The NASCTN "LTE Impacts on GPS" Project

Brief for the National Space-Based Positioning, Navigation, and Timing Advisory Board

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NASCTN
National Advanced Spectrum and Communications Test Network

Outline

- Discuss the scope of the recently completed NASCTN Project: "LTE Impacts on GPS"

- Review comments and questions received in June, 2016 during the test plan review process from

  the Honorable John Stenbit, Dr. Brad Parkinson, and Dr. John Betz

- Information on the project is found here:
  - https://www.nist.gov/programs-projects/impact-lte-signals-gps-receivers

What is NASCTN?

National Advanced Spectrum and Communications Test Network (NASCTN)

- Established by NIST, NTIA, and DoD in 2015
- Mission: provide robust test processes and validated measurement data necessary to
  - develop, evaluate, and deploy spectrum-sharing technologies
  - inform spectrum policy and regulations

National Institute of Standards and Technology
U.S. Department of Commerce

Test Summary Statistics and Information

3 Month Measurement Campaign

- 1476 test hours
- 38222 raw data files
- 19220 parsed data files

Deliverable: 3859 data files (780 MB)

Encompassed:

- 968 LTE exposure tests
- 83 Timing tests
- 5155 Time-To-First-Fix tests
- 891 Time-To-First-Reacquisition tests

- Final report is found here:
  - http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1952.pdf
- Request data from the testing via this link:
  - https://www.nist.gov/sites/default/files/documents/2017/02/15/impact_of_lte_on_gps_-_measurement_data_request_form.pdf

Date Time	LTE power dBm	Stdev LTE power dB	Fix	Sats In View	Longitude deg	Longitude truth deg	Latitude deg	Latitude truth deg	Altitude meters	Altitude truth meters
7/7/2016 1:50:22	-67.1	1.2	1	11	31.598227	31.598227	-110.27785	-110.27785	1351.8964	1352.3

ECEFx meters	ECEFx truth meters	ECEFy meters	ECEFy truth meters	ECEFz meters	ECEFz truth meters	positionError3D meters
-1884901	-1884901	-5101612	-5101612	3323277	3323277	0.405502

Acknowledgments

U.S. Army Electronic Proving Ground (EPG), Fort Huachuca, Arizona

National Technical Systems (NTS), Longmont, Colorado

Manufacturers for support of their products

Objectives

- Develop rigorous test methods to investigate the impact of adjacent-band LTE signals on GPS L1 devices
  - Repeatable
  - Calibrated
  - Well-documented
- Perform radiated measurements on a representative set of GPS devices to validate test methods
- Provide test data

Comment 1: To justify replacing the 1 dB criterion for tolerable interference will require a very extensive justification looking at many worst case GPS/GNSS operational situations.

- The NASCTN test method and report makes no value judgement on the 1 dB degradation in C/N_0 criterion.
- Data from the NASCTN test include the 1 dB degradation results.
  - For all devices, LTE power level sweeps crossed the 1 dB degradation condition, or reached the limits of the LTE power output
    - i.e., in excess of -5 dBm LTE Effective Isotropic Incident Power (EIIP)/ @ DUT.
  - Time-to-first-fix, time-to-first-reacquisition tests included a 1 dB degradation target
- Associated uncertainty analysis and depth of testing enables clear distinction on changing C/N_0 and other measurand (or Key Performance Indicator (KPI)) behavior.
- Allows comparison of the data with other measurement efforts that only provide the 1 dB degradation criterion results.
- Testing beyond the nominal 1 dB degradation C/N_0 point allows the data to be used to estimate margins and supports extrapolation to real-world conditions.

