Loss of Lock Analysis

GPS-ABC Workshop VI

RTCA, Washington, DC

March 30, 2017

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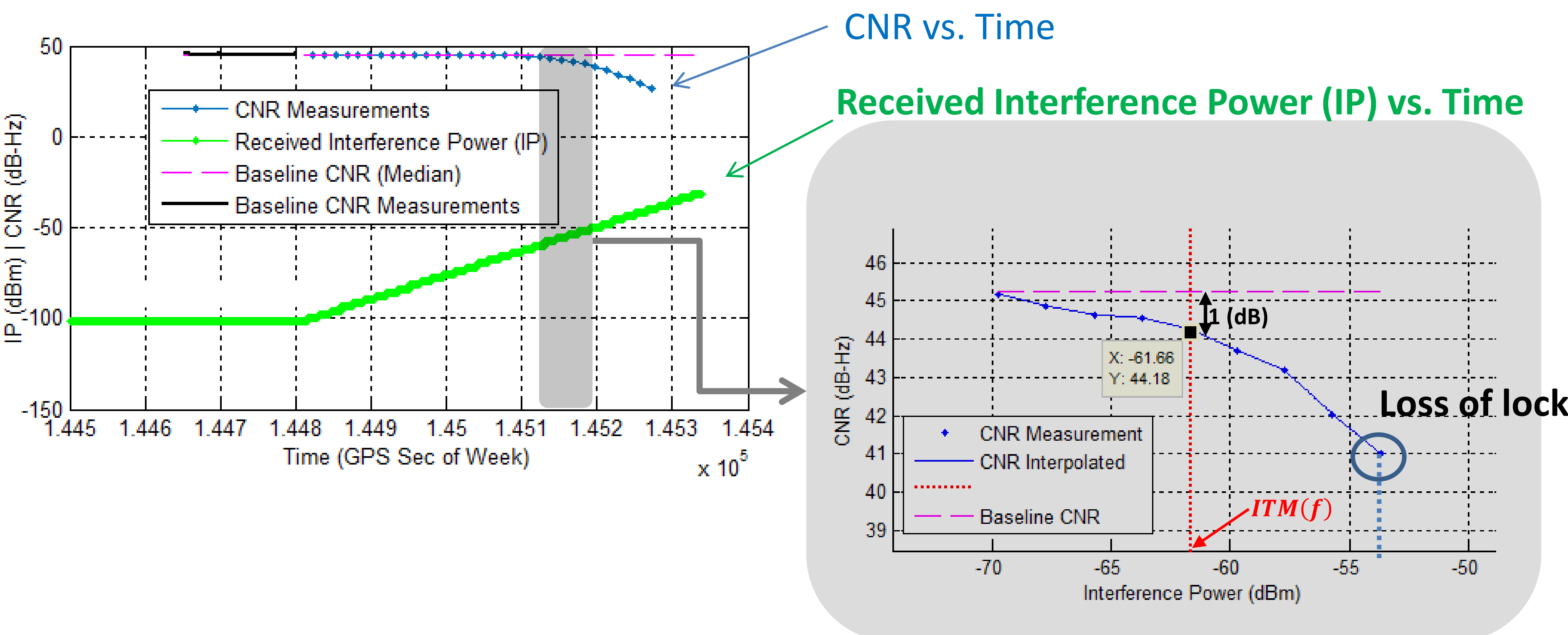
Overview

- Previous Workshop presentations have detailed:
  - Radiated/chamber testing of 80 GNSS receivers at White Sands Missile Range (WSMR) Electromagnetic Vulnerability Assessment Facility (EMVAF)
  - Resulting 1-dB Interference Tolerance Masks (ITMs) for 1-MHz bandpass noise and 10-MHz Long Term Evolution (LTE) signals
- This presentation provides a summary of loss-of-lock results of two types in the presence of 10-MHz LTE signals:
  1. Interference level for which "low-elevation" satellites are no longer tracked
  2. Interference level for which no satellites are tracked
- Proper interpretation of results, as described herein, supports use of 1-dB ITMs for adjacent band transmitter masks

