DOT GPS Adjacent Band Compatibility (ABC) Assessment

International Committee on GNSS (ICG-12)

December 2, 2017

Kyoto, Japan
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)

- 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

<table>
<thead>
<tr>
<th>Signal</th>
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<tbody>
<tr>
<td>GPS L1 C/A-code</td>
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<tr>
<td>GPS L1 P-code</td>
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<tr>
<td>GPS L1C</td>
</tr>
<tr>
<td>GPS L1 M-code</td>
</tr>
<tr>
<td>GPS L2 P-code</td>
</tr>
<tr>
<td>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>
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 Profiles Graph](image)
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

<table>
<thead>
<tr>
<th>Category</th>
<th>ITM at 1530 MHz (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAV - General Aviation (non certified)</td>
<td>-61.0</td>
</tr>
<tr>
<td>GLN - General Location/Navigation</td>
<td>-60.5</td>
</tr>
<tr>
<td>HPR - High Precision &amp; Networks</td>
<td>-73.0</td>
</tr>
<tr>
<td>TIM - Timing</td>
<td>-59.4</td>
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<tr>
<td>SPB - Space Based</td>
<td>-73.5</td>
</tr>
<tr>
<td>CEL - Cellular</td>
<td>-15.3</td>
</tr>
</tbody>
</table>
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

Drone/Emergency Response/Disasters

Ankle Bracelet Monitoring

Police/Emergency Response/Resource Tracking

Emergency Response/Resource Tracking

Photo courtesy Tiero/ThinkStock

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Photo courtesy Mrdoomits/ThinkStock

Photo courtesy Mokee81/ThinkStock

Photo courtesy ThinkStock

Photo courtesy ThinkStock
Construction/Infrastructure Scenarios

GPS HPR receiver used in construction/surveying

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 guidance

Photo courtesy ThinkStock

Construction/Surveying

Photo courtesy Medvedkov/ThinkStock
Agriculture/Farming Scenario

Drone/Crop Monitoring

GPS Guidance System

High Precision Farming

High Precision Farming

Photo courtesy Valio84sl/ThinkStock

Photo courtesy of John Deere

Photo courtesy of John Deere

Photo courtesy of John Deere
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)

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/N₀ 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

<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>Macro Urban</td>
<td>10</td>
<td>-31.0</td>
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<tr>
<td></td>
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<tr>
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<tr>
<td></td>
<td></td>
<td>GLN</td>
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<tr>
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<td>79.4 mW</td>
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<td>104 mW</td>
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<td>Deployment Scenario</td>
<td>Number of Base Stations</td>
<td>Max Tolerable Power</td>
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</tr>
<tr>
<td></td>
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<tr>
<td>Macro + Micro Cell</td>
<td>39,695</td>
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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