GNSS in a Spectrum-Challenged Future:
Adjacent Band Interference Impacts on High-Precision GNSS Receiver Performance

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IGS WORKSHOP 2017 - Paris, France

Introduction

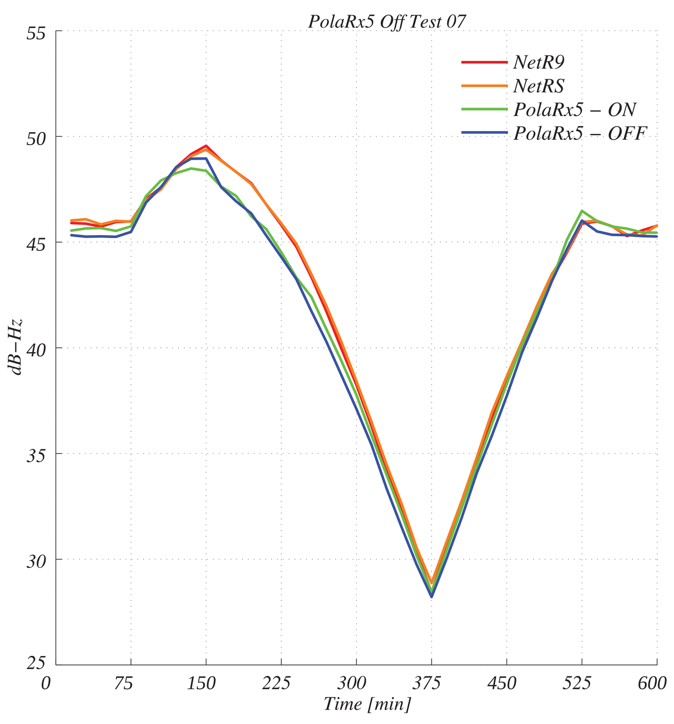
In 2012 the Federal Communications Commission (FCC) reversed its decision to allow communications company LightSquared to use GPS-adjacent spectrum for a ground based network after testing demonstrated harmful interference to GPS receivers. Now rebranded as Ligado, they have submitted modified application to use a smaller portion of the L-band spectrum at much lower power. Many GPS community stakeholders, including the hazard monitoring and EEW communities remain concerned that Ligado's proposed use could still cause harmful interference, causing signal degradation, real-time positioning errors, and total failure of GNSS hardware in widespread use in hazard monitoring networks.

The Department of Transportation (DoT) has conducted hardware tests to determine adjacent-band transmitter power limit criteria that would prevent harmful interference from Ligado's operations. UNAVCO and many Federal agencies representing the high-precision geodesy were invited to participate by testing our own hardware in our typical use configuration. We present preliminary results produced from the data collected by the three UNAVCO receiver types tested: Trimble NetRS, Trimble NetR9, and Septentrio PolaRx5.

In the first round of testing, simulated GNSS signals were broadcast in an anechoic chamber while interfering signals are broadcast simultaneously with varying amplitude and frequency. The older GPS-only NetRS receiver showed smaller reductions in SNR at frequencies adjacent to GPS L1 as compared to the other receivers, suggesting narrower L1 filter bandwidth in the RF frontend. The NetR9 showed greater decreases in observed SNR in the 1615 to 1625 MHz range when compared to the other two receivers. This suggests that the NetR9's L1 filter bandwidth has been increased to accommodate GNSS signals. Linearity tests were conducted to better relate SNR measurements between receiver types. The PolaRx5 receiver showed less SNR variation between tracking channels than both Trimble receivers. Our results show the power levels at which adjacent-band interference begins degrading receiver performance and eventually disables tracking.

As the demand for spectrum for mobile applications increases, operators of hazard networks may need to consider the impact of RF interference on data quality and continuity. UNAVCO's participation ensures that our high precision GNSS community interests are represented in the future spectrum allocation decisions.

