Presentation to PNT Advisory Board
15 November 2017, Redondo Beach

Logan Scott

National Advanced Spectrum and Communications Test Network (NASCTN) Results and Their Implications with Regards to National Infrastructure

Four Major Interference Studies to Draw From

- Technical Working Group "TWG"
- Roberson Report "Roberson"
- Adjacent Band Compatibility "ABC"
- National Advanced Spectrum and Communications Test Network "NASCTN"

- Where they overlap, the data generally agree
  - BUT NOT the conclusions

The claim is that an LTE network will not harm GPS device performance

NASCTN Report: We then discussed the NASCTN report, a Government study conducted by the research center jointly run by the U.S. Department of Defense and Department of Commerce and housed at NIST's facilities in Boulder, Colorado.[2] This comprehensive 428-page study that involved 1,476 hours of testing validates the conclusion reached by the major GPS companies over the last 14 months: An LTE network operating within the specifications proposed in Ligado's pending FCC applications will not harm the performance of GPS devices.

February 24, 2017

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: *Ex parte* presentation in IB Docket No. 11-109; RM-11681; IBFS File Nos. SES-MOD-20151231-00981, SAT-MOD-20151231-00090, and SAT-MOD-20151231-00091

Dear Ms. Dortch:

On February 22, 2017, Valerie Green, Executive Vice President and Chief Legal Officer of Ligado Networks LLC ("Ligado") and the undersigned met with Ron Repasi, Michael Ha, and Paul Murray of the Office of Engineering and Technology; Charles Mathias, Paul Powell, and Aalok Mehta of the Wireless Telecommunications Bureau; Jennifer Tatel of the Office of General Counsel; and Bob Nelson of the International Bureau. The purpose of the meeting was to discuss both Ligado's process in working with the FAA and the final report by the National Advanced Spectrum and Communications Test Network ("NASCTN") on the impacts of mid-band LTE signals on GPS receivers.

The stated objective of the NASCTN testing was to "develop a test method" and "validate the test method".

National Advanced Spectrum and Communications Test Network (NASCTN) NIST 1952 Focuses on Three Specific Interference Sources

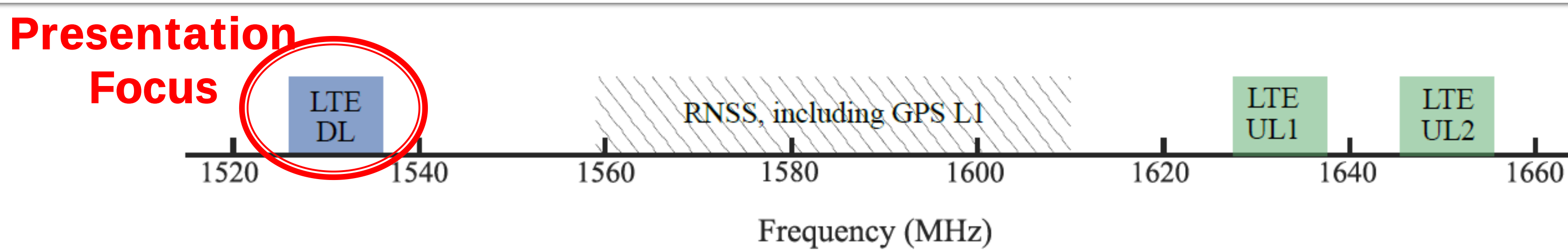


Figure 1.1: Spectrum allocations showing RNSS, which includes the GPS L1 band, and the various adjacent bands proposed for LTE use.

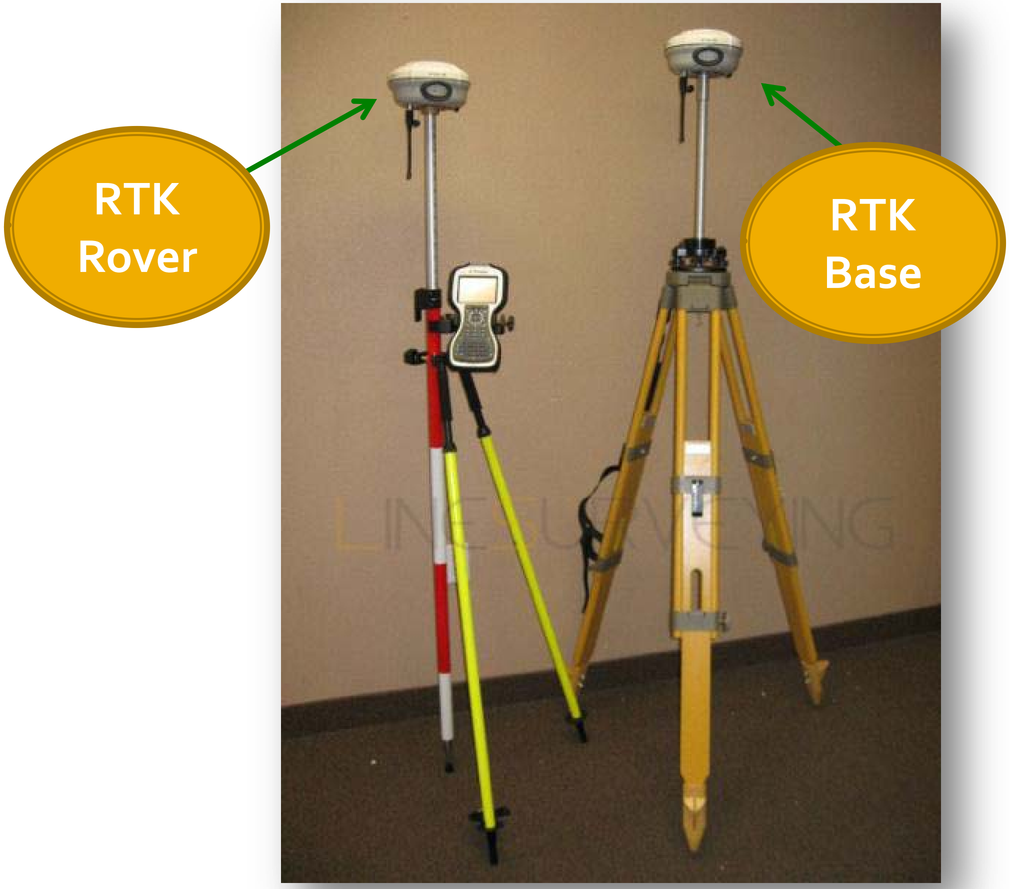
- **Adjacent-band LTE activity was represented through emulated, modulating LTE waveforms**
  - **Down Link 1526MHz – 1536 MHz, "DL" 1585 Watts EIRP**
  - **Uplink 1627.5 MHz – 1637.5 MHz "UL1" 200 mWatt EIRP**
  - **Uplink 1646.5 MHz – 1656.5 MHz "UL2" 200 mWatt EIRP**

High Precision Reference & RTK Receivers Come In Many Flavors

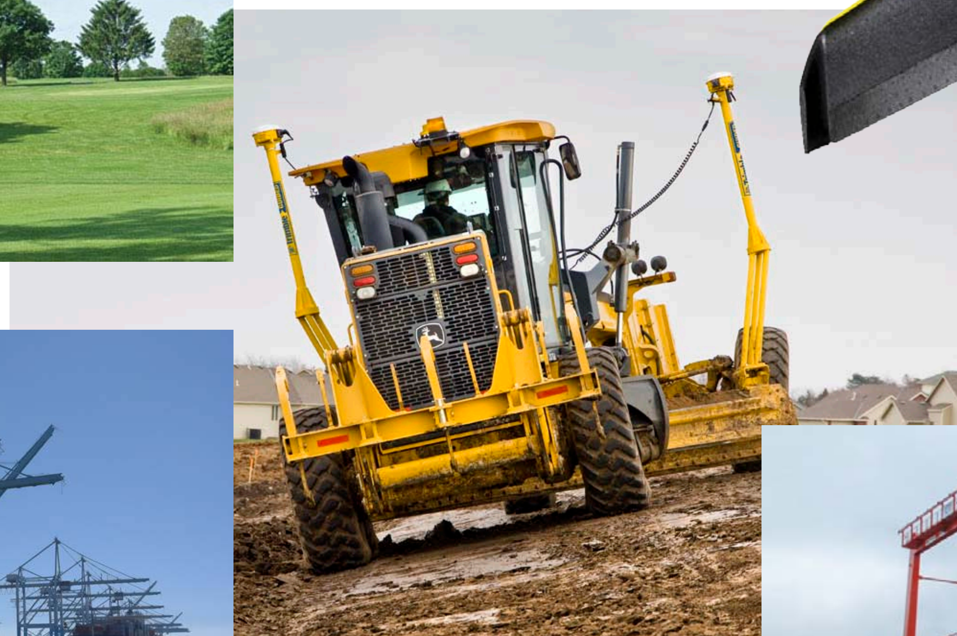
Wide Bandwidth and High Linearity Needed for Precision Can Make These Types More Susceptible to Interference

