GPS Adjacent Band Compatibility Assessment

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Surveying, Mapping, and Geosciences Subcommittee
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Overview

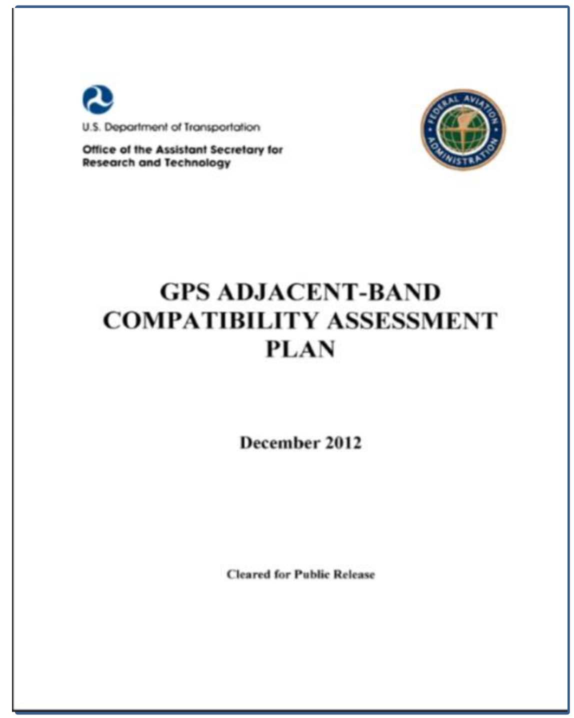
- Assessment origins
- Test activities to date
- Preliminary test results

GPS Adjacent Band Compatibility Assessment

- EXCOM co-chair letter to NTIA (Jan. 2012)

Proposed development of GPS Spectrum interference criteria: "…that will help inform future proposals for non-space, commercial uses in the bands adjacent to GPS signals and ensure any such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs."

- DOT study to evaluate:
  - Phase 1: Adjacent-band power levels, as a function of offset frequency, necessary to ensure continued operation of all applications of GPS services
  - Phase 2: Adjacent-band power levels to ensure continued operation of all applications of GPS services by future GPS receivers utilizing modernized GPS and interoperable Global Navigation Satellite System (GNSS) signals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GPS ADJACENT-BAND COMPATIBILITY ASSESSMENT PLAN

December 2012

Cleared for Public Release

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Approach to DOT GPS Adjacent Band Compatibility Assessment

- Main elements of assessment
  - Determine equipment interference tolerance limits
  - Develop use cases/Interaction scenarios (assuming LTE base stations & handsets)
  - Derive tolerable interference power vs. frequency offset
  - Six categories of GPS/GNSS receivers
    - General Aviation (non certified), General Location/Navigation, High Precision & Networks, Timing, Space Based, and Cellular
- Conduct public outreach to ensure the plan, on going work, and assumptions are vetted and an opportunity to gain feedback