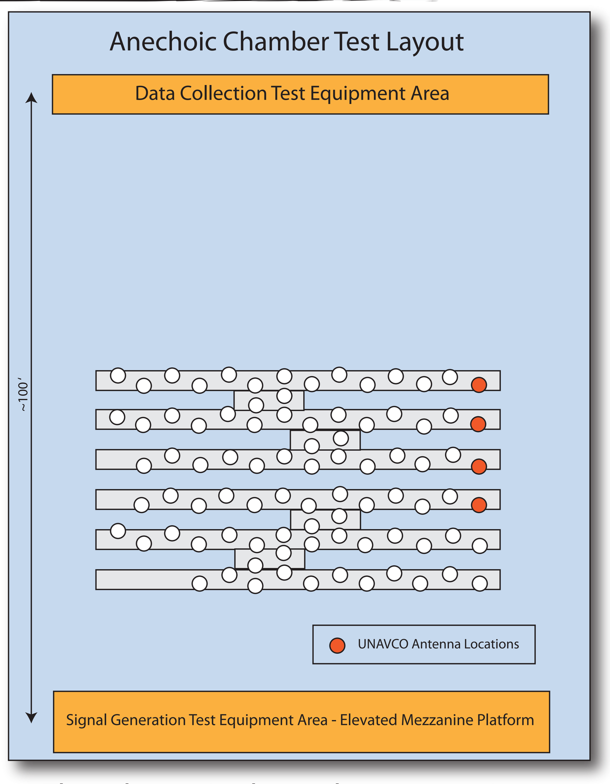
This material is based on data, equipment and engineering services provided by UNAVCO through the GAGE Facility with support from the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) under NSF Cooperative Agreement No. EAR-1261833



A linearity tests were conducted to relate receiver carrier-to-noise measurements with varying test signal power levels. The figure above shows the results from the 4 receivers provided to the DoT by UNAVCO for testing. Signal power was stepped every 15s. The L1 1Hz SNR observations from all visible satellites were averaged for each signal power step. The test signal power was also mapped in the chamber between each experiment to account for differences between antenna locations.

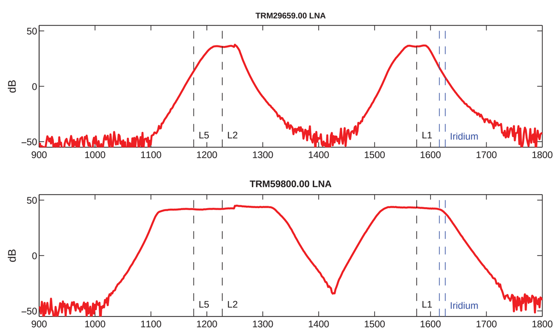
Conducted Receiver Testing

After the radiated testing was completed, the Zeta Associates performed wired receiver testing. The objective was to test receiver aquisition performance at different interference power levels. Satellite aquisition time was measured as a function of interference power. Testers observed slower aquistion times for some receiver types at 1 dB interference level.



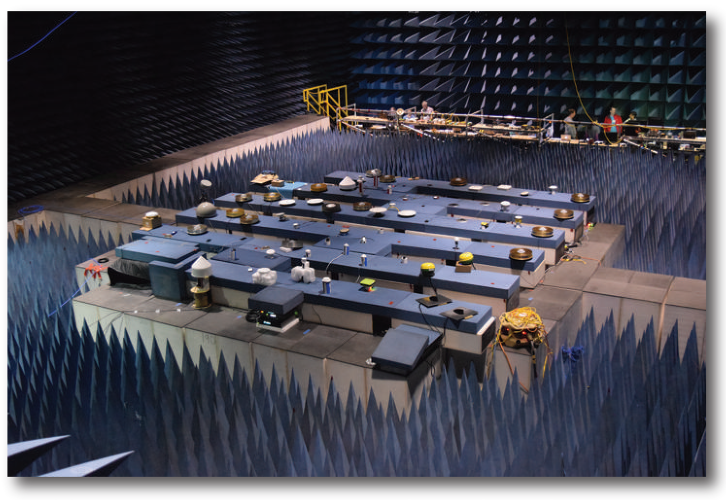
The schematic above shows map view of the approximate location of the test antennas. Receivers that supported external antennas were staged in the data collection area to minimize potential error sources. All of the signal generation equipment was staged at the opposite end of the chamber on an elevated platform .

Antenna Characterization



After the radiated testing was completed, the Mitre Corporation conducted antenna testing so that the radiated and conducted test results could be compared. Antenna characterization also allows ITM's to be applied to use cases where adjacent band transmitters are seen by GNSS receiver antennas at directions other than zenith. Gain patterns and saturation measurements were characterized for 14 external antenna types.