How to: Examples of Steady-State Median Plots

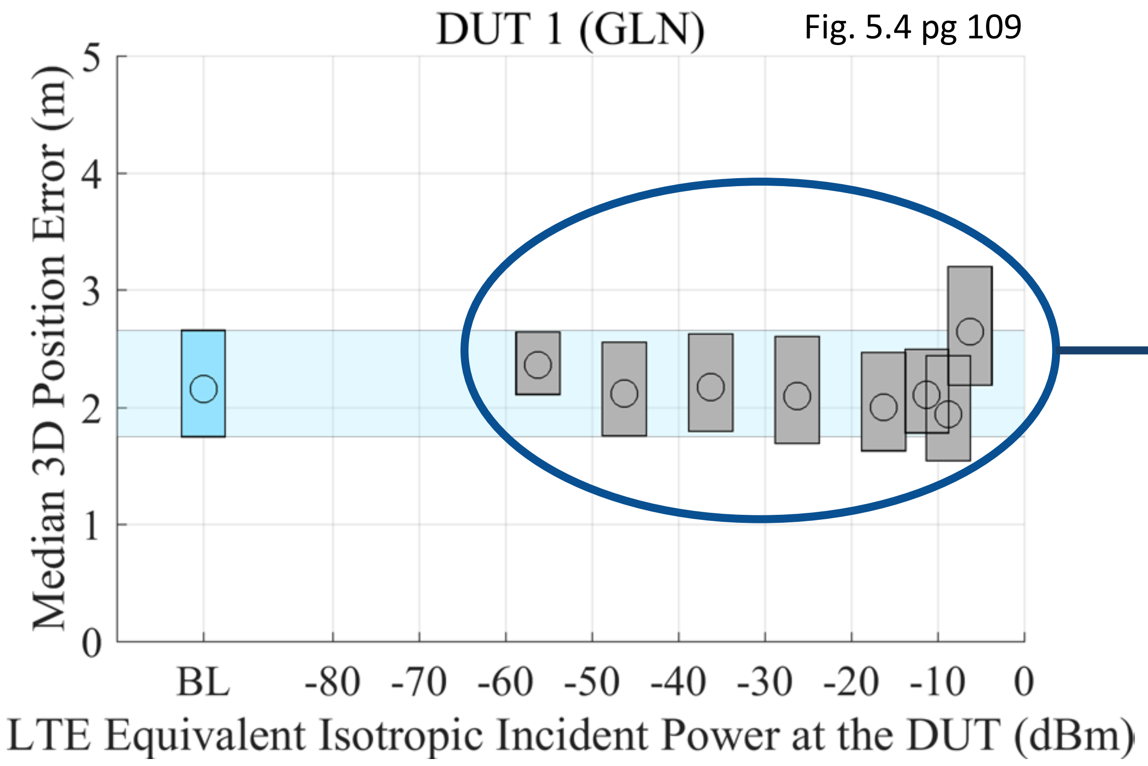


Fig. 5.4 pg 109

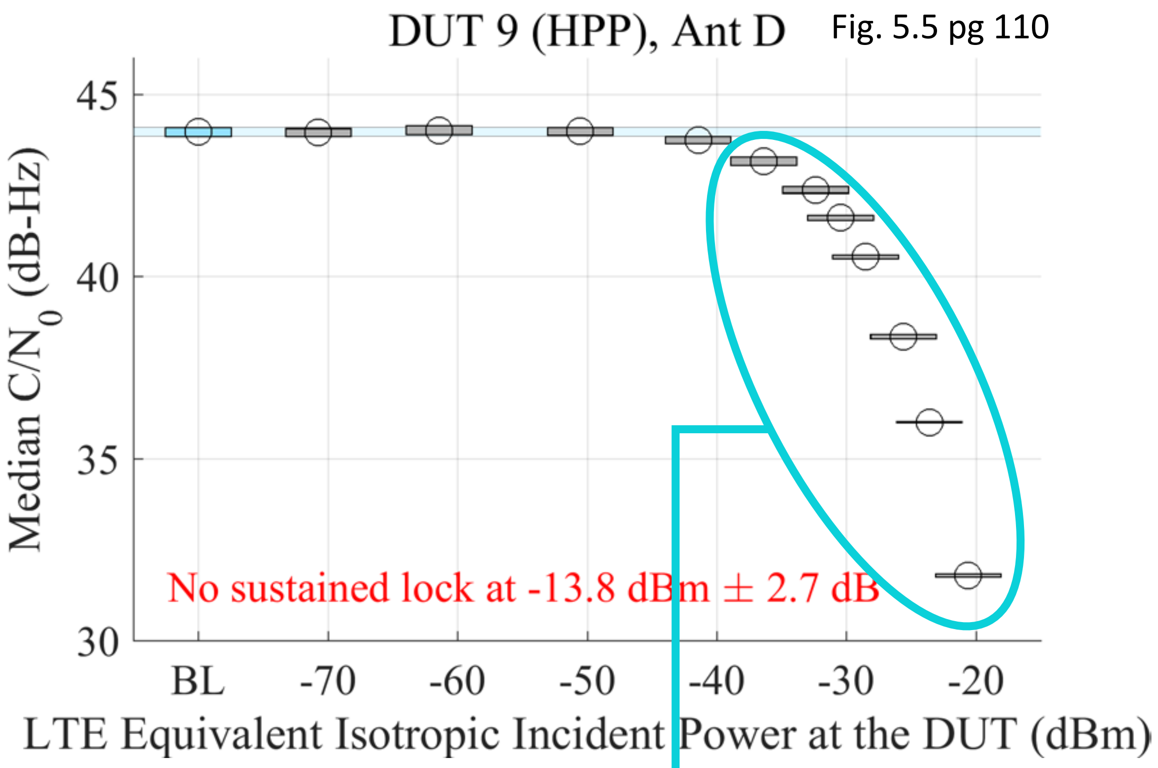


Fig. 5.5 pg 110

Baseline (BL) – No LTE Power

Overlapping with the confidence bound of the baseline – No statistically significant difference