Data Processing

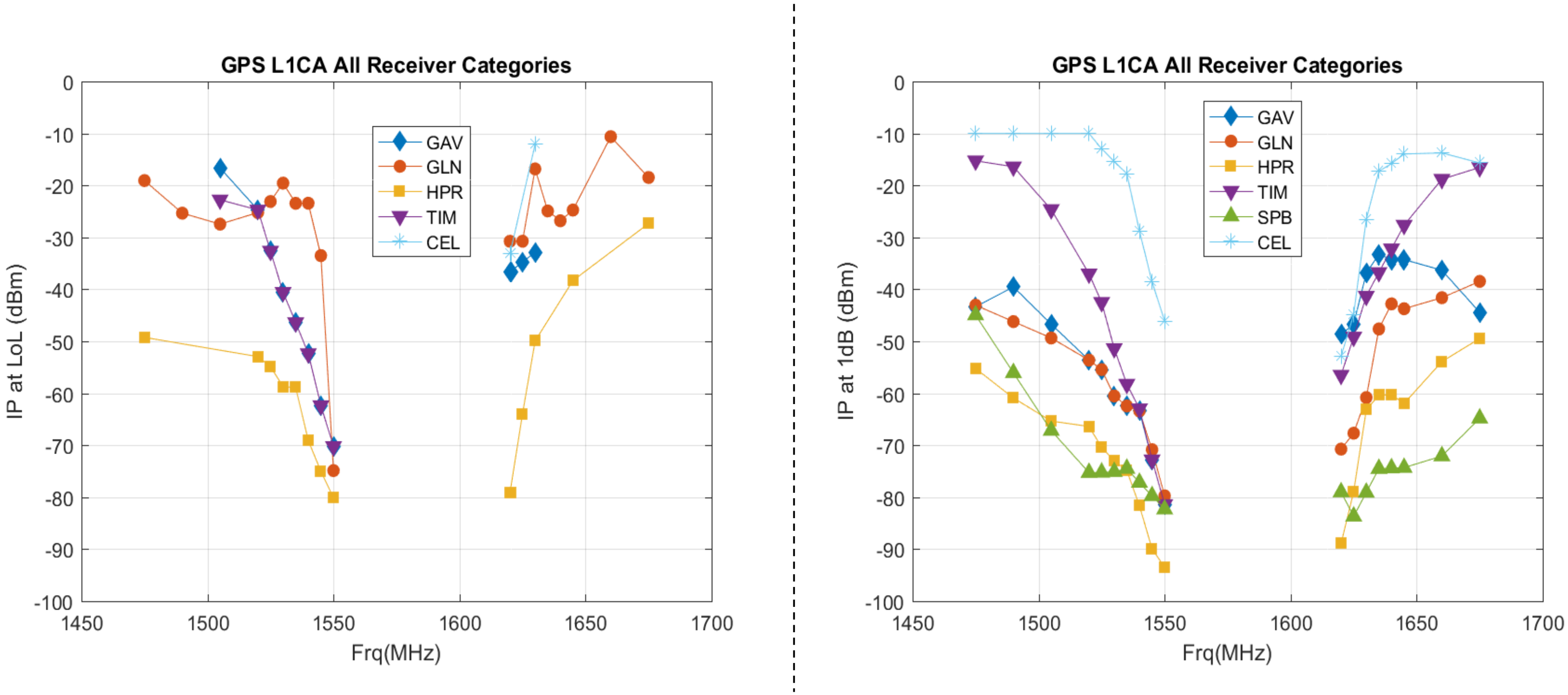
- Similar to ITM processing, but referenced to point where carrier-to-noise ratio (CNR) is no longer reported vs where it is reduced by 1 dB
- Results provided for both "high-" and "low-elevation" satellites



Interference Power Resulting in Loss-of-Lock of Low-Elevation GPS C/A-code Signals