  - Held many public workshops

  - Federal Register Notice for comments/input on draft Test Plan

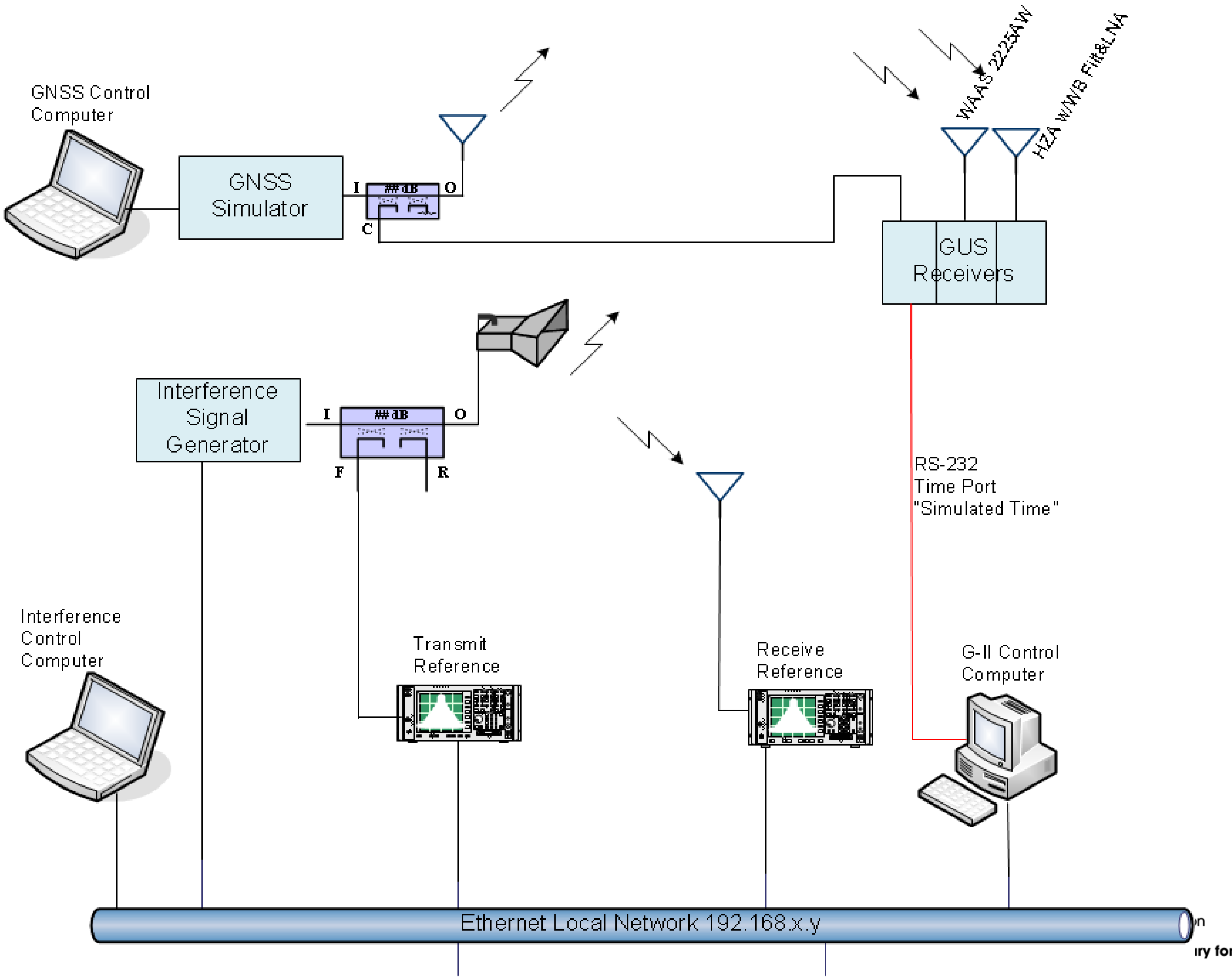
  - One-on-one discussions with industry

  - Open and transparent approach as possible

Receiver Interference Tolerance

- Equipment interference tolerance evaluations executed with radiated and wired (conducted) tests
- Radiated tests involved transmitting GNSS and interference signals in an anechoic chamber
  - Provides system evaluation with integrated receiver/antenna
  - Allowed wider participation
- Wired tests involved injecting GNSS and interference signals directly into receivers
  - Evaluated receivers and antennas separately
    - Antennas evaluated in anechoic chamber
  - Allowed extended evaluations for signal acquisition performance and Out-of-band emission (OOBE) levels