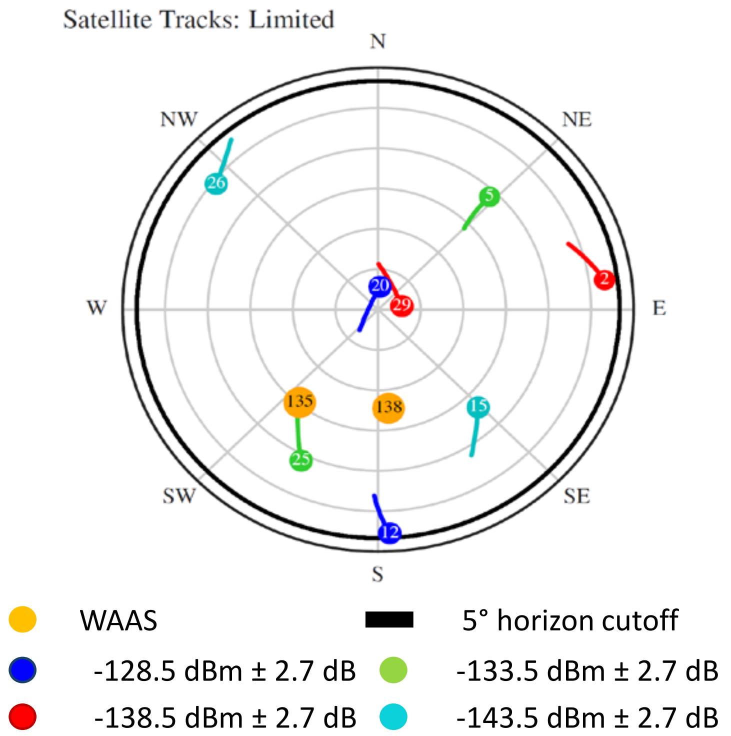
Statistically significant difference

Comment 2: Plan should add goal of answering the key question: determining the level of LTE interference that can be accepted by satnav receivers operating satisfactorily under all relevant conditions.

- NASCTN worked within the bounds of a realizable test within a meaningful timeframe for all stakeholders as well as regulators.
- GPS L1 is the primary satnav signal used in the proposed region of LTE deployment– testing must ensure first and foremost that potential impact on this satnav signal is understood.
- Additional points with respect to test integrity are answered in question 9 below

Comment 3: Plan should address highly stressed conditions – the "envelope" conditions.

- Test plan priorities:
  - 1) Detailed results for nominal conditions
  - 2) Detailed results for "limited" conditions
  - 3) Time permitting, motion for receivers designed and intended for motion
- Testing includes a "limited" satellite constellation condition:
  - Reduced number of available satellites
  - Carrier power levels were reduced w.r.t. nominal
- Testing included LTE power-sweeps that either
  - identified the loss-of-fix point for the device
  - or reached an LTE power level that exceeds -5 dBm at the device-under-test (DUT)
- <u>Motion was not tested – more discussion in answer to question 5 below.</u>



Comment 4: Plan should include all receiver classes, receiving modes and states, particularly those that are well known to be most sensitive to interference, e.g. acquisition (cold start) and reacquisition.

Selected receivers reflect recommendations from a variety of stakeholders

- Original device list was modified to focus on precision devices, including timing, after input from stakeholders
- Access to measurands was a key consideration in device selection
  - 5 General Location and Navigation (GLN);
  - 4 High Precision Positioning (HPP) with 2 in Real Time Kinematic Mode (RTK) & Multiple antenna options
  - 3 GPS Disciplined Oscillator (GPSDO)
  - 2 Development Boards (DEV)
- Total number of device configurations: 20
- Time-to-first-fix, time-to-first-reaquisition are the most rigorous completed to date (100 trials per LTE power level.)

Receiver classes not tested:

Certified-aviation, non-certified aviation, space-based, cellular, and military grade

Comment 4 (cont.): Assessing all classes of Precision Receivers

- Testing included HPP and RTK receivers, which have similar receiver chip architecture as other high precision receivers (timing, geodetic, etc.)

> These include, for example, precision real-time measurements of earth-fault movement in three dimensions (with accuracies better than 1 millimeter)