Loss-of-Lock IP

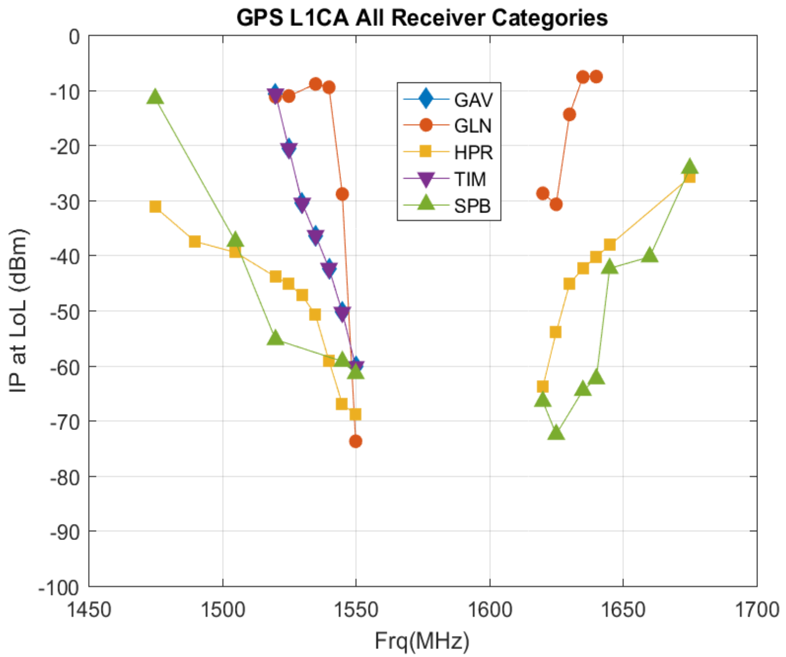
1dB ITM



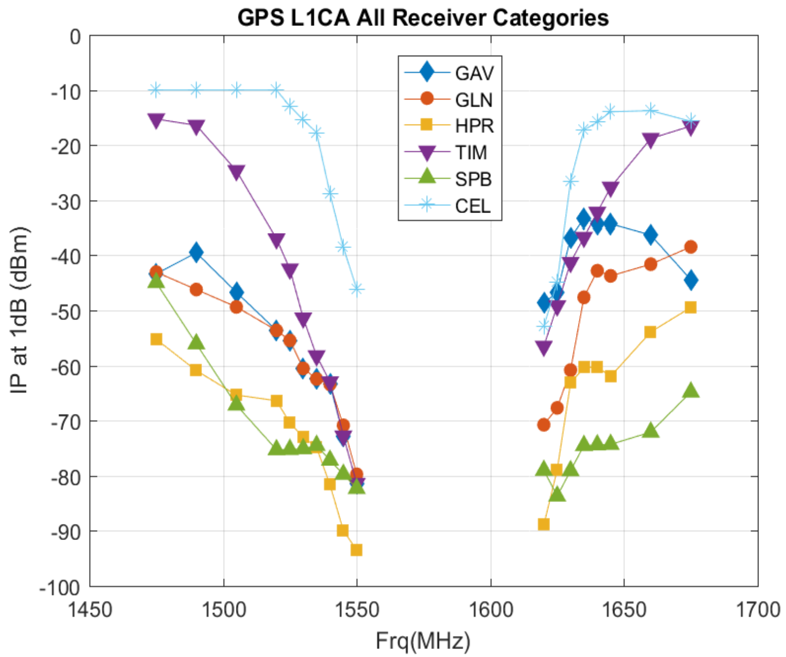
- **Loss-of-Lock IP computed using only PRN-24 fixed at -10 dB relative to the nominal received power levels; this relative power is typical of what would be seen for low-elevation satellites**
- **Interference Powers resulting in loss-of-lock are typically 5 – 15 dB higher than 1 dB ITMs**

Interference Power Resulting in Loss-of-Lock of High-Elevation GPS C/A-code Signals

Loss-of-Lock IP



1dB ITM

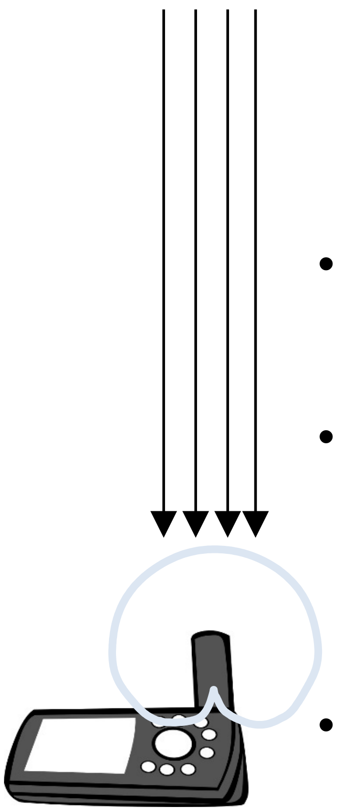


- **Loss-of-Lock ITM computed using only "nominally" powered GPS signals**
- **Interference Powers resulting in loss-of-lock of all satellites are typically 15 – 25 dB higher than 1 dB ITMs**

Interpretation of Results

- In the chamber, the difference between: (1) interference power resulting in loss-of-lock for the "low elevation" satellite, and (2) interference power resulting in 1-dB C/N_0 degradation was on the order of 5 – 15 dB
- As described in the following charts, GPS/GNSS receiver operation in the "real world" can be considerably more difficult than the conditions experienced during the WSMR testing
- In realistic challenged environments, a 1-dB C/N_0 degradation can often result in loss-of-lock of one or more satellites
  - And, as determined from conducted testing at Zeta, reacquisition time for some receivers significantly increases when C/N_0 is degraded by 1 dB
- DOT and many Federal and non-Federal partners continue to support the 1-dB criterion