Chamber System Configuration

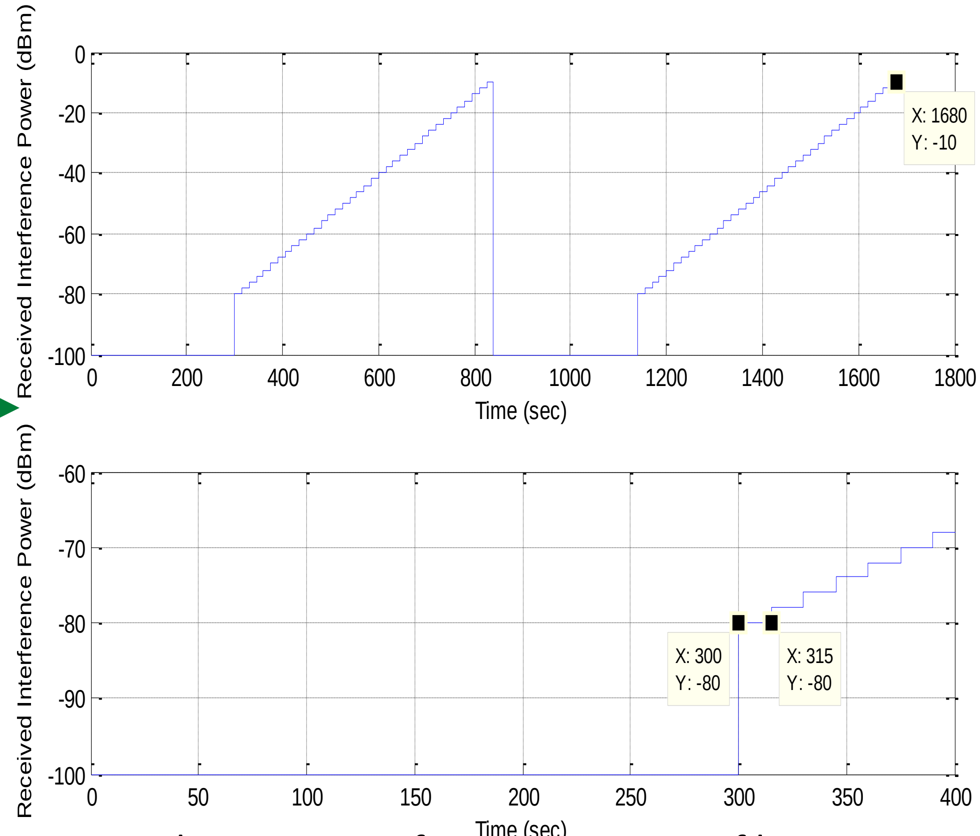


GNSS Signals Used in Testing

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

Interference Test Signal Frequencies and Power Profiles (1/2)

Name	Value	Unit
f_{start}	1475	MHz
f_{end}	1675	MHz
$[p_{min_1}, p_{max_1}]$ (1475 to 1540 MHz)	[-80,-10]	dBm
$[p_{min_2}, p_{max_2}]$ (1545 to 1555 MHz)	[-100,-30]	dBm
$[p_{min_3}, p_{max_3}]$ (1575 and 1595 MHz)	[-130,-60]	dBm
$[p_{min_4}, p_{max_4}]$ (1615 to 1625 MHz)	[-100,-30]	dBm
$[p_{min_5}, p_{max_5}]$ (1630 to 1675 MHz)	[-80,-10]	dBm
Δf_1(1475 to 1520 MHz)	15	MHz
Δf_2(1520 to 1555 MHz)	5	MHz
Δf_3(1575 and 1595 MHz)	N/A	MHz
Δf_4(1615 to 1645 MHz)	5	MHz
Δf_5(1645 to 1675 MHz)	15	MHz
ΔP	2	dB
Startup Time	15	min
T_{BL}	5	min
T_{step}	15	s
N_{cycle}	2	N/A



Nominal receive interference power profiles at GNSS antenna location for the (1475 to 1540 MHz) and (1630 to 1675 MHz) frequency ranges.

