# AWS-3 Spectrum Sharing

Presenters: Jason Coder, Adam Wunderlich, Melissa Midzor

Contributors: NASCTN, RF Technology Division, ITL, MITRE, JHU APL

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

CTL Communications Technology Laboratory

# AWS-3 Auction and AMT

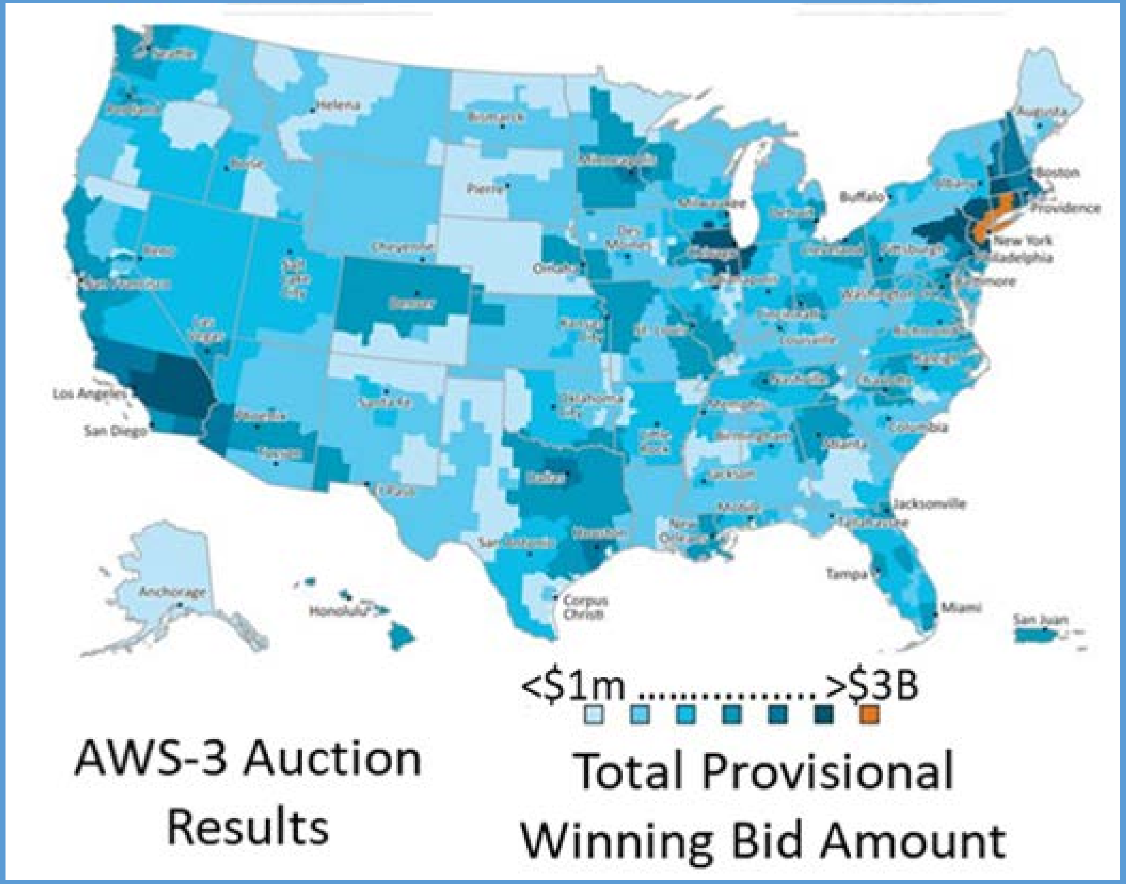
NIST

March 2014

**FCC Report and Order FCC 14-31**

- Established AWS-3 Band: 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz
  - **Included indefinite period of sharing with limited number of Federal systems which are relocating to different bands.**
  - FCC auctions spectrum → $41.3B

- Challenges:
  - Federal assets co-located/adjacent to AWS-3
    - Geographically and frequency
  - Coordinating early entry with commercial entities
    - Agreed upon interference model
    - Must deploy by 2020




*How can the interference risk be assessed and mitigated?*

Figure created by Mosaik Solutions

# Outline

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## NASCTN Project (DSO): Characterizing LTE User Equipment Emissions

- How can DoD/Defense Spectrum Organization (DSO) improve their interference risk assessment?
- NASCTN project aims to inform modeling LTE UE emissions, a component of the DoD aggregate interference model
- Goal: increase DoD/DSO's confidence in allowing systems to deploy