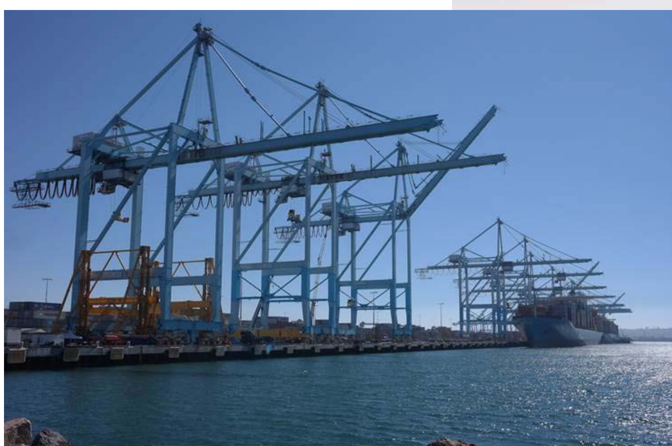
Network Reference Receiver

Survey Receiver Pair



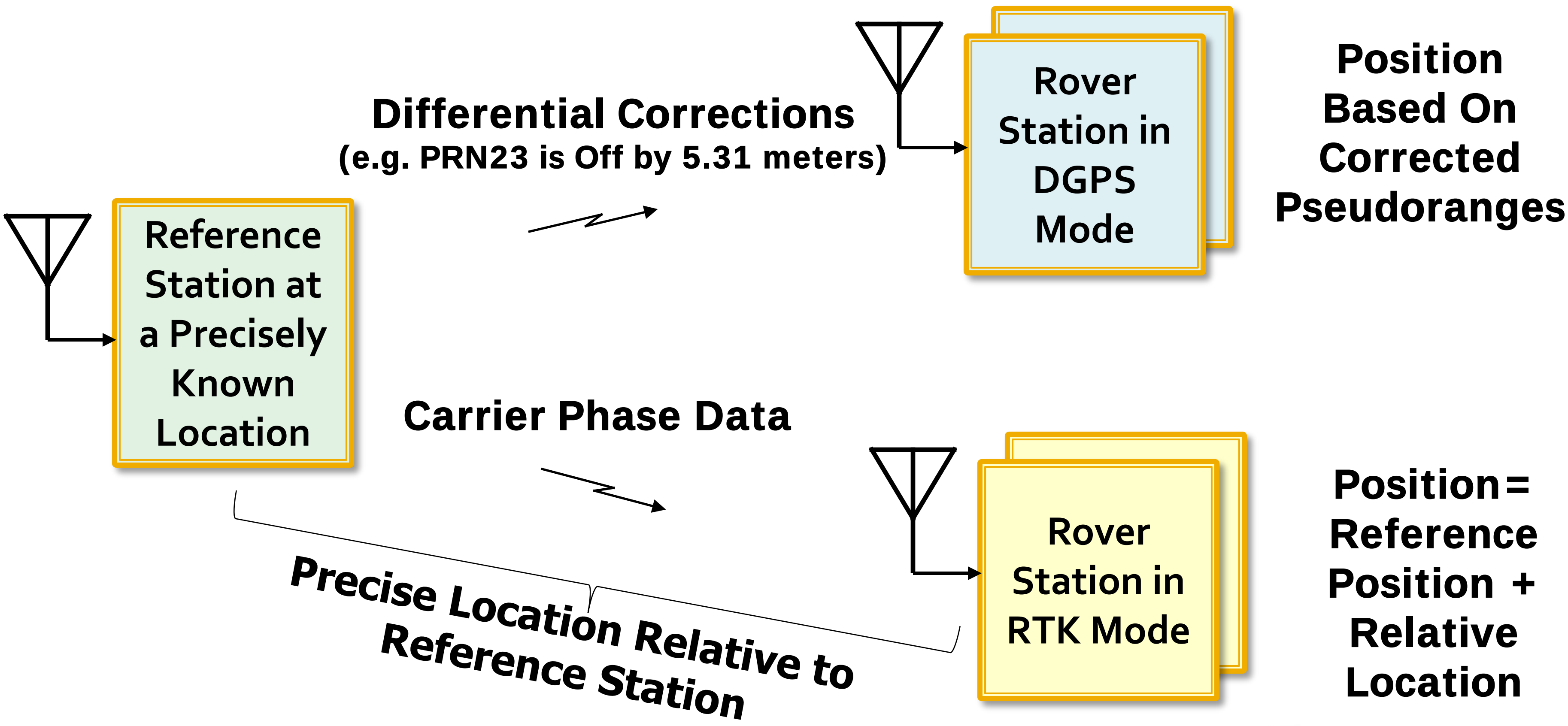
RTK Applications Extend Far Beyond Survey
Core National Infrastructure



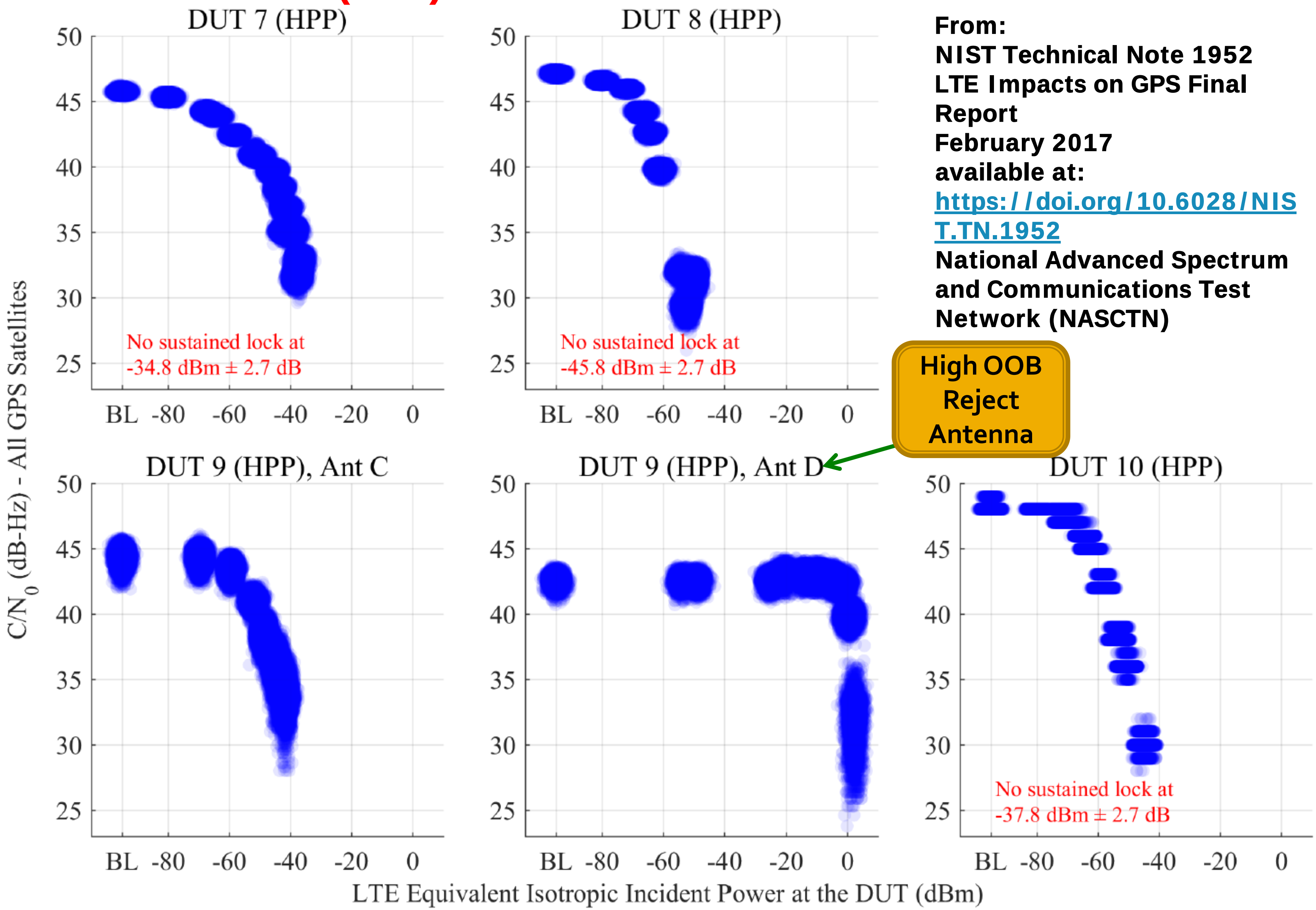


Reference Stations Provide the Basis for High Precision Navigation and RTK

Can Simultaneously Support Multiple Rovers Operating In Multiple Modes



High Precision Position (HPP) Receivers



From:
NIST Technical Note 1952
LTE Impacts on GPS Final Report
February 2017
available at:
https://doi.org/10.6028/NIST.TN.1952
National Advanced Spectrum and Communications Test Network (NASCTN)

Figure 6.24: Scatterplots of reported C/N_0 from HPP receivers, swept with LTE power level. The GPS scenario is nominal, and the type of incident LTE is DL.