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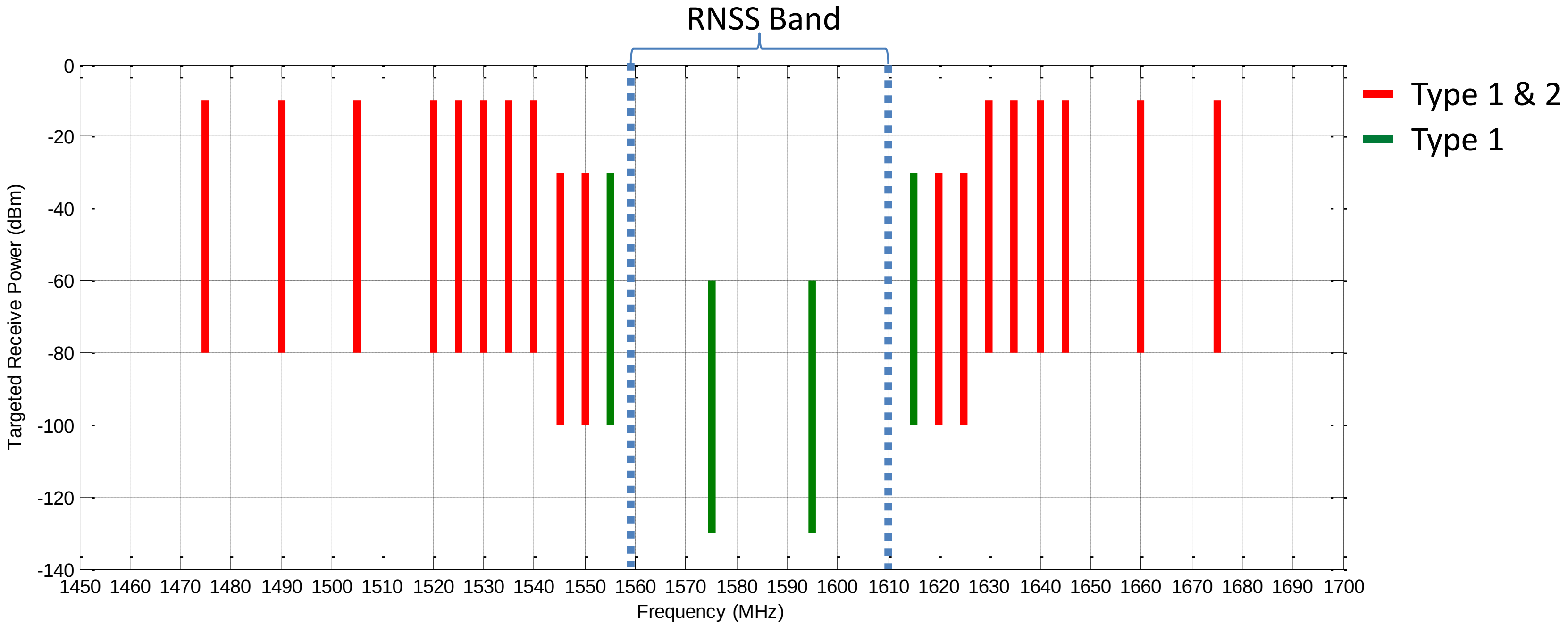
Interference Test Signal Frequencies and Power Profiles (2/2)



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Data Collected

- Data needed to develop an interference tolerance mask (ITM) for each receiver:
  - $CNR(s, i, j.\Delta t)$ (here, s identifies the GNSS, i the SV, Δt is the reporting time increment)

- To the extent possible, additional data to report the state of the receiver at each time step
  - Number of satellites tracked for each GNSS service: $N_{SV}(s, j.\Delta t)$
  - Location: Lats($j.\Delta t$), Lons($j.\Delta t$), hs($j.\Delta t$) (relative to WGS84 or other Datum)
  - Pseudorange: Rs,i($j.\Delta t$)
  - Carrier phase
  - Cycle slip or loss of carrier phase lock indicator (per satellite)
  - Loss of code and carrier tracking indicator, or inferred loss of tracking in the case when it is not reported by the receiver (per satellite)