## NASCTN Project (EAFB): LTE Impacts on AMT

- How can DoD Ranges quantify interference and improve mitigation protocols from future LTE emissions
- NASCTN project utilizes a three part integrated strategy: Develop a set of compatible methodologies for susceptibility testing, waveform capture, and environment scanning
- Goal: Enable other ranges with AMT systems to perform testing with improved methodology, and appropriate scenarios and waveforms

**Challenges are not band-specific. Results will inform future auctions.**

# NASCTN Project (DSO): Characterizing LTE User Equipment Emissions


Jason Coder
RF Technology Division

Adam Wunderlich
NASCTN

# Diverse set of expertise & collaborators

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**Skills and expertise across NIST**

- Technical leadership
- Programmatic support
- RF Metrology
  - Data acquisition
  - Measurement automation
- LTE engineering
- Data processing
  - Parsing; time alignment
- Statistics
  - Experiment design
  - Data verification
  - Data analysis
- CTL, ITL, PML

**Skills and expertise across stakeholders**

- MITRE, JHU-APL, DoD working group
  - LTE engineering
  - Future studies
  - Measurement automation
  - Engineering analysis
  - Reproducible results
- Benefit of NASCTN model
  - Diverse skill sets at each phase
  - Total number of contributors: 30+

# AWS-3 Coordination Process

Government agencies have been asked to release RF spectrum for commercial use

- Coordination zones in some geographic areas
- DoD gathers information, analyzes risk, makes a determination based on a model (red light, green light)
    - How much confidence do they have in that model?
- New measurement methods and data can provide insight to the modeling and decision process

NASCTN: Refine LTE emission characterization for interference analysis

NASCTN develops test methods → Demonstrate test methods → Disseminate test method and results → DoD makes decisions with increased confidence

# Project Objectives

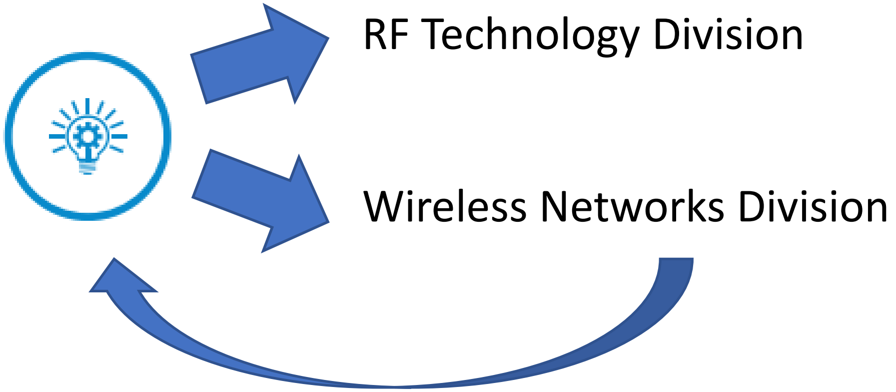
Design, demonstrate, & validate a **test methodology** to measure LTE handset (UE) emissions for use in aggregate interference calculations.

Key benefits:

- Collect measurements in a controlled laboratory setting
  - Control or mitigate uncontrolled variables present in field measurements
- Test a wide range of network configurations/morphologies
  - Provide bounds by testing extreme settings
- Rigorous uncertainty assessment and statistical analyses

# Small investment ➡ large impact

- Impacts beyond coordination request process
  - Interference modeling
    - What parameters are important?
    - Increase confidence by linking models and measurements
  - “Spin-off” research projects; considered during CTL strategic planning process
    - Improving device power control
    - Statistical testing of LTE/wireless communications hardware
    - Behavior in specific scenarios (e.g., negative power headroom)
    - Development/validation of sector models based on measurements
- Spin-off research feeds back into our ability to do trusted spectrum testing