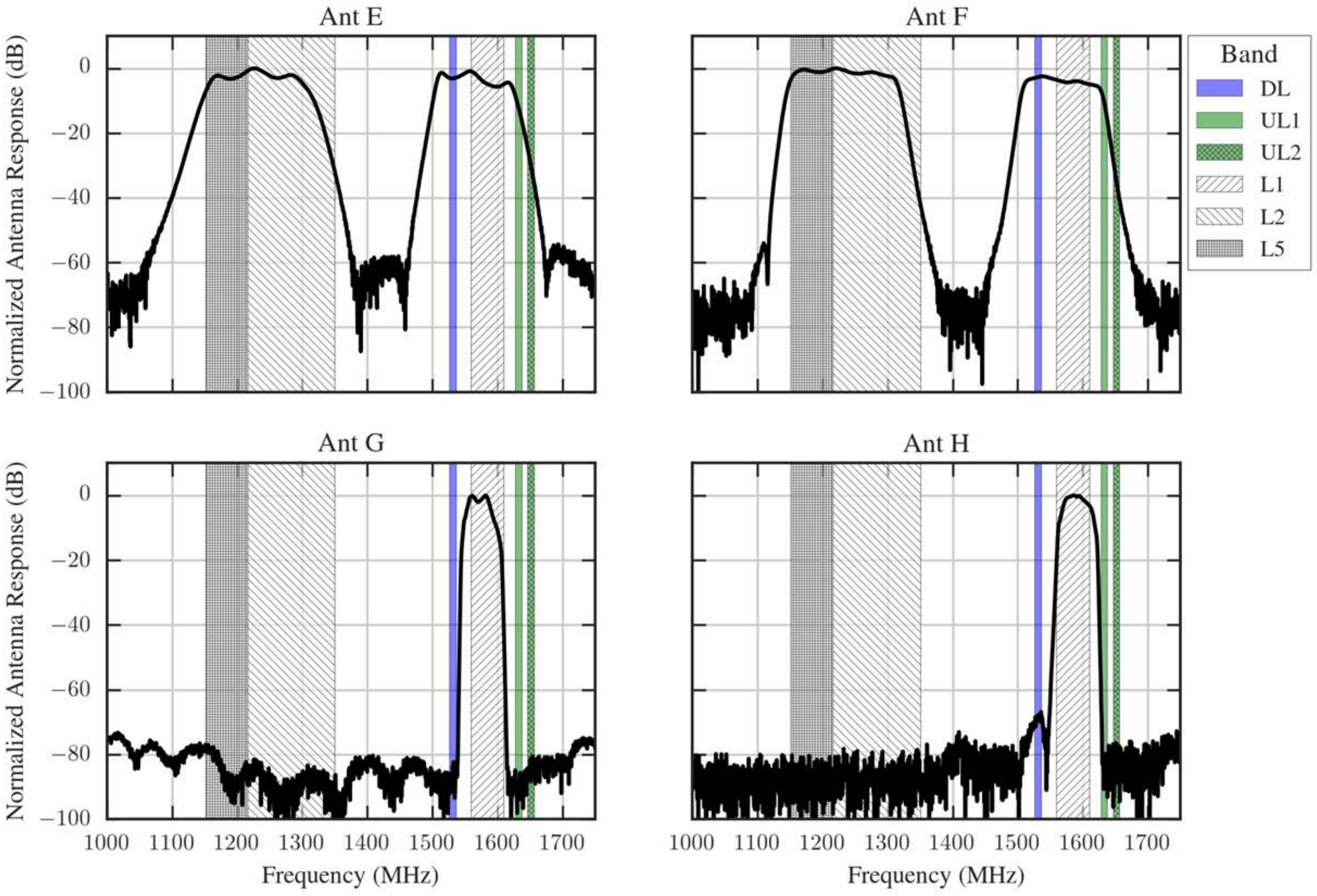
- Geodetic receivers (resolution abilities better than 1 mm) requiring:
  - Sophisticated RTK : Multiple reference stations and NOAA reference tables.
  - Real time subscription services
  - Significant networked backhaul infrastructure
  - Long-term averaging capabilities

  Are impractical to test: maintain efficient test times, time-syncing of data streams or purchasing of subscription services
- Test conditions on order of multiple weeks for a single LTE power level.
  - Note: The NASCTN tests of GPSDOs disciplined by a cesium clock required 2.5 hrs per LTE power level, 40 hr test run times were the upper limit of practical test sequences.

Comment 4 (cont.): Assessing all classes of Precision Receivers

- Precision receivers must use very wide bandwidth for accuracy

- HPP devices were tested with **wide**, *narrow*, & <u>dual</u> bandwidth antennas
  - Normalized boresight antenna pattern measurements are provided in the report
- The test data is publicly available in a common format. It can be used to independently ascertain the accuracy of measurands.



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Comment 4 (cont.): Assessing all classes of Precision Receivers

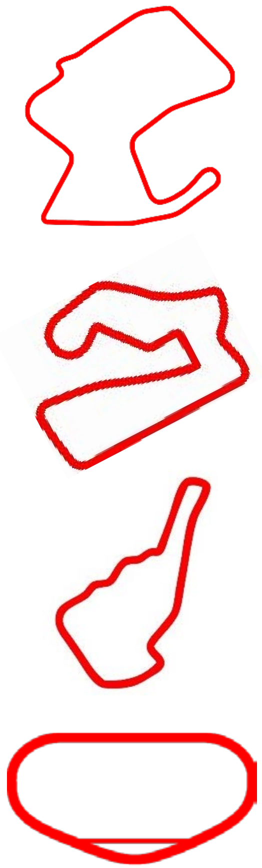
- Not just Tracking - impact on ***measurement jitter is more critical***

- The NASCTN test data allow analysis of KPI jitter
  - Baseline (no LTE) and LTE-present

- New Designs may somewhat reduce (but not eliminate) susceptibility
  - Receivers are retained for many years . Repacement and renewal timing a very real issue.
  - To completely understand impacts - carefully evaluate representative wide-band (precision) receivers.

- The NASCTN tests of precision and timing receivers performance are extensive and detailed, and include devices from the late 1990's to current technology

Comment 5: Plan should include moving receivers.