145

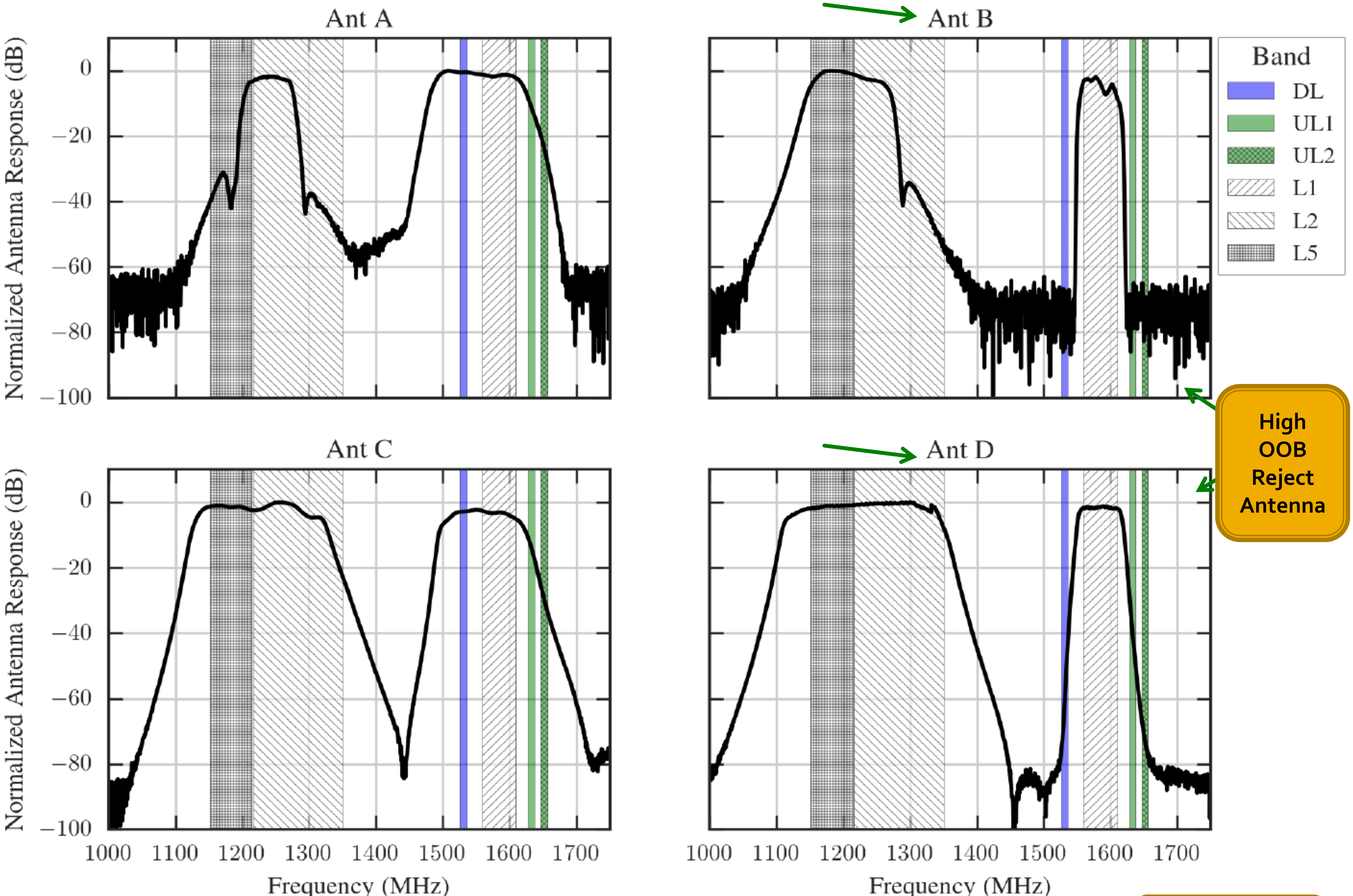


Figure 6.2: Normalized S_{21} S-parameter responses of external DUT antennas.

Real Time Kinematic (RTK) Receivers

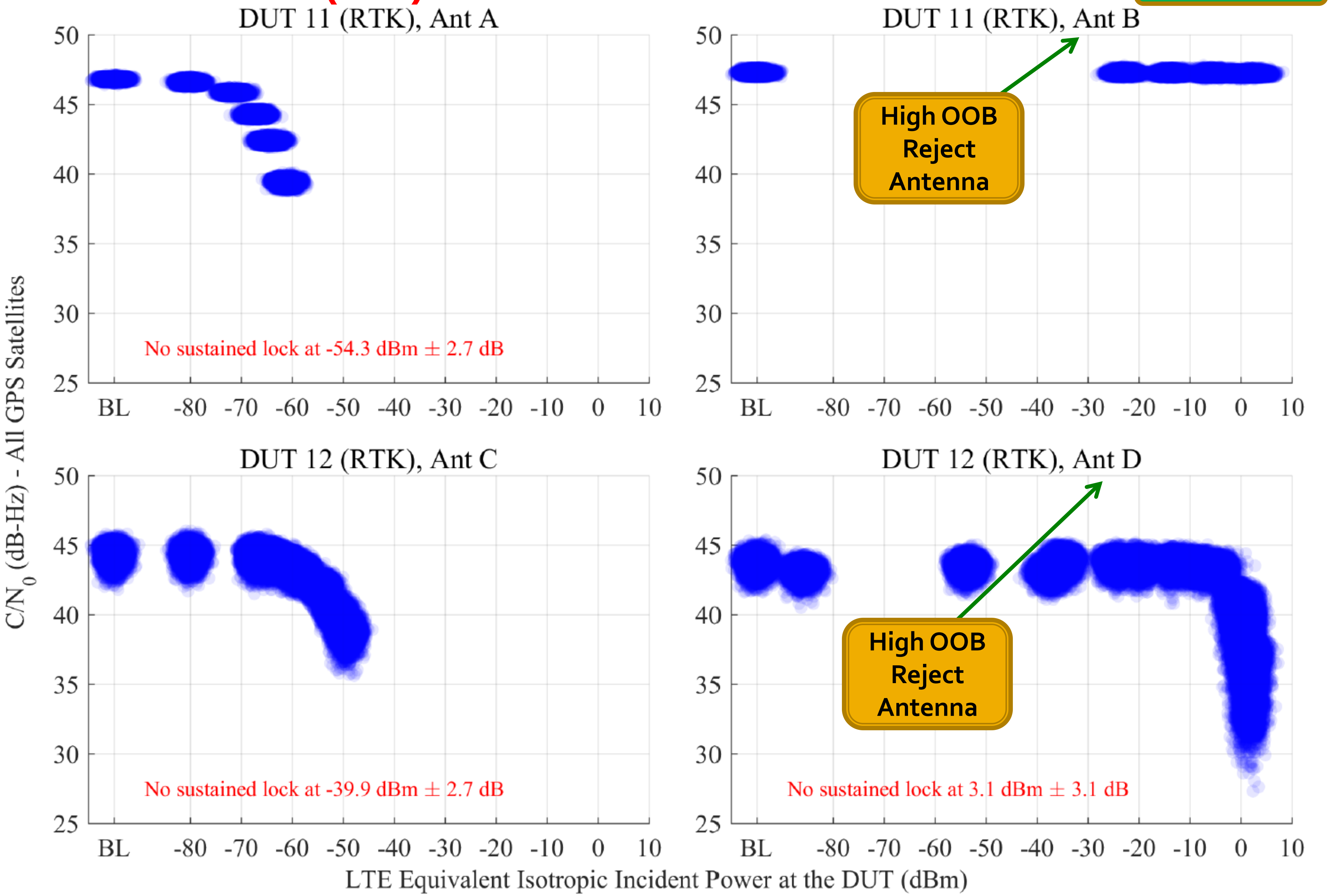


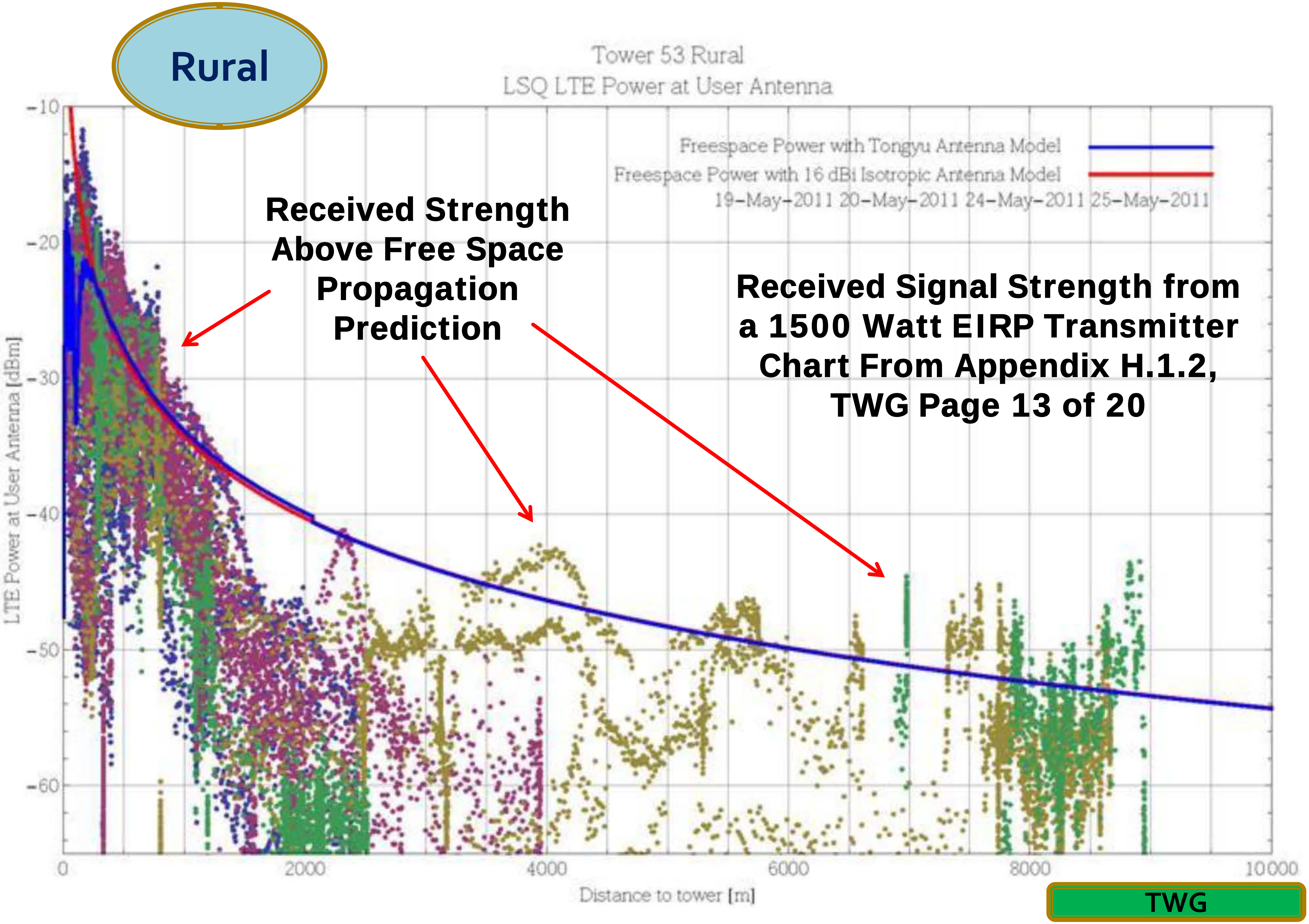
Figure 6.49: Scatterplots of reported C/N_0 from RTK receivers, swept with LTE power level. The GPS scenario is nominal, and the type of incident LTE is DL.