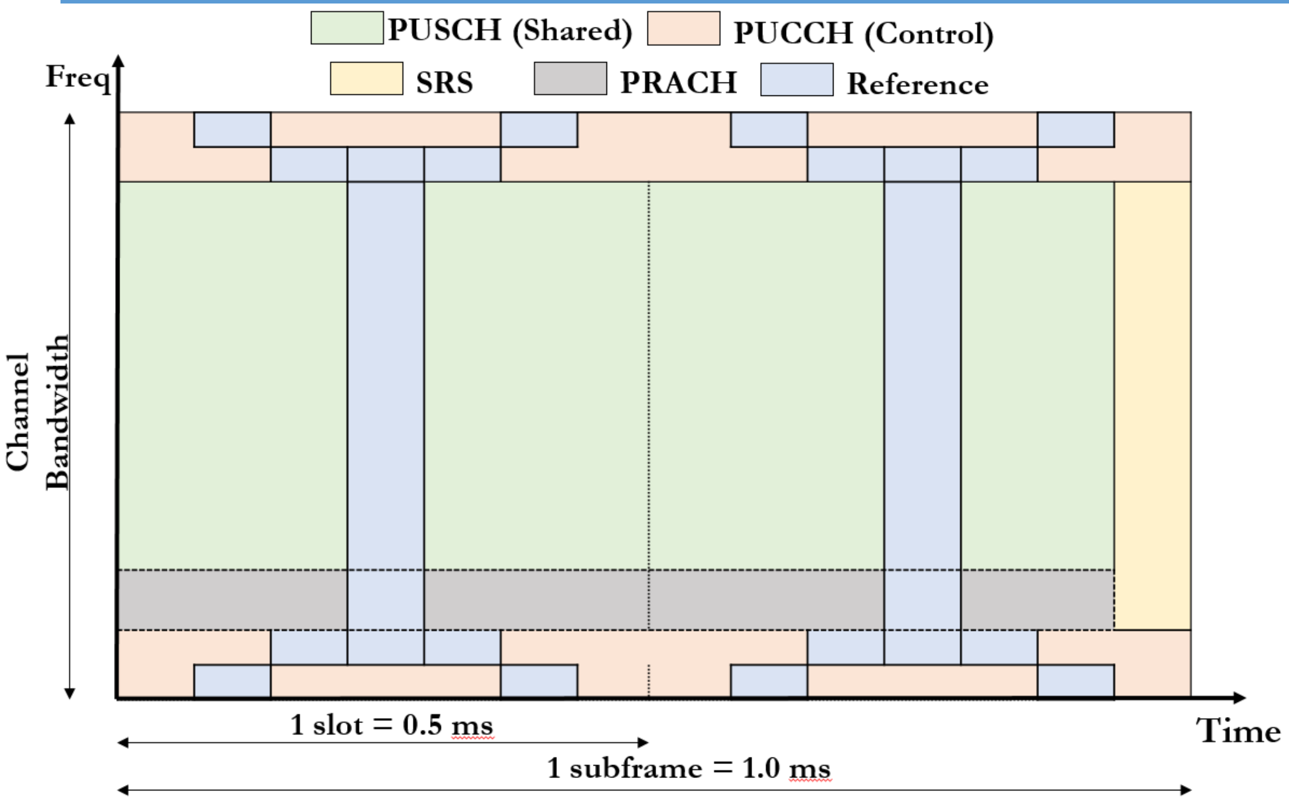


# Project Deliverables

1. Distribution of power radiated from a UE in an active resource block, over an appropriate range of path loss values, UE settings, and LTE network settings
   - Separate distributions for PUSCH, PUCCH, SRS