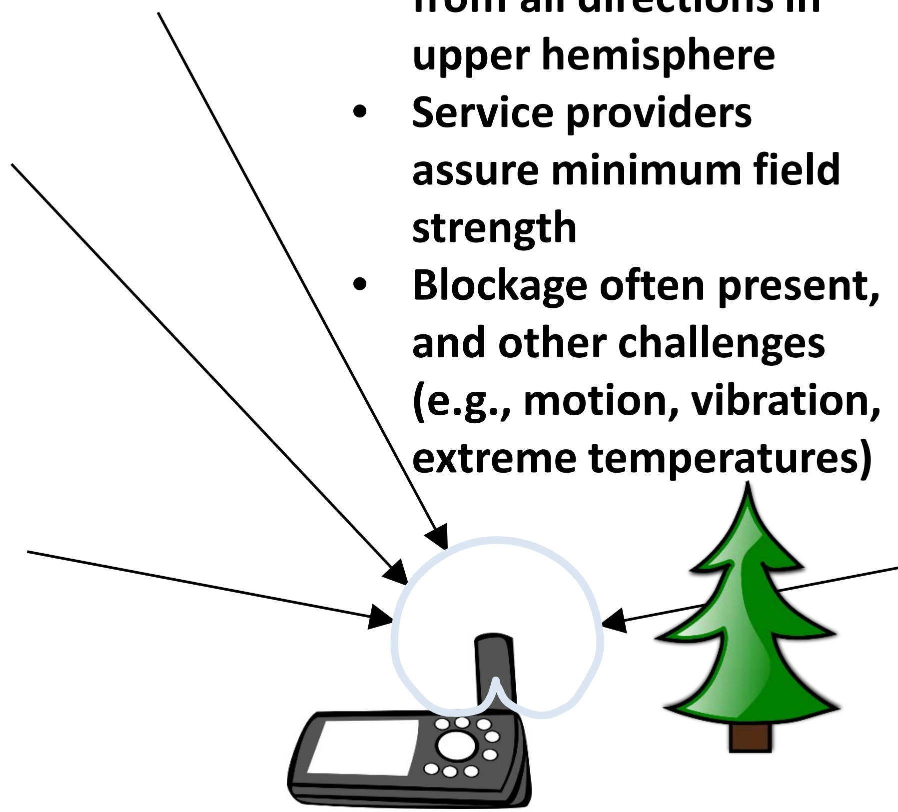
Radiated Testing vs. Real World



- All incident GNSS signals at boresight of device under test (DUT) antenna, where gain is maximum
- Minimum specified field strength for most satellites
- Additionally, for all constellations except SBAS, one at -10 dB, one at -20 dB, relative to minimum specified
- No blockage