Summary NASCTN Results for High Precision and RTK Receivers

Receiver (Mode)	Antenna Type	KILL Threshold (dBm Isotropic)	IMPAIR Threshold† (dBm Isotropic)
DUT7 (HPP)	Normal	-35	-70
DUT8 (HPP)	Normal	-46	-70
DUT9(HPP)	Normal	-45	-60
DUT10(HPP)	Normal	-38	-70
DUT11(RTK)	Normal	-54	-70
DUT12(RTK)	Normal	-40	-60
DUT9(HPP)	High OOBE Reject	>0	0
DUT11(RTK)	High OOBE Reject	>5	>5
DUT12(RTK)	High OOBE Reject	3	-5

† NASCTN test results provide very coarse information on where C/No degradation occurs since large step sizes in LTE power were used at lower powers. ABC tests show ~-65 dBm lower power bound for 1dB C/No degradation for HPR

Figure 16 Received Power versus Range at Tower 53 (0-10 km)



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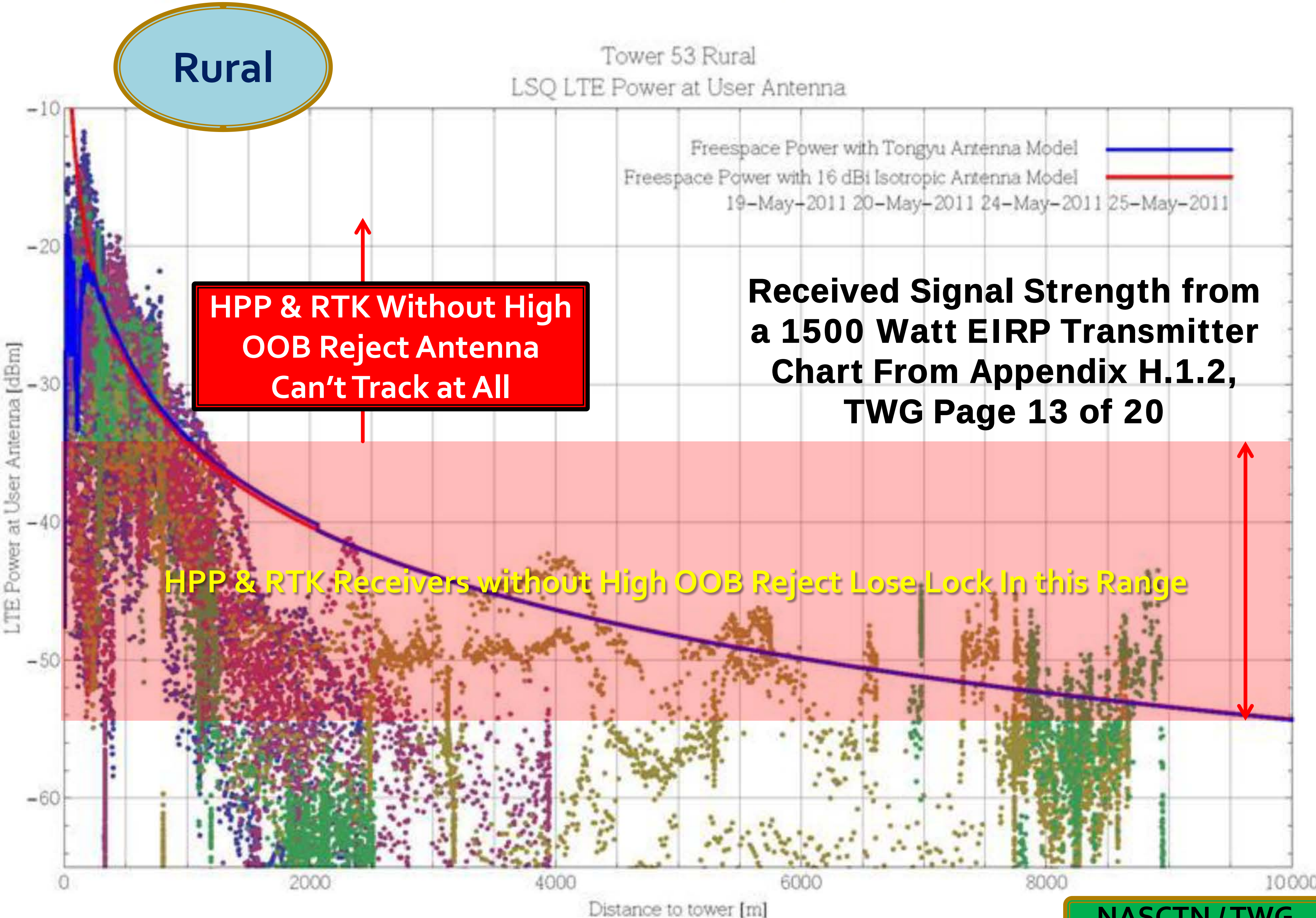

NASCTN / TWG

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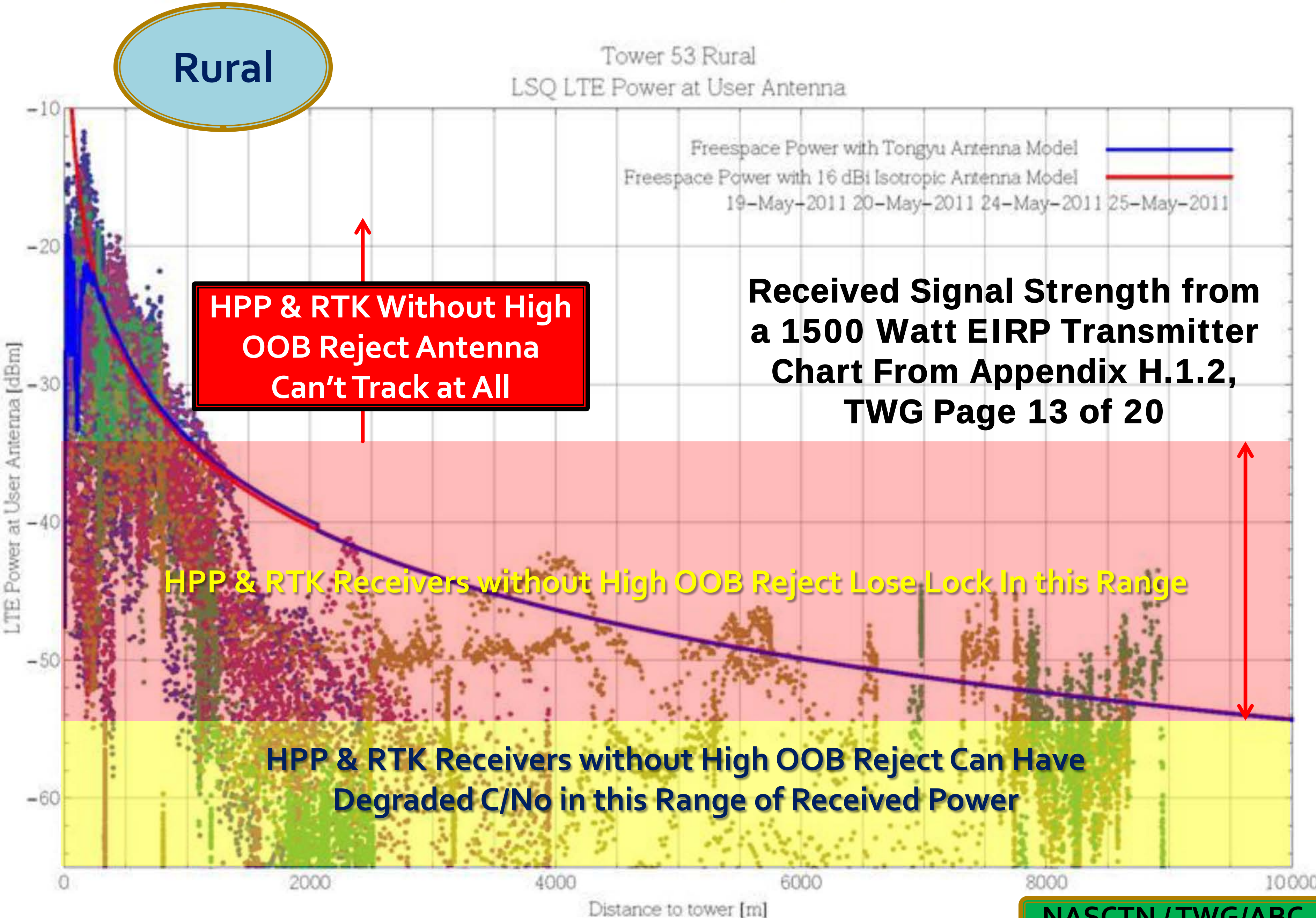