Example tracks courtesy of: Mazda Raceway Laguna Seca, Road America, Road Atlanta, Daytona 500

- Highly dependent on specific use cases
- GPS receiver design limitations
- Measurands to consider:
  - position- latitude, longitude, and altitude;
  - velocity- x, y, and z directions
  - acceleration – x, y, and z directions
- Motion track:
  - Length, elevation change,
  - corner design , laps
- Statistical Considerations
  - Need sufficient sampling and randomization:
    - Multiple repetitions of motion path – e.g., number of laps
  - Limited by maximum <u>practical test time</u>
  - Randomize over motion parameters, e.g., (jitter-walk)
  - Reduce variability by maintaining view of simulated satellites
    - KPIs are sensitive to satellite transitions over horizon

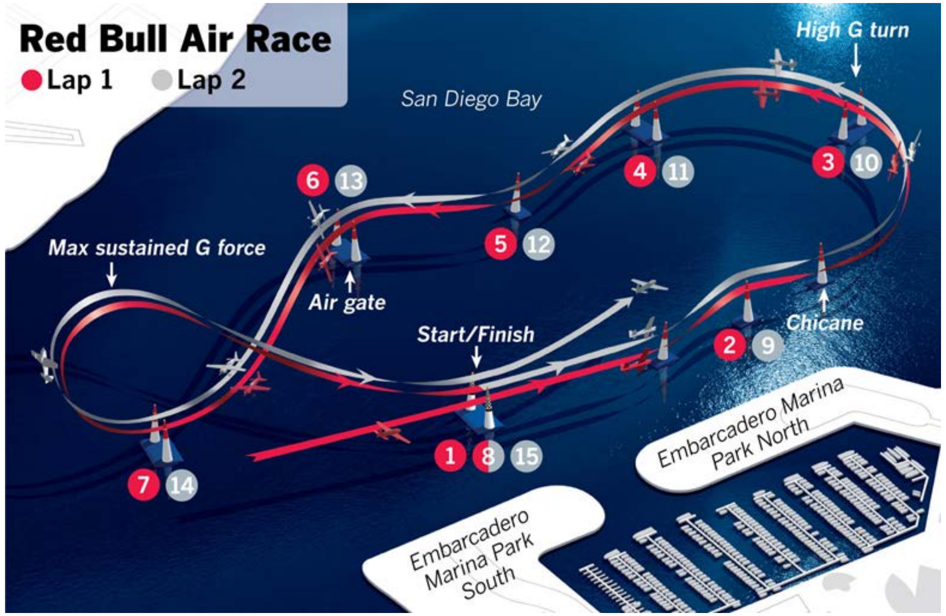


Image from: http://www.pacificsandiego.com/local-entertainment/red-bull-air-race-2017/

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Comment 6: Plan should include other sources of interference.

- Other sources need to be well-defined, and specific details and their impact on GPS need to be known before inclusion in a rigorous testing protocol
  - i.e., what specific noise profile(s) should be included
  - Test conditions must remain consistent during testing to correctly attribute the source of changes to the DUT performance

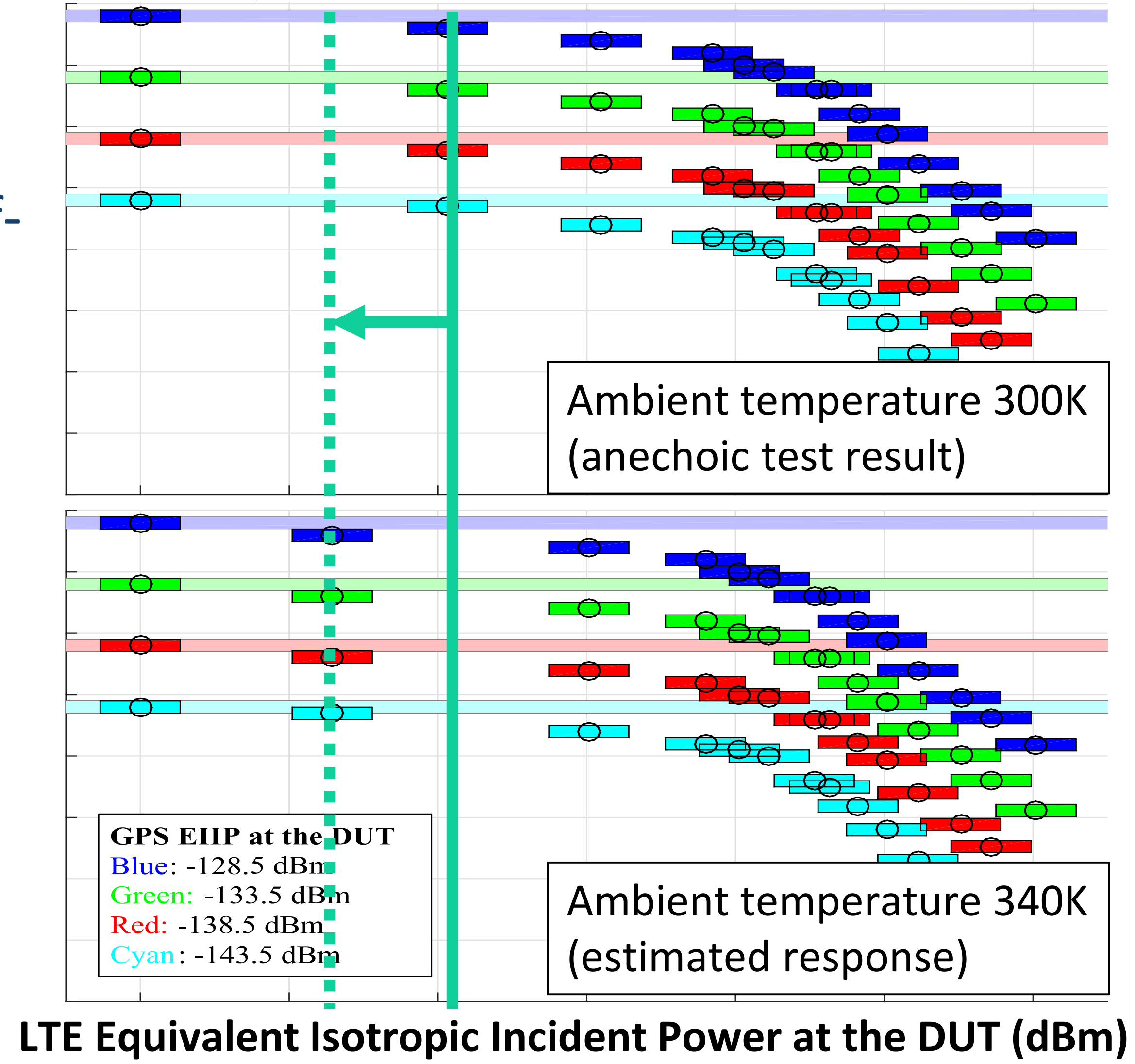
- Overall raising of the noise floor due to out-of-band and in-band emissions of other sources is a regulatory issue and was not considered.