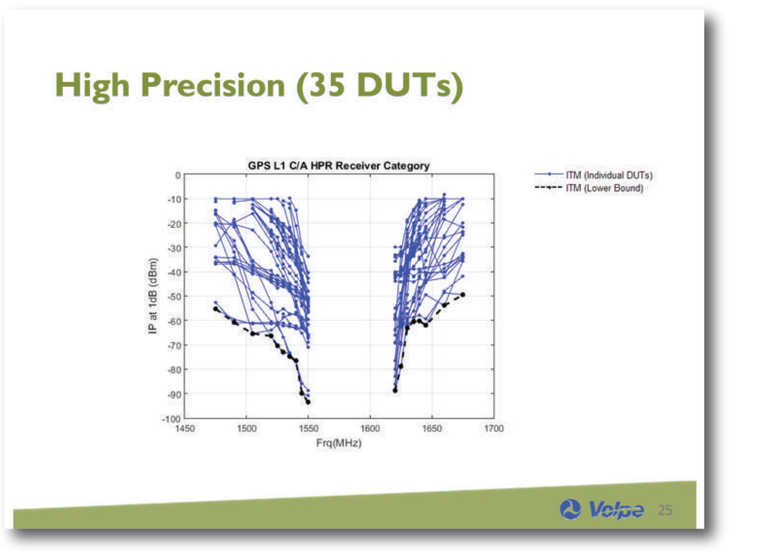
Radiated Test Overview



GNSS receiver testing was conducted April 25-29, 2016 at the Army Research Laboratory's (ARL) Electromagnetic Vulnerability Assessment Facility (EMVAF), White Sands Missile Range (WSMR), NM. The picture above shows equipment layout in the EMVAF's 100' x 70' x 40' anechoic chamber.

A total of 80 GNSS receivers were tested representing six user categories: General Aviation (non-certified), General Location/Navigation, High Precision & Networks, Timing, Space Based, and Cellular. The Geodetic research community is best represented by the High Precision category. UNAVCO provided three High Precision GNSS receiver types for testing: Septentrio PolaRx5, Trimble NetR9, and Trimble NetRS (shown above). We chose these three types because they represent the majority of receivers currently operated by UNAVCO.

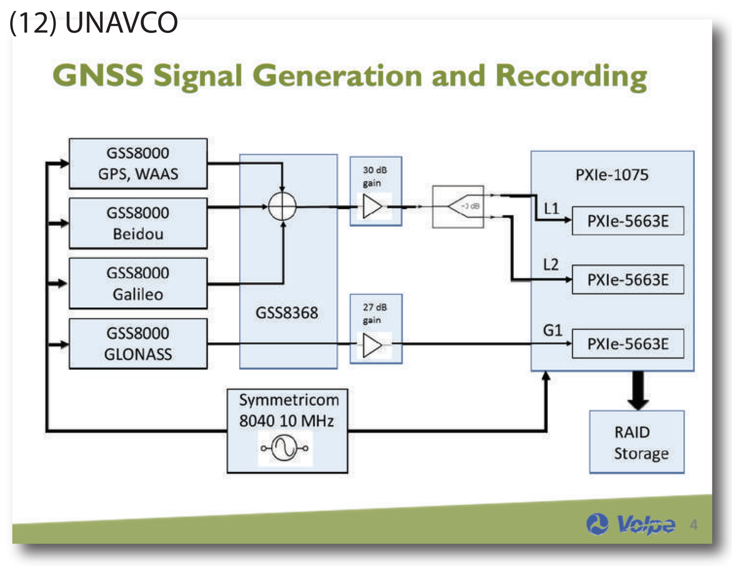
Trimble TRM59800.00 type antennas were included with the four UNAVCO receivers. We selected this antenna type because it is the most common antenna type deployed in networks operated by UNAVCO.



The primary objective of the DoT's Adjacent Band Compatibility Test was to determine Interference Tolerance Masks (ITM) for COTS GPS and GNSS receivers. The figure above shows the ITM mask results from receivers that were categorized as high-precision. The blue curves show the interference power levels where the individual receivers showed a 1 dB/Hz reduction in observed L1 carrier-to-noise . The black curve shows the lower bound from all receivers tested in this category.