Figure 12 Received Power versus Range for Tower 68

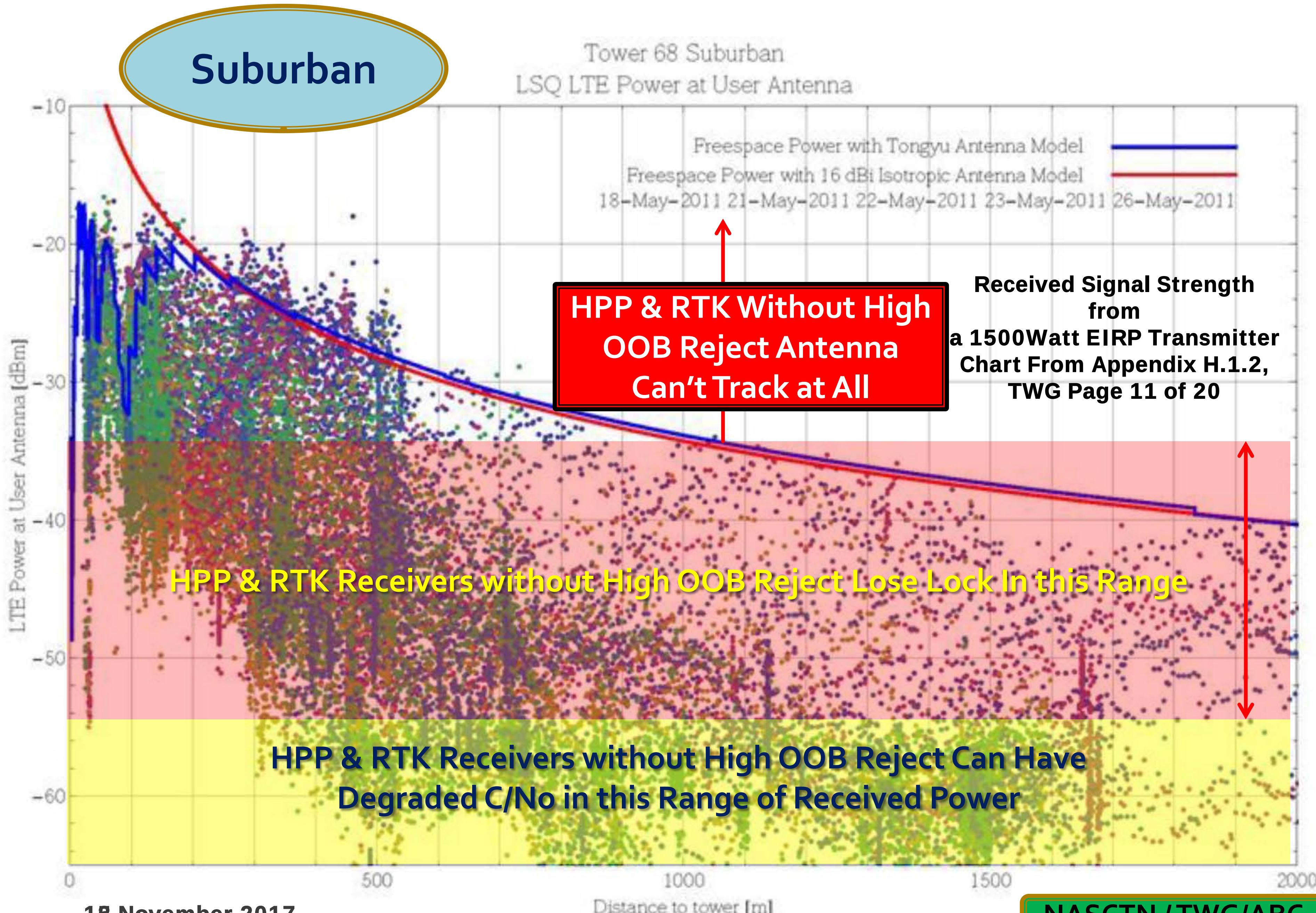
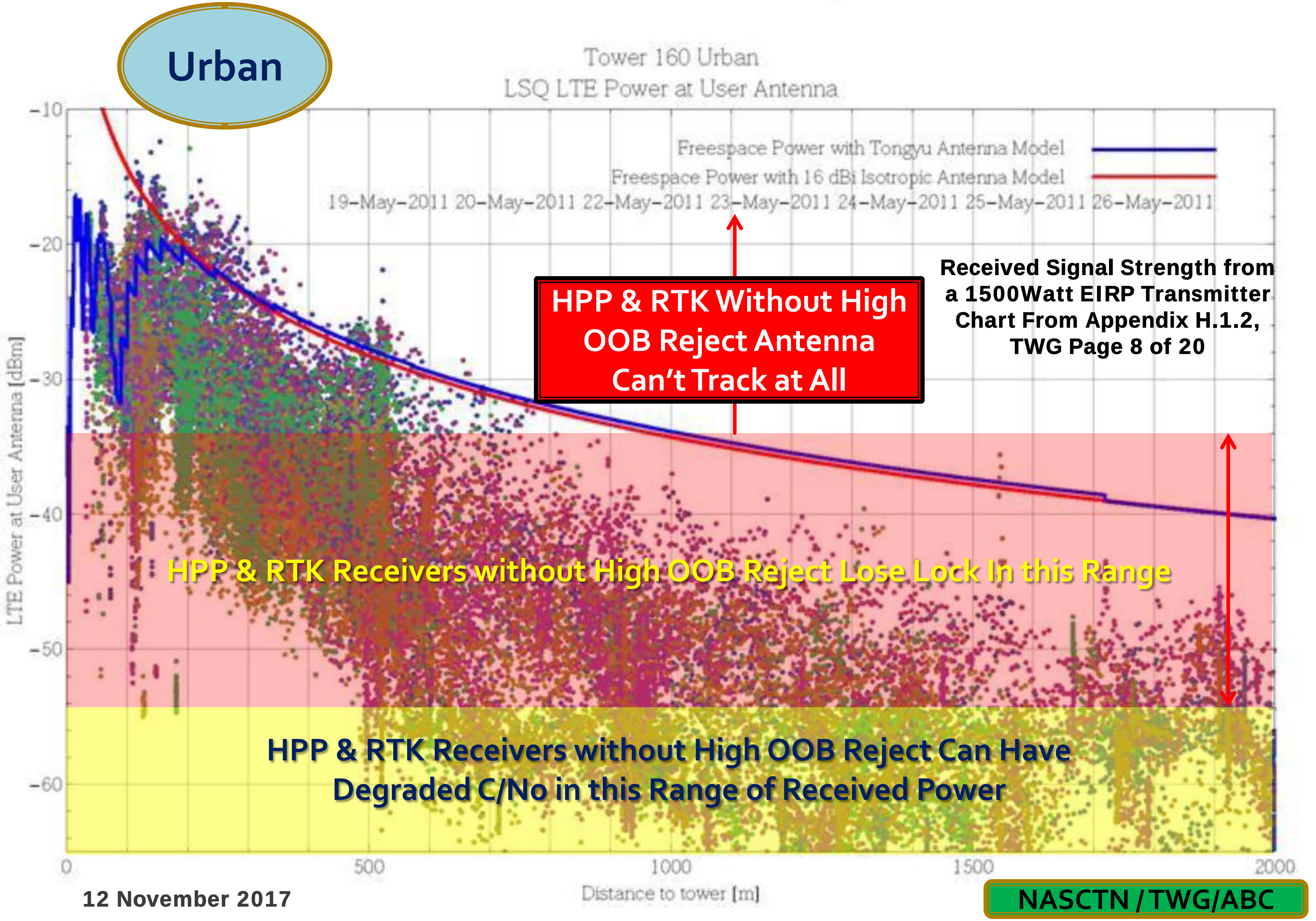


Figure 8 Received Power versus Range at Tower 160

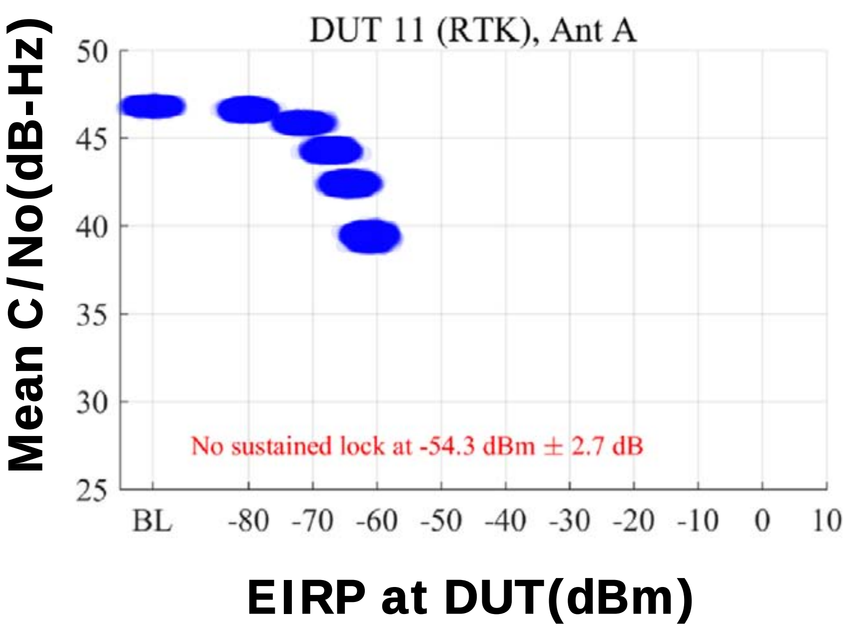


Acquisition Anomalies in the Two RTK Receivers Tested

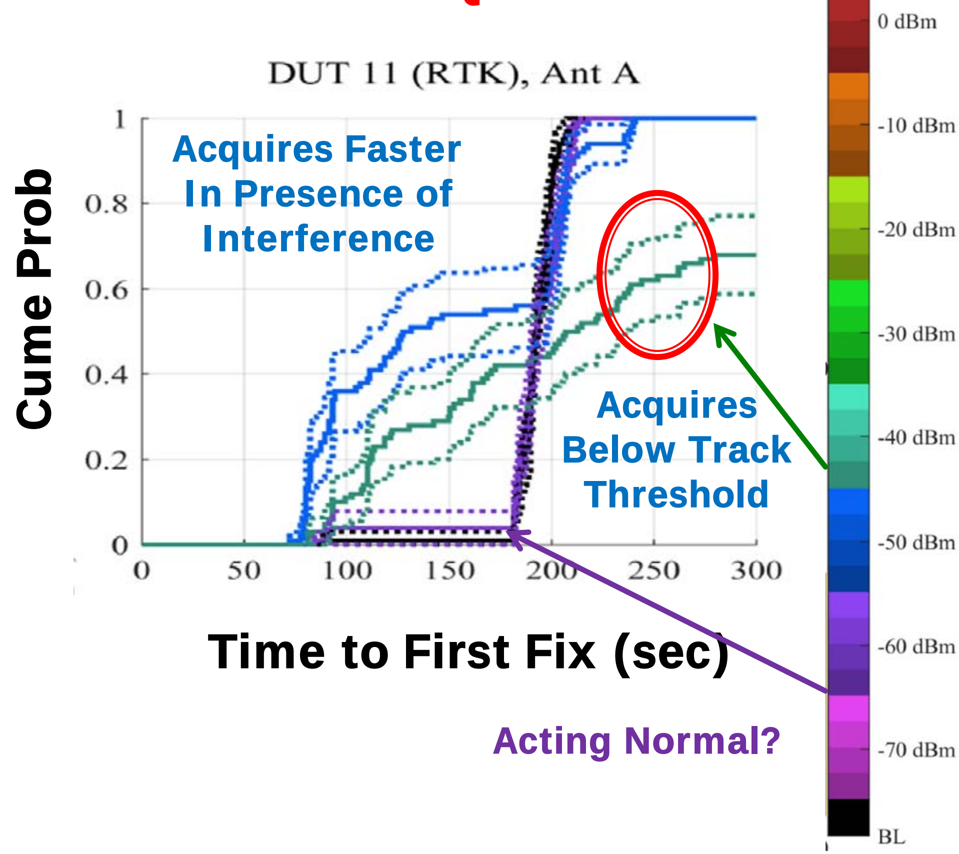
DUT11 (RTK) Shows Symptoms Consistent with Possible False Acquisition