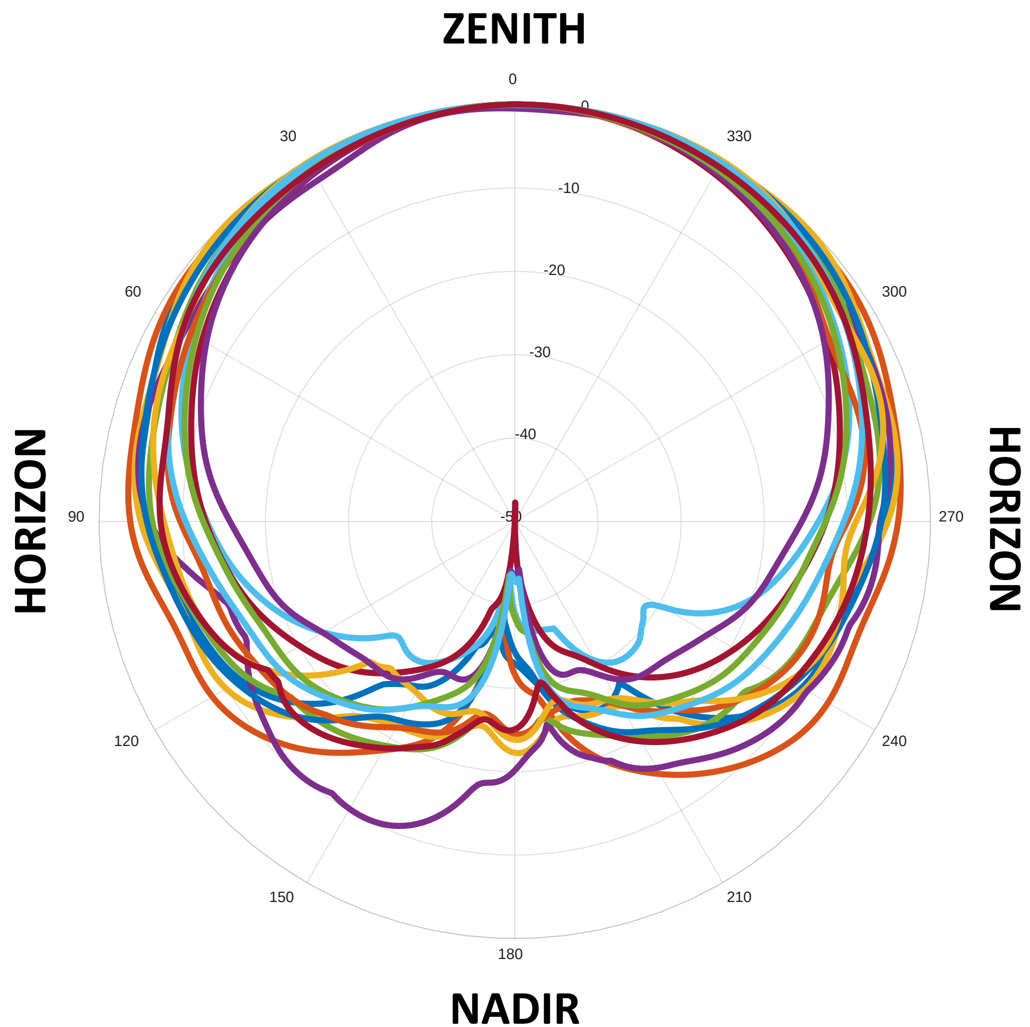
Radiated Testing at WSMR

- Incident GNSS signals from all directions in upper hemisphere
- Service providers assure minimum field strength
- Blockage often present, and other challenges (e.g., motion, vibration, extreme temperatures)



Real World

DUT L1 Relative Antenna Gain Patterns



- Curves are measured right hand circularly polarized (RHCP) gain for 14 external, active GNSS antennas
- See October 2016 “Antenna Characterization” presentation for details of measurement campaign
- For all measured patterns, gain decreases as elevation angle decreases towards horizon; -10 dB is typical
- Justifies referring to -10 dB signals from WSMR testing as “low elevation”

Signal Blockage and Other Real-world GPS/GNSS Receiver Challenges

- Many instances where trees, buildings, or other objects may attenuate GNSS signals without attenuating adjacent band interference sources
  - At L-band, attenuation through foliage typically ranges from 0.3 – 2 dB/m
  - Buildings and other man-made structures can result in far greater attenuations
  - Ionospheric scintillation can result in signal losses of 10s of dBs; multipath can also result in smaller levels of destructive fading
- Significant interference is occasionally encountered
- Line-of-sight acceleration and jerk can significantly increase a receiver's C/N_0 threshold for loss-of-lock
  - As can increased oscillator phase noise in the presence of vibration
- Receiver filtering frequency response can shift significantly over hot/cold temperature extremes
- DUTs at WSMR were not subject to these conditions

Examples of GNSS Signal Blockage

Arlington, VA

New York, NY

- **GLN users frequently encounter road-side cellular base stations, with GNSS signals at low elevations suffering severe attenuation from foliage or buildings**
- **High probability in these situations for there to be a GNSS signal with received power level such that 1-dB drop in C/N_0 will result in loss-of-lock**

Summary

- Loss-of-lock data presented from WSMR radiated testing
  - For "low-" and "high-" elevation satellites
  - Typical results:
    - Interference power resulting in loss-of-lock of low-elevation angle satellites is 5-15 dB higher than interference power resulting in 1-dB C/N_0 degradation
    - 15 – 25 dB for all satellites (high- and low-)
- WSMR testing conditions were significantly less challenging than many "real-world" conditions that GNSS receivers are expected to operate in
- As described in this briefing, GNSS users frequently encounter conditions such that 1-dB drop in C/N_0 will result in loss of lock on one or more satellites
  - And, a result from conducted testing shared at the last Workshop, reacquisition time for some receivers significantly increases when C/N_0 is degraded by 1 dB