2. Comparison of UE-reported and measured power distributions

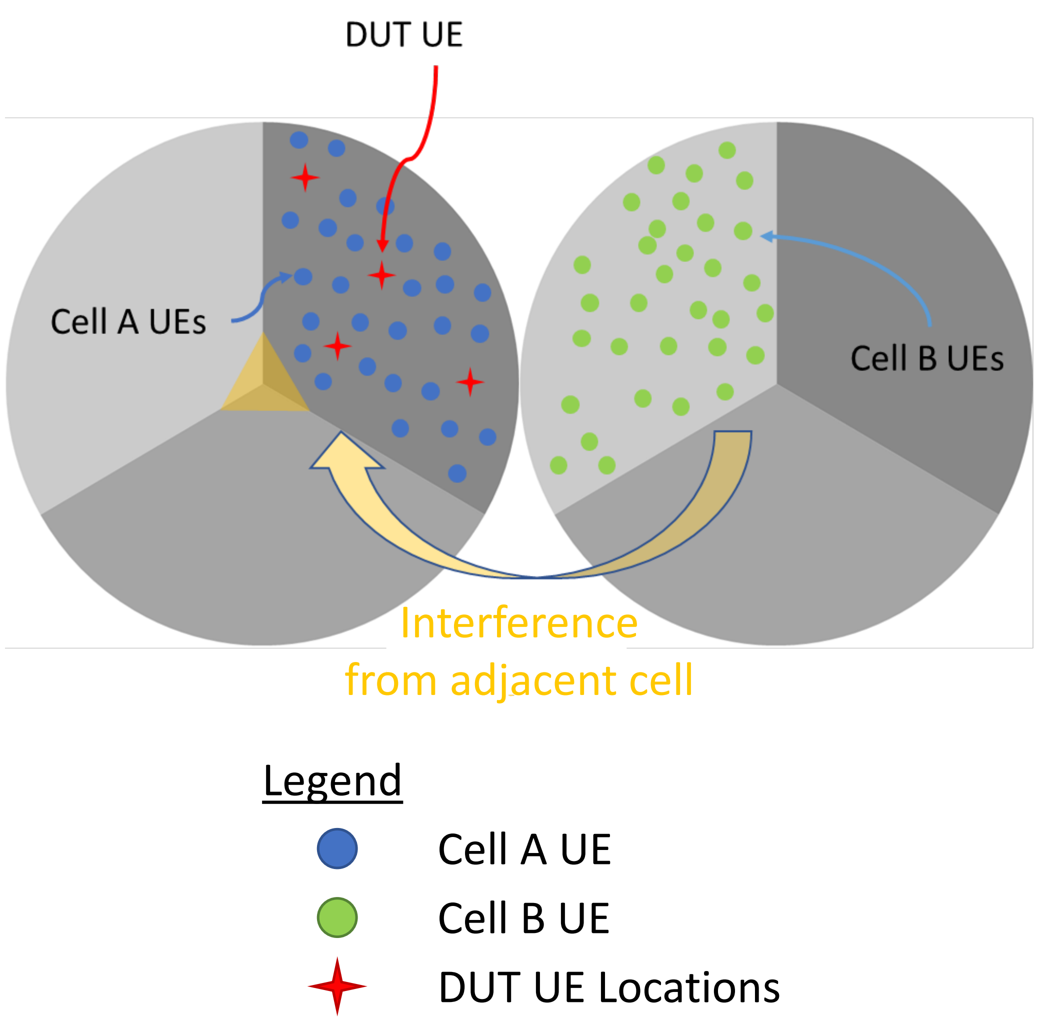
3. UE beam pattern measurements



# Measurement Concept

- Cell A and Cell B are loaded with UEs
- Cell A UEs load eNB scheduler
- Cell B UEs increase noise at eNB

- At different virtual positions of DUT UE
  - Measure DUT UE emitted power
  - Measure DUT UE emitted spectrum
  - Measure number of UEs emitting in each 1 mS subframe (and many other parameters)
- Combine these data over entire cell to obtain statistics for particular configuration



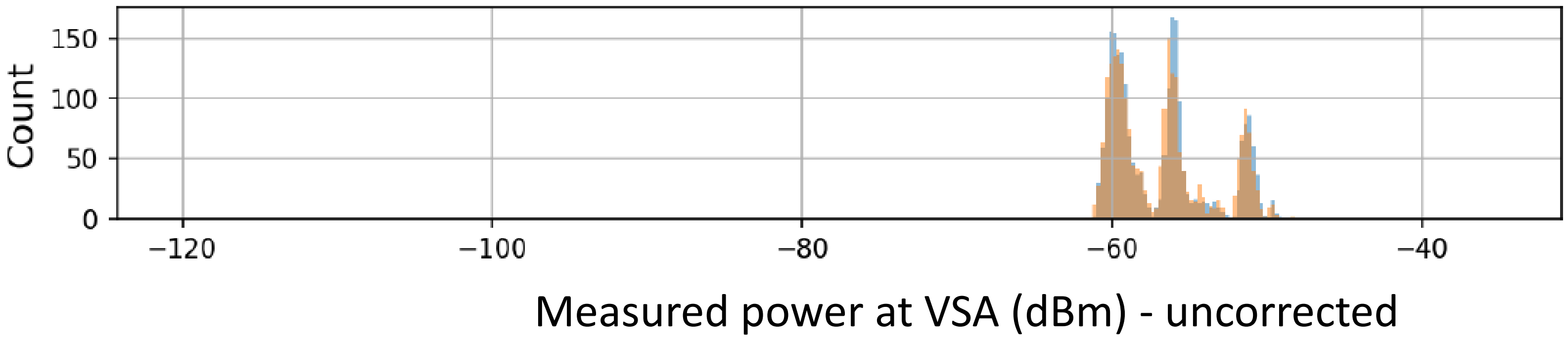
# Progress

- Add details not included in high-level test plan
- Integrate test equipment and automated measurements
- Validate testbed - gain confidence in the data
- Verify stability and repeatability
- Characterize and calibrate measurement setup
- Identify relevant experimental factors
- Design factor screening experiment to investigate the impact of each factor
- Factor screening experiment and analysis
- Next step: follow-on experiments based on results