Test Was Repeated According to 4 May 2017 NASCTN Briefing

TRACK

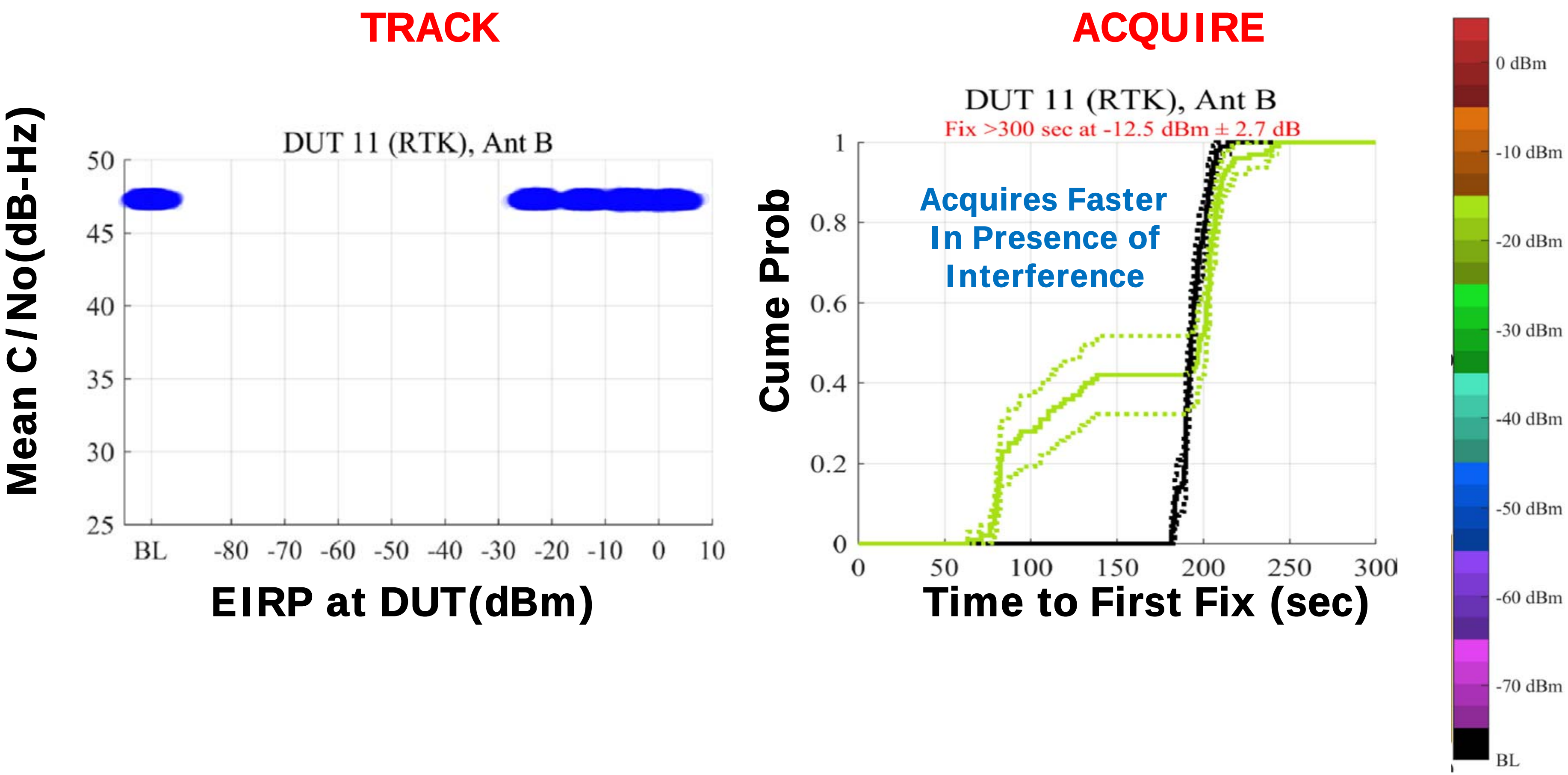


ACQUIRE



Extracted from NASCTN Figures 6.49 and 6.101

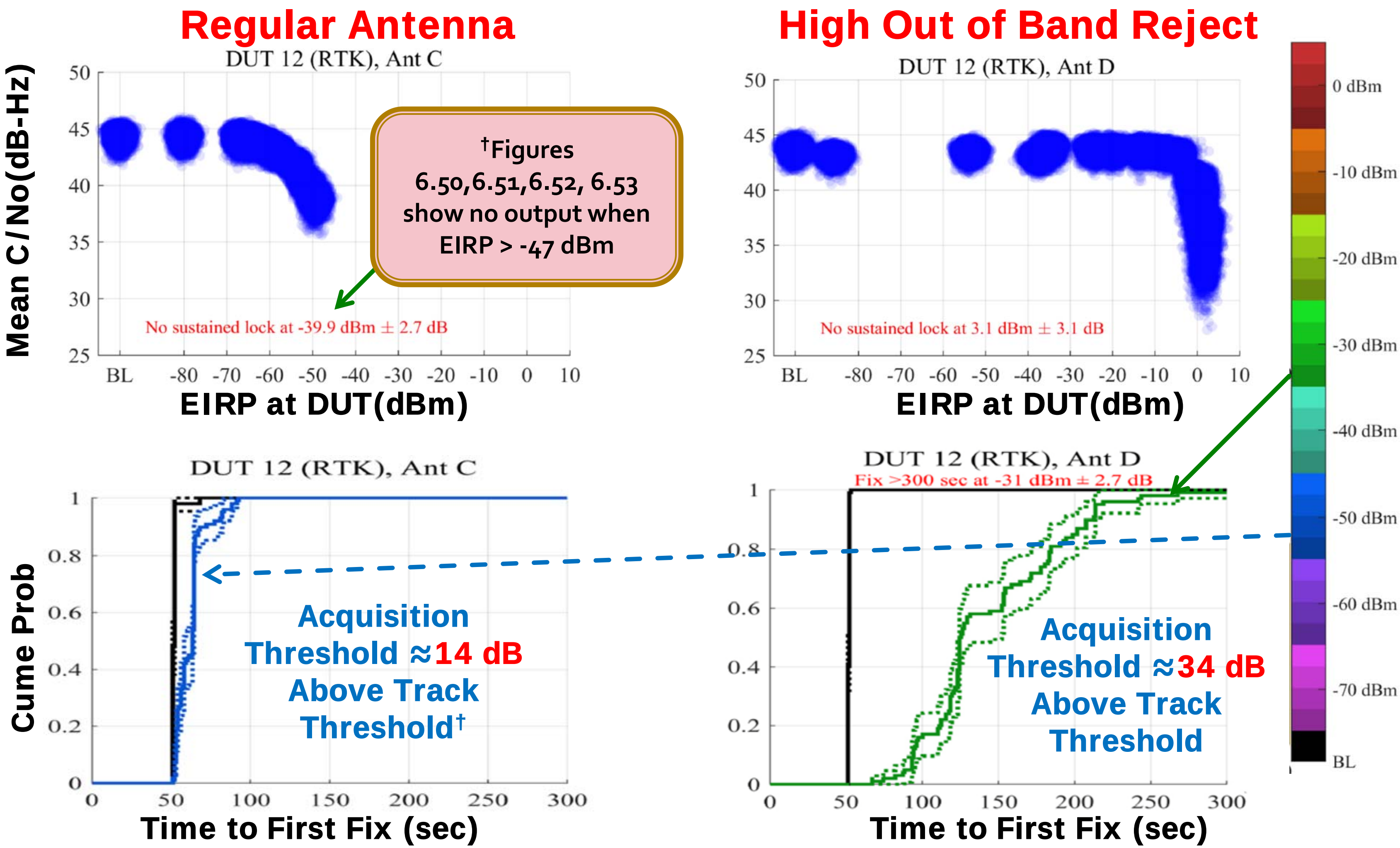
DUT11 (RTK) With High OOB Reject Filter Still Shows Symptoms Consistent with Possible False Acquisition



Extracted from NASCTN Figures 6.49 and 6.101

High Out Of Band Reject Filter is Not a Cure-All, Acquisition Threshold Rises 20dB (100x) Relative to Track Threshold for DUT12 (RTK)

Problems Resolving Phase Ambiguity due to Filtering?



