>
<td>10</td>
<td>36.3 mW</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>3.6 W</td>
</tr>
<tr>
<td>Micro Urban</td>
<td>10</td>
<td>44.7 mW</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>4.5 W</td>
</tr>
</tbody>
</table>

**1475 MHz**

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Stand off distance (m)</th>
<th>Max Tolerable EIRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GLN</td>
</tr>
<tr>
<td>Macro Urban</td>
<td>10</td>
<td>0.8 mW</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>79.4 mW</td>
</tr>
<tr>
<td>Micro Urban</td>
<td>10</td>
<td>1 mW</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>104 mW</td>
</tr>
</tbody>
</table>

**1530 MHz**

*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*


• 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
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
  – Response Timeline: January 30, 2017


• 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
Validate CI requirements for Timing

Participation by industry experts essential

Cross-sector assessment will provide information to support decision regarding additional sector specific studies.
Signed by the Administrator in October 2016, defining the next 15 years of PBN Implementation for the agency.

Download Here
### PBN Strategy Goals by Benefit Area

<table>
<thead>
<tr>
<th>Improved predictability</th>
<th>More cost effective &amp; agile service delivery</th>
<th>Increased access</th>
<th>Improved resiliency</th>
</tr>
</thead>
</table>
| Near-Term (2016-2020)   | • Shorten development and implementation time for new ATS routes by removing rulemaking requirement  
  • Begin ILS Rationalization at NSG 4-5 airports | • 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 | • 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 |
| Mid-Term (2021-2025)    | • Key airports transitioned to time and speed-based management  
  • 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 | | • 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 |
| Far-Term (2026-2030)    | • NAS transitioned to time and speed-based management | | • ILS rationalization complete at NSG 4 and 5 airports  
  • ILS rationalization analysis for NSG 1, 2, and 3 airports | • Re-evaluation of need for remaining VOR facilities |
Navigation Programs Strategic Alignment

**PBN Strategy**
Strategy for deploying and effectively using PBN as the means of navigating in the NAS

**DME Programs**

- **NextGen DME**
  Supports PBN with the optimization of the DME infrastructure to expand coverage and eliminate critical DMEs

- **DME Sustain**
  Supports CAST requirements, replaces ILS markers with DMEs, and replaces DMEs at decommissioned VOR locations

- **NNE**
  NextGen Navigation Eng.
  Defines DME service volume to eliminate need for ESVs

**NESS**
NAS Efficient Streamlined Service

- **VOR MON**
  Collaborative effort to execute a safe transition from a legacy network of VORs to a minimum operational network (MON) as backup capability in the event of a widespread GPS outage

- **ILS Rationalization**
  Rationalize the need for duplicate vertical guidance with ILS when LPV approaches are available

**Other NAV Programs**

- **VOR Establish/Sustain**
  Establish, dopplerize, and sustain VORs

- **VOR Sustain**
  Sustain existing equipment as needed and support establishment

- **ILS Sustain**
  Sustain existing equipment as needed and support establishment

**APNT Research**
Alternate Position, Navigation, & Timing
Research for alternatives for providing higher precision back-up for GPS-based position, navigation, and timing services

**LEGEND**

- **Nav Program w/ CIP funding**
- **NextGen PLA/Initiative**
- **New/Emerging Initiative**

**WAAS**
Wide Area Augmentation System
A satellite-based navigation system to provide horizontal and vertical navigation for all classes of aircraft in all phases of flight - including en route navigation, airport departures, and airport arrivals
## FAA Navigation Systems Portfolio

### Legacy Navigation Infrastructure
- LOC
- RVR
- GNSS

### Future Navigation Infrastructure
- GNSS
- LOC
- RVR

<table>
<thead>
<tr>
<th>Departure</th>
<th>Cruise</th>
<th>Metering/Descent</th>
<th>Final Approach</th>
<th>Landing</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOR TACAN DME GNSS</td>
<td>VOR TACAN DME NDB GNSS</td>
<td>VOR TACAN DME NDB GNSS</td>
<td>ILS/LOC RVR VOR / DME / TACAN / NDB GNSS MALSR ALSF-2 REIL PAPI/VASI</td>
<td>GNSS ILS/LOC RVR DME / TACAN VOR MALSR ALSF-2 REIL PAPI</td>
</tr>
</tbody>
</table>

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/installled 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
GPS Information, Presentations, etc.

Federal GPS site: [www.gps.gov](http://www.gps.gov)

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

Contact Information:

Ken Alexander
Co-Chair National PNT Engineering Forum
National Coordination Office for Space-Based PNT
1401 Constitution Ave, NW – Room 2518
Washington, DC  20230
Phone: (202) 482-5809
[www.gps.gov](http://www.gps.gov)

GPS: Accessible, Accurate, Interoperable