Radiated Testing Overview

- Radiated tolerance tests on April 25-29, 2016 at Army Research Laboratory's Electromagnetic Vulnerability Assessment Facility, White Sands Missile Range (WSMR), NM
- Participation included DOT's federal partners/agencies and GPS manufacturers
  - 80 receivers tested representing all six categories of GPS/GNSS receivers
- Tests executed
  - Linearity (CNR's estimators characterization)
  - 1 MHz Bandpass Noise (Type 1)
  - 10 MHz LTE (Type 2)
  - Intermodulation (effects of 3rd order intermodulation)

WSMR April 4th-29th Test Record

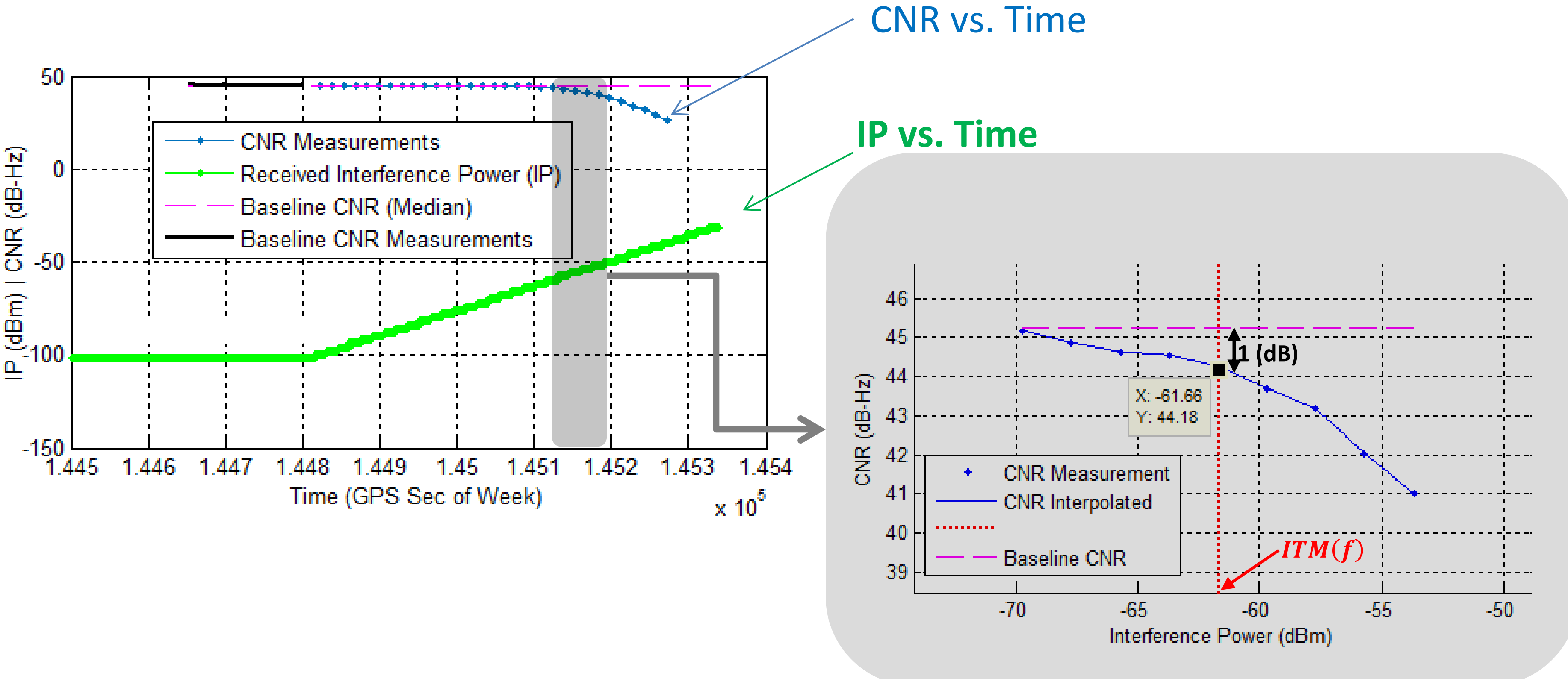
- Week 1:
  - Unpacked equipment, installed transmit antennas, established grid, characterized HPA and cables, dry-ran calibration and mapping, calibrated GNSS signals.
- Week 2: Dry-runs
  - Mapping, characterization & calibration
  - 1 MHz Noise and LTE tests
  - Linearity and in-band noise tests
  - Intermodulation tests
  - DoD started DUTs setup
- Week 3: DoD Test Week
  - Mapping and Calibration
  - 2 x Linearity Test
  - 2 x 1 MHz Noise & 10 MHz LTE tests
  - Intermodulation tests
- Week 4: DoT Test Week
  - Mapping and Calibration
  - 2 x Linearity Test
  - 2 x 1 MHz Noise & 10 MHz LTE tests
  - Intermodulation tests