Data from NASCTN Figures 6.49 and 6.101

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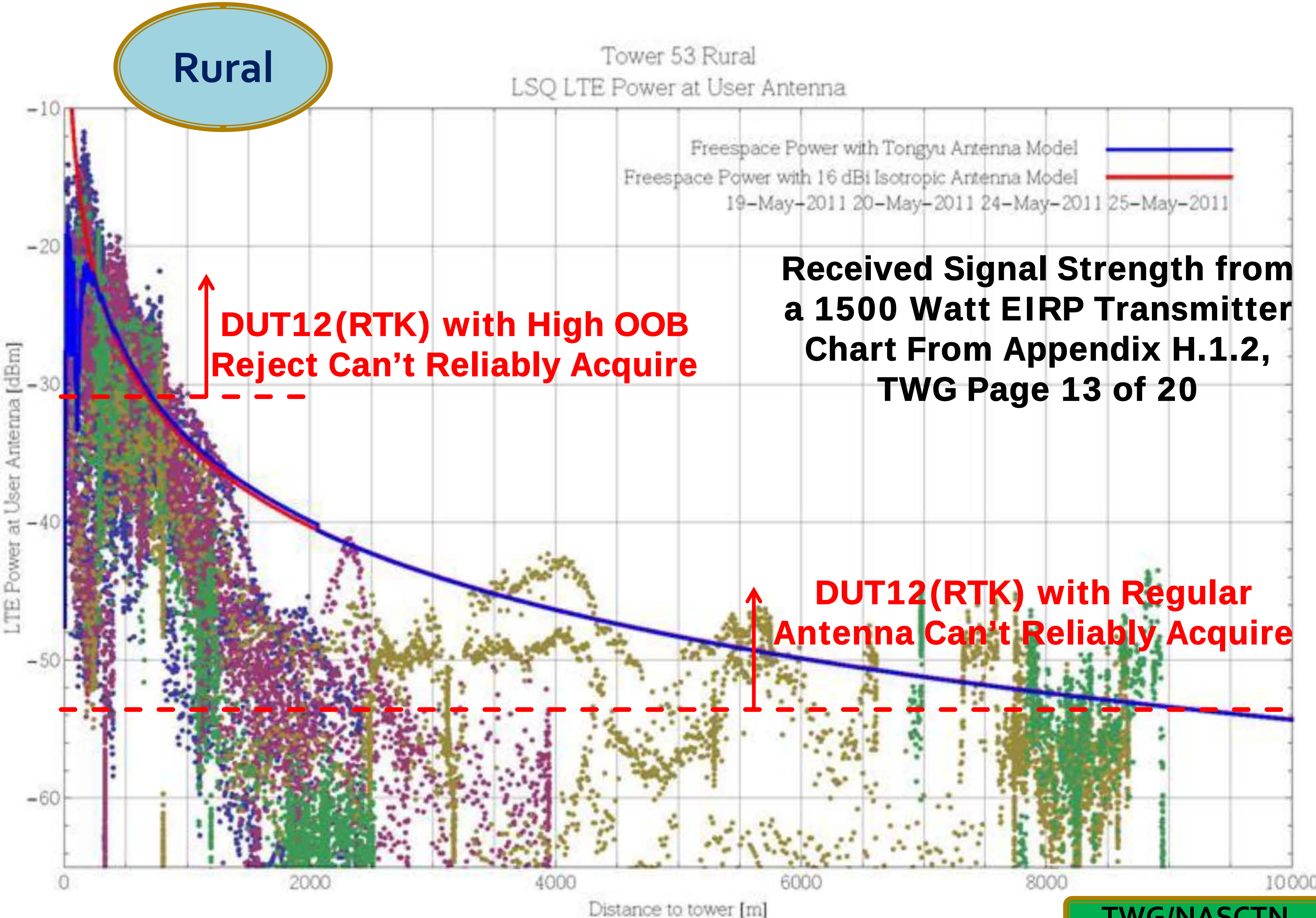

TWG/NASCTN

NASCTN Testing Provides an Insufficient Basis for a Decision to Proceed

Both RTK Receivers In NASCTN Tests Showed Anomalies

- RTK Receivers Lose Signals in the Course of Normal Operation and Need to Reacquire & Perform Phase Fix-ups
  - Multipath Eats Margins in Observables
  - False Acquisitions Would Complicate or Break Fix-ups
- High OOB Reject Filters Seem to Make Ambiguity Resolution Harder

RTK Operating Environments are Complex

NASCTN Does Not Capture This Complexity

Conclusions on HPP and RTK

- HPP and RTK receivers can expect significant impairment up to and including complete failure at ranges upwards of a mile.
- One of the two RTK receivers tested shows symptoms consistent with false acquisition induced by interference.
- High OOB reject filters appear to cause acquisition impairments.
  - Effect needs to be understood
- Small sample size and lack of field data in NASCTN provides inadequate basis for a decision
  - Two RTK receivers

The claim is that an LTE network will not harm GPS device performance

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The data does not support this statement

Recommendations Moving Forward

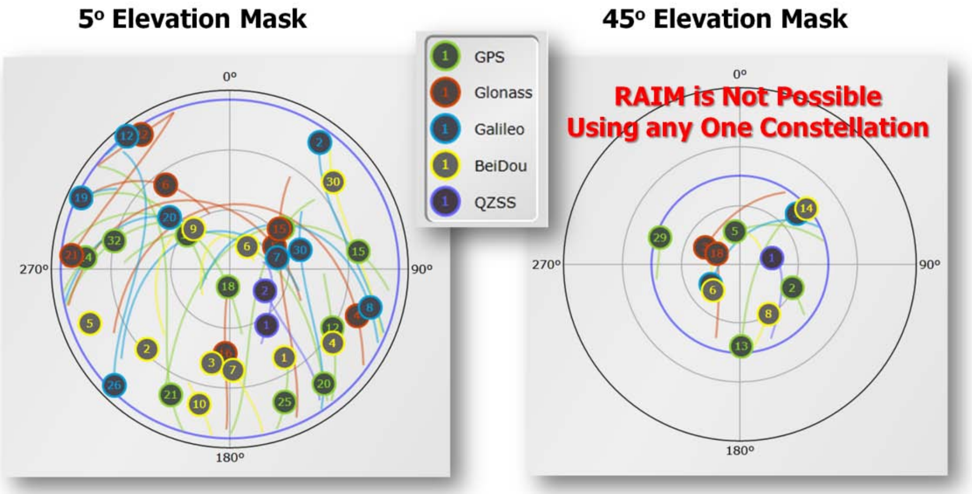
Protect Existing Applications

- High Precision and RTK applications are critical infrastructure and require strong protections

- Adopt a 1dB Interference Protection Criterion for equipment <u>AS IS</u>
  - 1 dB IPC corresponds to 20% Reduction in SNR
  - Many fielded RTK and HPP receivers were not designed or tested for a high interference environment
  - High Out of Band Reject Filter effects on RTK are not well understood

Provide Spectrum Protections for ALL GNSS
NASCTN tests were with GPS Signals ONLY

- Multi-constellation GNSS is the foundation of high integrity, robust operation.
  - Provides Coverage & Accuracy In Challenged Environments
  - Enhances RAIM and ARAIM Effectiveness
    - Both Glonass and GPS have had Constellation Failures
  - Makes Spoofing Significantly Harder
  - Is in Widespread Use NOW



Backup

ETSI EN 303 413 V1.1.1 (2017-06)
GNSS Radio Equipment Directive "RED"

- EU Requirement for New Equipment starting 13 June 2017
  - DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

- Specifies Requirements for Tolerating Out of Band Interference with No more Than 1 dB C/No Degradation

Table 4-2: Frequency bands, adjacent frequency signal test point centre frequencies and power levels for the 1 559 MHz to 1 610 MHz RNSS band

Frequency band (MHz)	Test point centre frequency (MHz)	Adjacent frequency signal power level (dBm)	Comments
1 518 to 1 525	1 524	-65	MSS (space-to-Earth) band
1 525 to 1 549	1 548	-95	MSS (space-to-Earth) band
1 549 to 1 559	1 554	-105	MSS (space-to-Earth) band
1 559 to 1 610	GUE RNSS band under test		
1 610 to 1 626	1 615	-105	MSS (Earth-to-space) band
1 626 to 1 640	1 627	-85	MSS (Earth-to-space) band

Requirements of ETSI 303 413 V1.1.1(2017-06)