- Additional considerations during testing
  - Temperature fluctuations impact the amount of noise contribution by the receiver
  - Ongoing research investigates the impact of temperature variation on C/N_0 degradation
    - Supports performance estimates under conditions outside of controlled chamber environments

Active Research: Application to "Live Sky" Noise Conditions

Tech Note under development:

- "Estimating Interference Impacts in Realistic Noise Environments Based on Receiver SNR Self-Estimates from Anechoic Test Results"
- *LTE Impacts on GPS* test conditions fixed to ambient thermal noise ~300 K
- Decoupling receiver and ambient noise contributions is challenging and time-consuming
  - LNA integrated into antenna
  - LNA integrated into antenna+receiver
- Instead: estimate impacts across representative values of
  - antenna efficiency, LNA NF, ambient temperature



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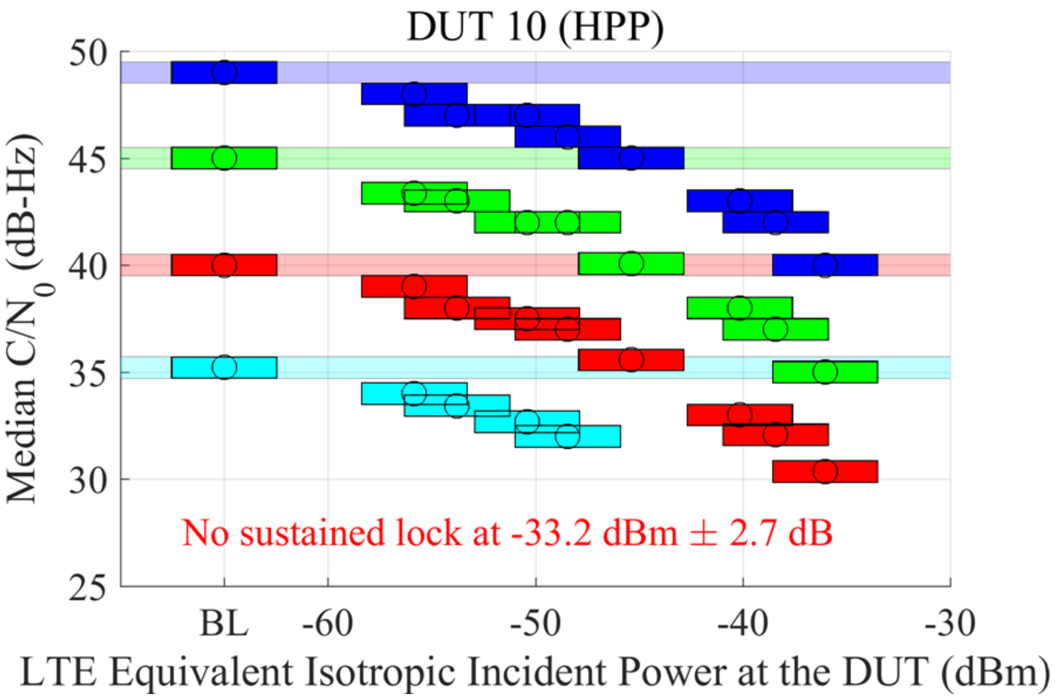
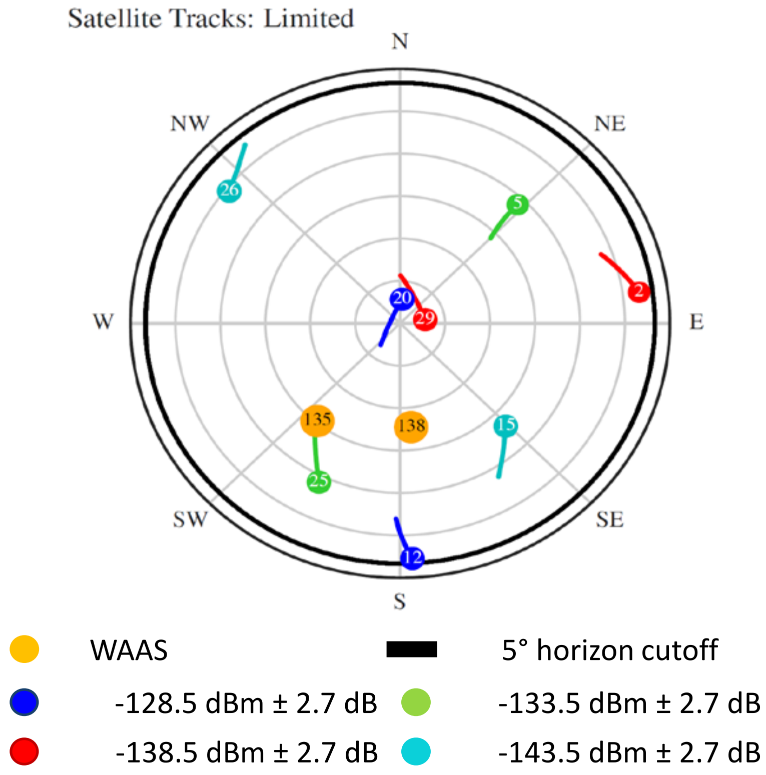
Comment 7: Plan should include various received power levels and numbers of satellites.