Wired (Conducted) Test Overview

- Laboratory/wired tolerance tests on 25-29 July, 2016 at Zeta Assc. Fairfax, VA; Antennas characterized at MITRE Bedford, MA June-August 2016
- Receiver testing used same GNSS and interference signal generation equipment as chamber
- Participation by DOT's federal partners/agencies only
  - 14 receivers tested representing at least one from each category
- Same LTE and AWGN tests as WSMR plus extended evaluations investigating signal acquisition and OOBE interference

Data Processed to Produce a 1 dB Interference Tolerance Mask (ITM)

- Example for determining ITM for 1 frequency (1545) for PRN 31 for one of the Devices Under Test (DUT).



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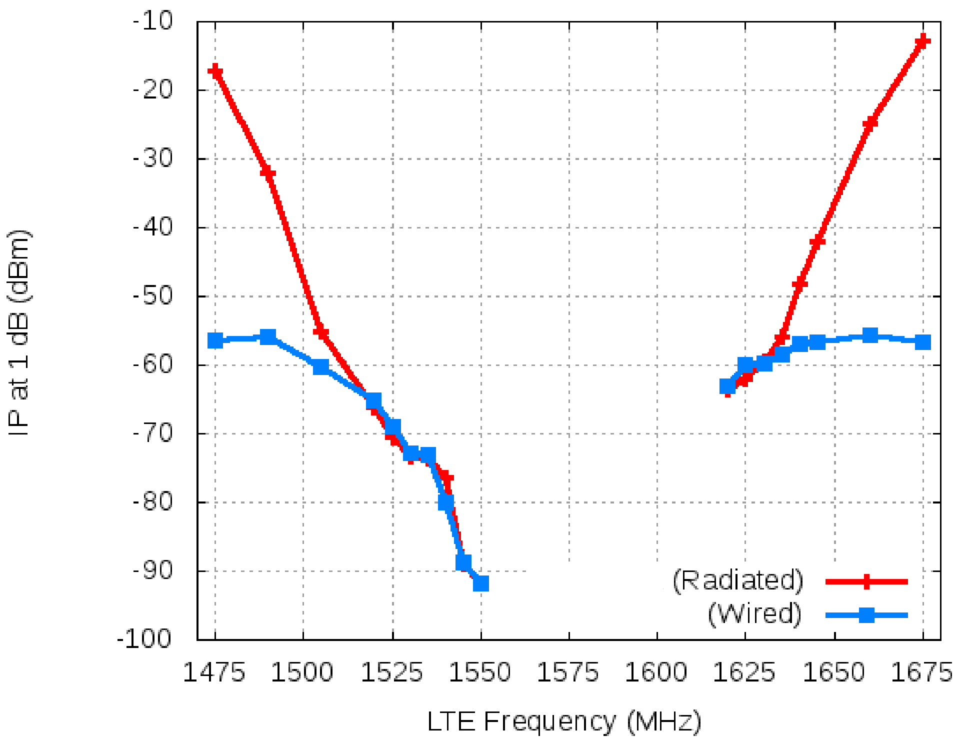
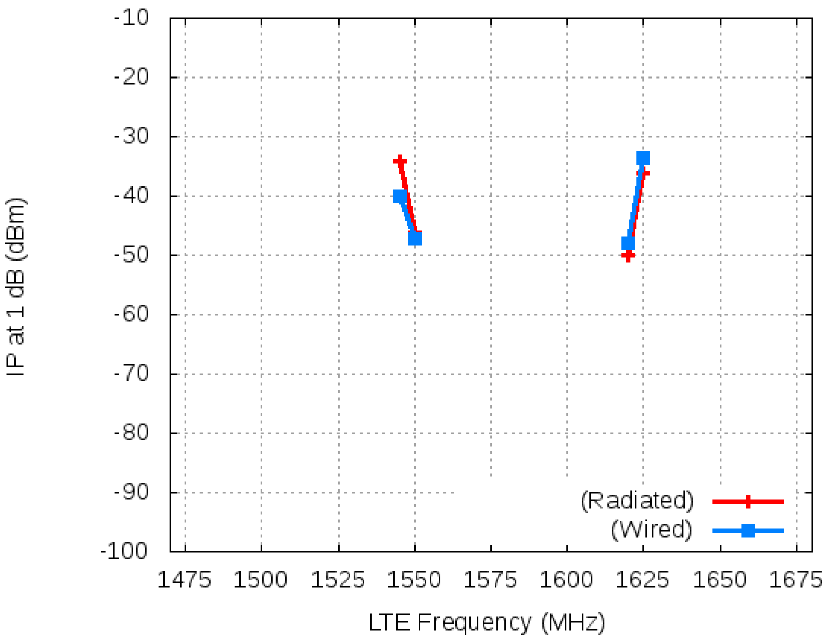
Example A DUT