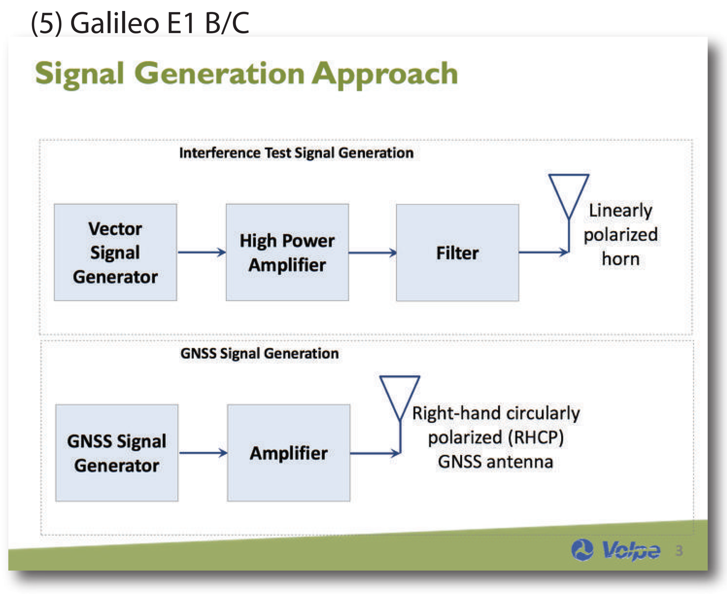
The following DoT federal partners/agencies and GPS manufactures participated in the radiated test:

(1) United State Coast Guard
(2) National Aeronautics and Space Administration
(3) National Oceanic and Atmospheric Administration
(4) United States Geological Survey
(5) Federal Aviation Administration
(6) United States Department of Transportation
(7) General Motors
(8) U-Blox
(9) NovAtel
(10) Trimble
(11) John Deere
(12) UNAVCO

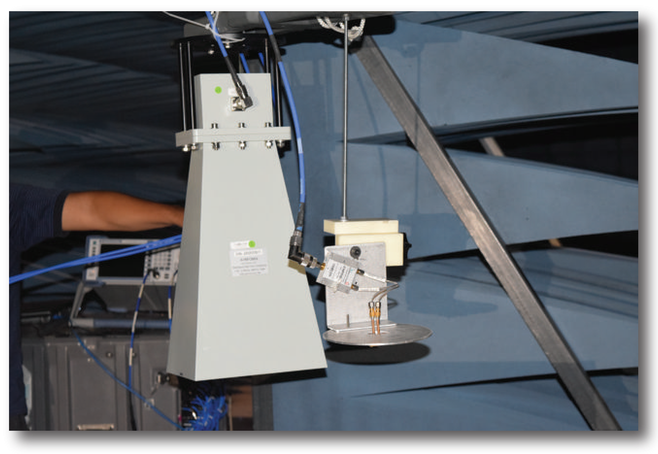


A total of 11 GNSS signals spanning 5 constellations were generated and recorded. The recording was replayed from the beginning for each test scenario. Each receiver had to be reset between tests to allow rollback of system time. A schematic showing the signal generation and recording process conducted by Volpe is shown above.