- NASCTN testing included a "limited" scenario, with 8 GPS satellites at various power levels





-128.5 dBm	Baseline (BL) – No LTE Power	-138.5 dBm	Baseline (BL) – No LTE Power
-133.5 dBm	Baseline (BL) – No LTE Power	-143.5 dBm	Baseline (BL) – No LTE Power

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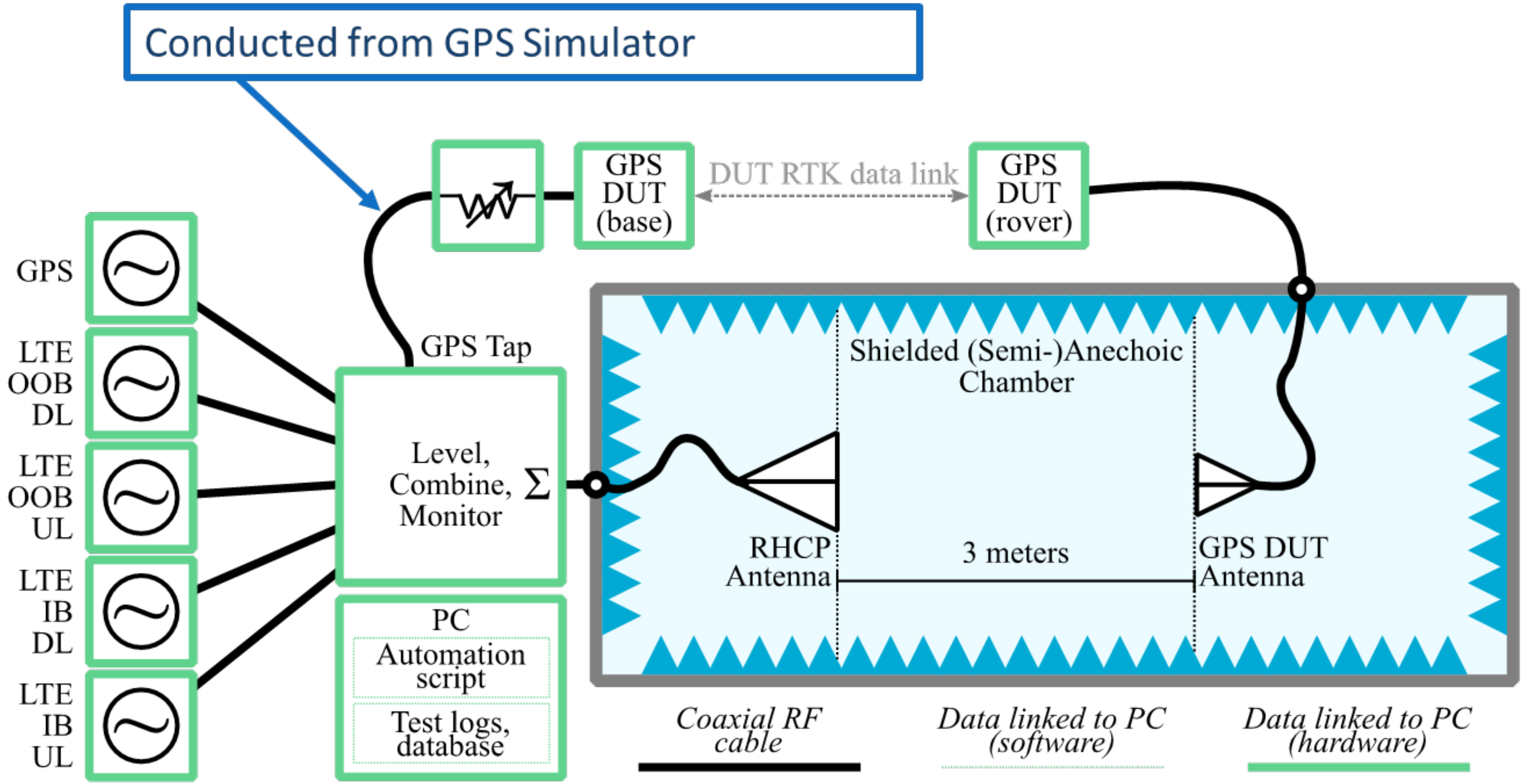
Comment 8: Plan must include multiple receivers simultaneously, at least in some cases.