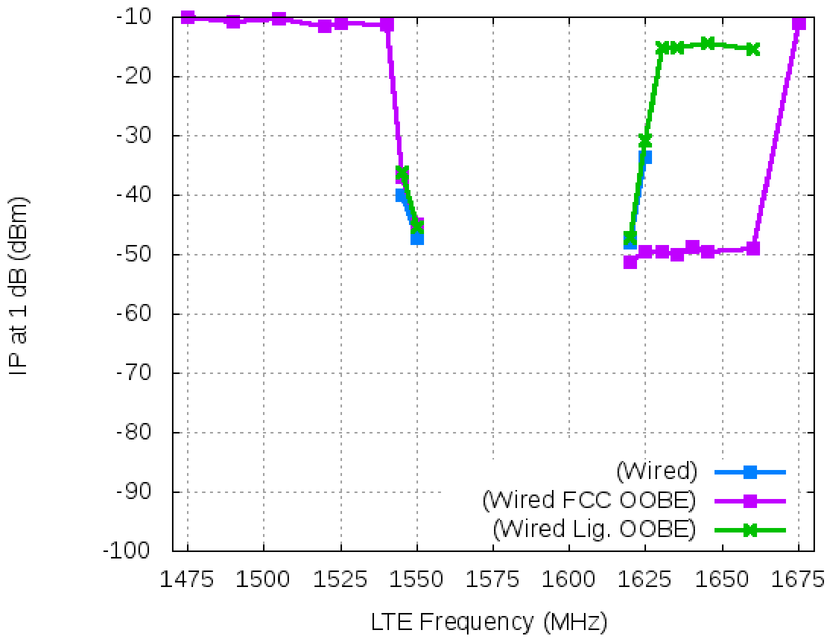


Antenna not characterized but Filtering evident in comparison of radiated and wired 1 dB ITM's

Example B DUT



Radiated and wired 1 dB ITM's in good agreement consistent with expectations since both tests used device filter/LNA



Example of OOBE effects from wired testing. Degradation levels consistent with predicted 1 dB ITM's

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Summary

- Significant testing completed and mask generation underway
  - Analysis continuing on other tests including acquisition, 1 MHz noise (including inband), linearity, Intermodulation…etc.
- Comparison of radiated and wired tests show good agreement
  - Differences primarily attributable to bypassing of (active) antennas in wired tests
- Wired OOBE results confirm predictions for tested levels