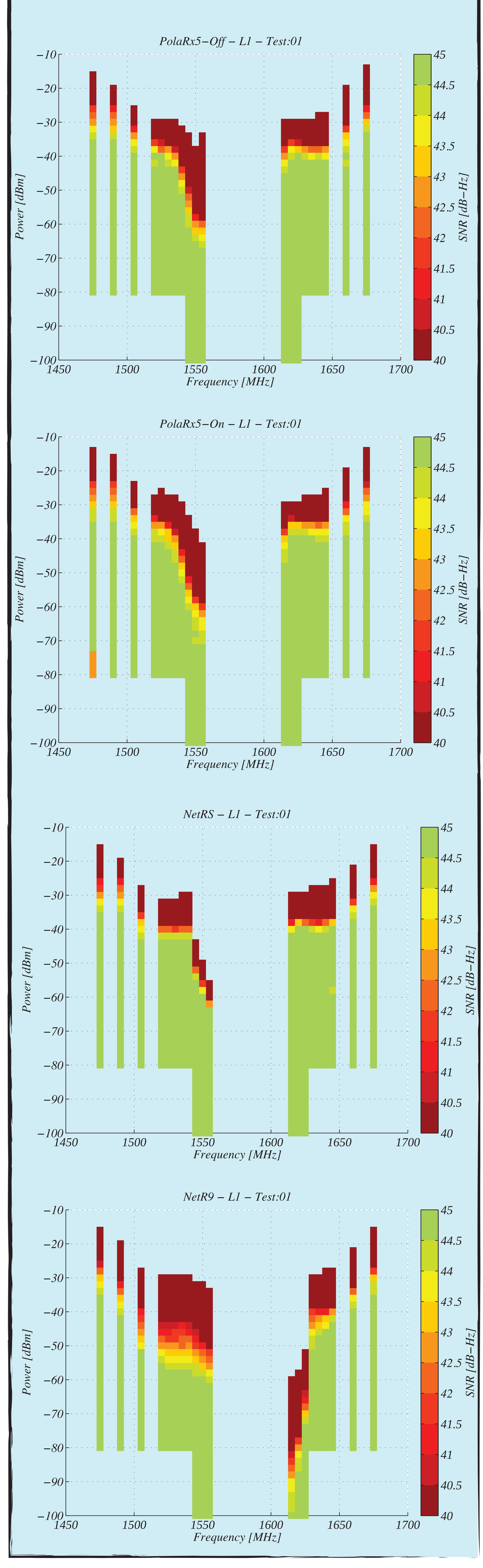
(1) GPS L1C, L1P, L1C, L1M, L2P
(2) SBAS L1C
(3) GLONASS L1C, L1P
(4) BeiDou B1I
(5) Galileo E1 B/C



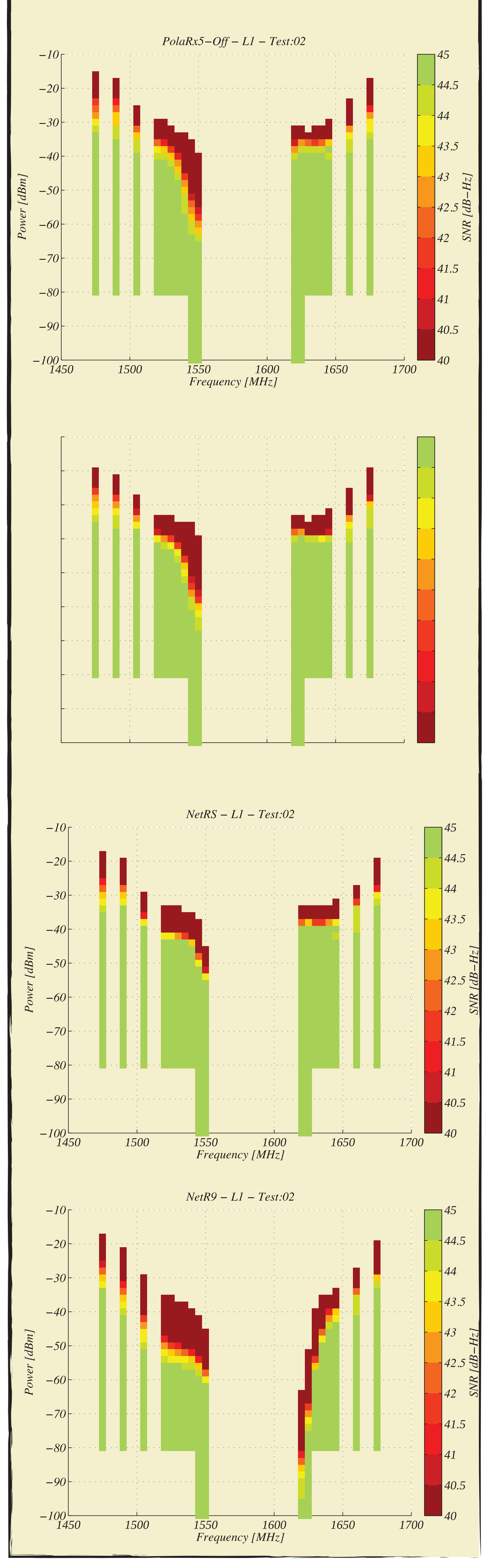
Separate antennas were used to transmit the GNSS and interference signals. A linearly polarized horn type antenna was used to broadcast the interference signal (below left). A Right-hand Circularly Polarized (RHCP) GNSS antenna was used to broadcast the GNSS test signals (below right). Both antennas were suspended from the ceiling of the chamber at the approximate horizontal center of the test array. Signal power mapping was conducted to account for variations in received power at the test equipment locations.