- The RTK setup included multiple receivers using “zero-baseline solution” method
- In discussions with stakeholder, the highest priority was interference on rover.



Note: Testing of multiple receivers simultaneously raises the potential for self-interference between receivers (and their support cabling).

Comment 9: Plan should include receivers for more satnav signals, including L1C and from other GNSS. These advanced signals are the basis for many high productivity applications.

- Testing included all of the GPS L1 signals that were supported in the simulator and were the focal point of the testing
  - See page 19 of report: L1 C/A, L1C pilot, Pseudo Y, and M-Code, WAAS
- Testing of GPS L2 and L5 bands, Galileo, and GLONASS was not within the scope of this project
- Testing *all GNSS* signals could be done with different simulator equipment or combining several simulators

Comment 9 (cont.): Plan should include receivers for more satnav signals, including L1C and from other GNSS

- Drawbacks with testing multiple satnav signals simultaneously:
  - can mask the impacts of a potential interfering source much like a device with dual band capability or network connectivity
    - difficult to determine which satellite signals are actually used by the device under test
  - increased uncertainty in the test conditions

Comment 10: Plan should focus on absolute received power levels, not signal to interference ratio.

- Testing did use absolute power levels
  - Uncertainty analyses of the power levels of the GPS signals and the LTE powers are provided
  - Testing of devices in the highly automated, controlled fashion allowed retesting a device
    - Verified repeatability
  - High-degree of automation reduced the contribution to uncertainty due to human error
- Codified a technically-specific way to discuss the incident power level condition at the device-under-test
  - Effective Isotropic Incident Power (EIIP)
  - Allows extrapolation of results to different propagation models and environmental conditions

Comment 11: Plan should address how test data will be extrapolated to operational conditions.

- The testing was akin to conducted testing but in a radiated manner
  - Required to incorporate the effects of antenna filtering or the use of embedded antennas often found in GLN devices
  - Result for a range of power levels beyond the 1 dB degradation in C/N_0 allows selection of point on the dB-Hz curve other than the baseline
- The test plan discussed how the Friis path loss model can be used to extrapolate the results to different separation distances between the LTE source and the GPS device
  - Other path loss models can be applied
- There is ongoing research on how to translate thermal noise conditions in an anechoic chamber to other temperature conditions

Comment 12: At a minimum, the test plan and test report should clearly and prominently highlight limitations of the testing, and the resulting restrictions on drawing conclusions from the tests.

- The limitations have been brought out in the test report and in briefings on the test data.
- If sufficient details, documentation, and data are available, comparisons across independent testing campaigns are both possible and useful
- From the Executive Summary,

"Comparison among results of different test campaigns (including this study and [2–5]) requires an understanding of any differences in test conditions, devices, and parameters. Specific examples include GPS and LTE signal parameters, power levels, and test environments. Understanding these factors is crucial to drawing conclusions based on the aggregate of these heterogeneous test results. These types of analyses are beyond the scope of this project, but may be undertaken by other interested parties such as the GPS and cellular communications industry, government agencies, or spectrum regulators."

- **No policy recommendations are made in the NASCTN report or in any NASCTN briefing**

Comment 13: To have credibility with the PNT community, it is clear that real PNT expertise must be added to the test team. If the plan is to answer the real question, the satnav community can provide assistance.

- The testing reflected input incorporated from over a 150 comments on the original test plan, including a review of the ones here.
- Personnel from U.S. Army Electronic Proving Ground (EPG), Fort Huachuca, Arizona that specialize in GPS testing supported the test team and helped design test conditions.
- World-renowned researchers in precision timing were consulted during the design of the timing device test development.
- GPS manufacturers were consulted in designing the test and the extraction of data from devices.

Comment 14: The test plan review process should be open and formal.

- The initial and revised test plans were posted publicly on the NASCTN website.
- The initial test plan was sent to leading stakeholders, including the leadership of the PNT Advisory Board.
- Adjudicated comments were posted on the NASCTN website.
- All products of the test development and execution, including the initial test plan, revised test plan, final report and test data are publicly-available on the NASCTN website.
- https://www.nist.gov/programs-projects/impact-lte-signals-gps-receivers

Questions?