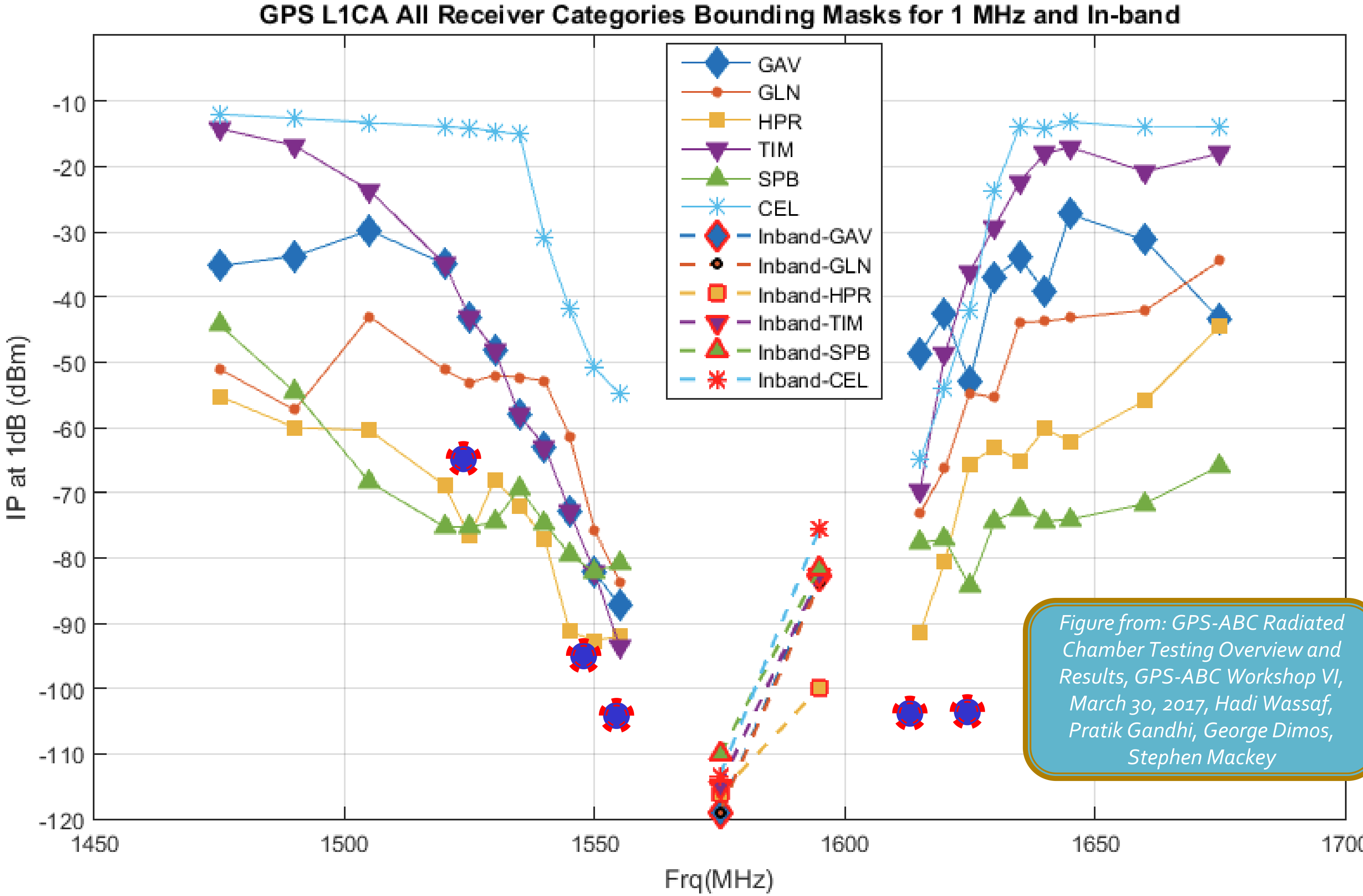
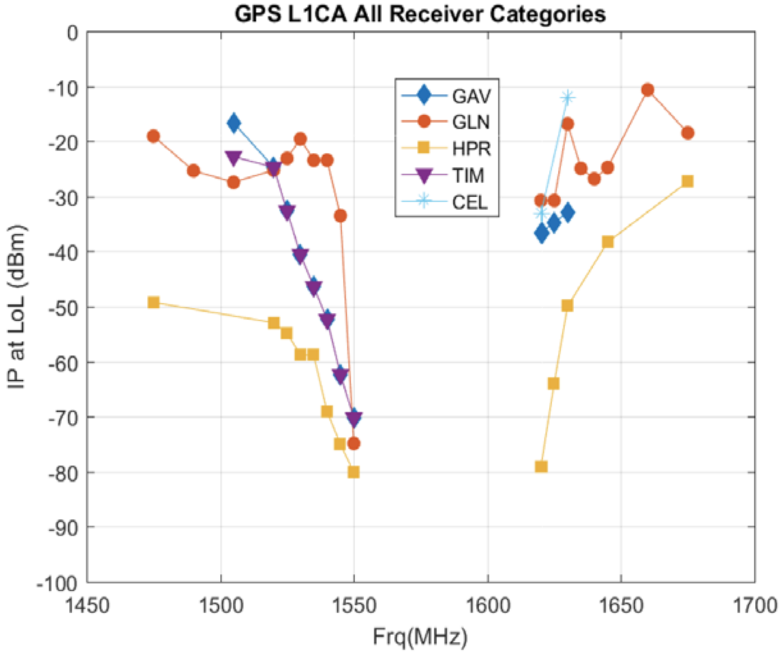


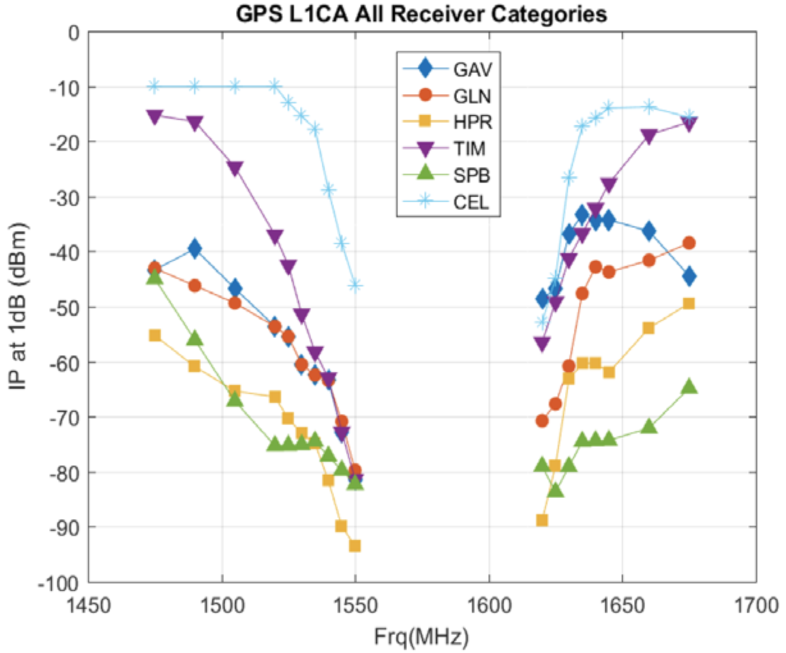
Figure from: GPS-ABC Radiated Chamber Testing Overview and Results, GPS-ABC Workshop VI, March 30, 2017, Hadi Wassaf, Pratik Gandhi, George Dimos, Stephen Mackey

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**

Chart from: Loss of Lock Analysis
GPS-ABC Workshop VI *RTCA, Washington, DC*
March 30, 2017
Christopher Hegarty and Ali Odeh, The MITRE Corporation

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

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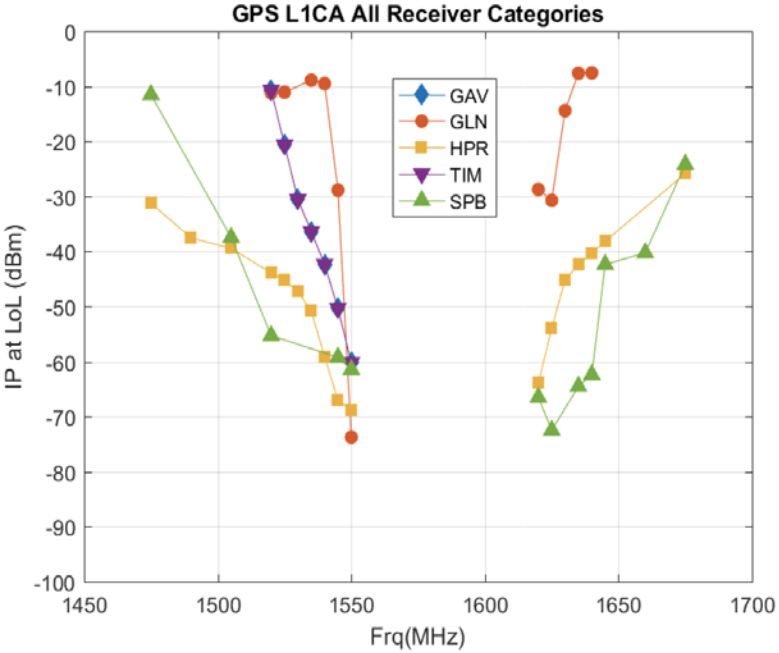
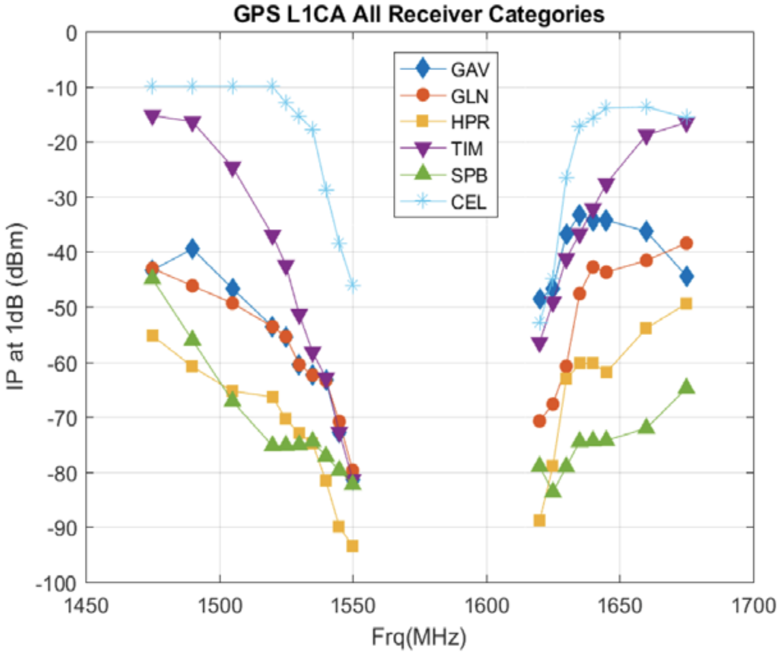


1dB ITM



- 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

Chart from: Loss of Lock Analysis
GPS-ABC Workshop VI *RTCA, Washington, DC*
March 30, 2017
Christopher Hegarty and Ali Odeh, The MITRE Corporation

Tower Parameters from TWG Appendix H

Table 2 Tower Locations

LightSquared Site ID	Latitude	Longitude	Antenna Height AGL (ft)	Number of Sectors	Azimuths (degrees)	City
LVGS0053-C1	35.9697	-114.8681	60	2	30, 270	Rural
LVGS0068-C1	36.1245	-115.2244	55	3	0, 120 ,240	Suburban
LVGS0160-C1	36.127	-115.189	50	3	0, 120, 240	Urban
LVGS0217-C1	36.1065	-115.1705	235	2	0, 240	Dense Urban