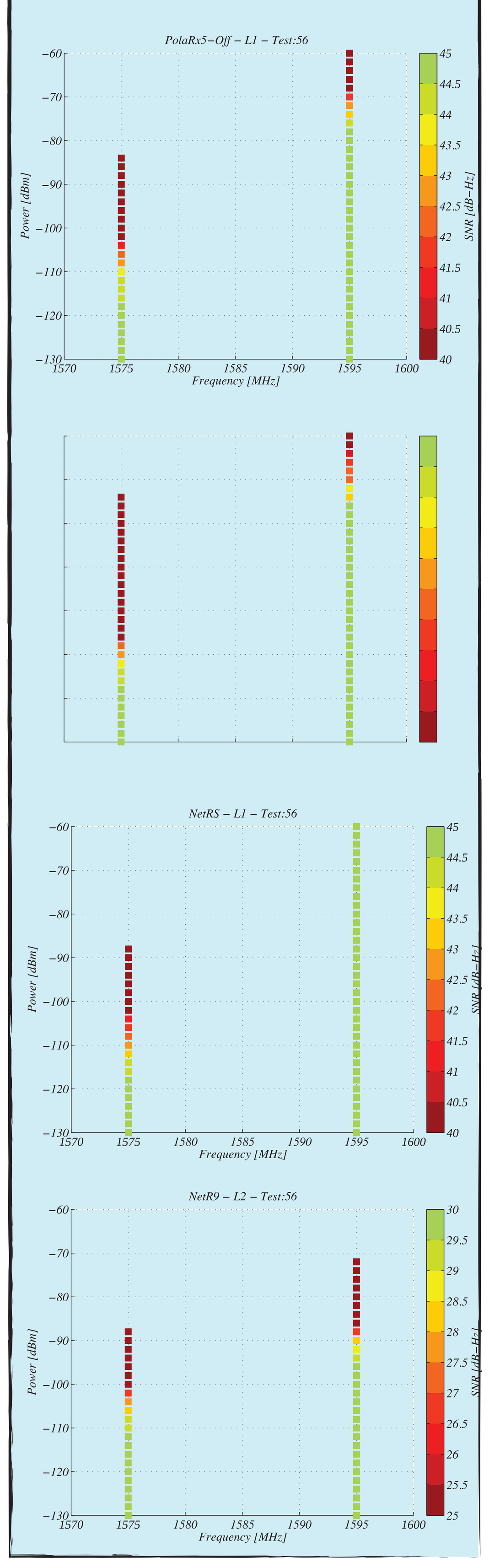
Test 01 - Bandpass white noise with a bandwidth of 1 MHz. An Interference Tolerance Mask (ITM) for a narrowband signal value at a frequency on the edge of a future proposed band (the edge closer to the center of the GNSS band) provides a conservative measure of the interference tolerance levels for some receivers. The bandwidth of 1 MHz was selected to be large enough so that the ITM results are not compromised for receivers that employ continuous wave (CW) jamming suppression capabilities.



Test 02 - A Long Term Evolution (LTE) signal with a bandwidth of 10 MHz. A vector signal generator equipped with the appropriate LTE package was used to generate a signal with a selectable center frequency. Additional downstream signal conditioning (amplification, filtering, and controlled attenuation) were used to appropriately control the power levels and out of band emissions (OOBE) of the interference signal.



Test 56 - In-band and intermodulation testing. Two or more signals operating simultaneously at different center frequencies can produce 3rd order intermodulation products generated by nonlinearities in the RF sections of the receiver and/or antenna.



Test 89 - In-band and intermodulation testing. Two or more signals operating simultaneously at different center frequencies can produce 3rd order intermodulation products generated by nonlinearities in the RF sections of the receiver and/or antenna.