# Creating new statistical tools

- The response variable is a **distribution**, not a scalar or vector.
  - PUSCH power per PRB distributions are frequently ***multimodal***
  - Not a textbook problem
- Create new statistical tools to analyze data

- How to detect general changes in distribution shape? Percentiles!
  - For each VSA capture, estimate all percentiles (1st through 99th)




*Preliminary data

# Replicating Results - MITRE

Independent measurements conducted on MITRE's testbed

- MITRE built an independent testbed
- MITRE testbed used configurations similar to NASCTN testbed
- Measurements acquired; distribution of results indicate good agreement
- Critical that NASCTN measurements can be repeated in other labs

# Technical Details

# Data Sources and Processing

Collecting, Parsing and Synchronizing data from three sources:

1. Vector Signal Analyzer (VSA) Spectrograms
   - 1 mS time-resolution, Two consecutive 5 second captures for each test configuration
   - Processed to remove noise and blurring
2. UE Traffic Generator (UTG) logs
   - 0.5 sec time-resolution
   - # UEs/TTI, PRB allocations, ….
3. UE diagnostic software logs
   - 1 mS time-resolution
   - Active PRBs (PUSCH, PUCCH, SRS), Reported Tx Power, Power Headroom Report, …

Developed Automated process to parse and time-align raw data files

- 28 different automated checks during parsing and time alignment
- For each 80 min test block, auto-generated of 294 pages of data verification plots for manual inspection

Factor Screening Summary Stats

- 4 month test campaign
- 1,056 unique test configurations
- 5,504 successful tests
- ≈230 hours of valid test time
- Nearly 1,000,000 raw and processed data files

Data used for test verification and deliverables

# Design of Experiment - Factor Screening

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28 total factors: 20 eNB (base station), 8 non-eNB

| Identifer | Testbed Component | Factor | # Levels |
|---|---|---|---|
| A | Variable Attenuator | Path Loss (Simulated DUT UE Position) | 2 |
| B | UTG | Spatial Size of Cell | 2 |
| C | UTG | Number of Loading UEs in Serving Cell (Cell A) | 2 |
| D | UTG | Number of Loading UEs in Adjacent Cell (Cell B) | 2 |
| E | UTG | Spatial Distribution of Loading UEs in Cell A | 2 |
| F | UTG | QCI Value of Loading UEs | 2 |
| G | DUT UE/UTG | Traffic Data Rate | 2 |
| H | DUT UE/UTG | Traffic Type (UDP/TCP) | 2 |
| I | eNB | UL Scheduling Algorithm Type | 3 |
| J | eNB | UL Scheduler FD Type | 3 |
| K | eNB | Power Control Type (Closed Loop/Open Loop) | 2 |
| L | eNB | SRS Config | 2 |
| M | eNB | SRS Offset | 2 |
| N | eNB | PUCCH Power Control: $P_0$ | 2 |
| O | eNB | PUSCH Power Control: $P_0$ | 2 |
| P | eNB | Power Control: $\alpha$ | 2 |
| Q | eNB | Receive Diversity | 2 |
| R | eNB | Filter coefficient for RSRP measurements | 2 |
| S | eNB | Maximum uplink transmission power (own cell) | 2 |
| T | eNB | Minimum PRB allocation for power-limited UEs | 2 |
| U | eNB | UL Improved Latency Timer Reaction | 2 |
| V | eNB | Initial Max # of Resource Blocks | 2 |
| W | eNB | UL Link Adaptation | 2 |
| X | eNB | Extended Link Adaptation | 2 |
| Y | eNB | Cell Scheduling Request Periodicity | 2 |
| Z | eNB | Scheduling Weight UL for SRS | 2 |
| a | eNB | Blanked PUCCH Resources | 2 |
| b | eNB | Target UL Outer Scheduling | 2 |

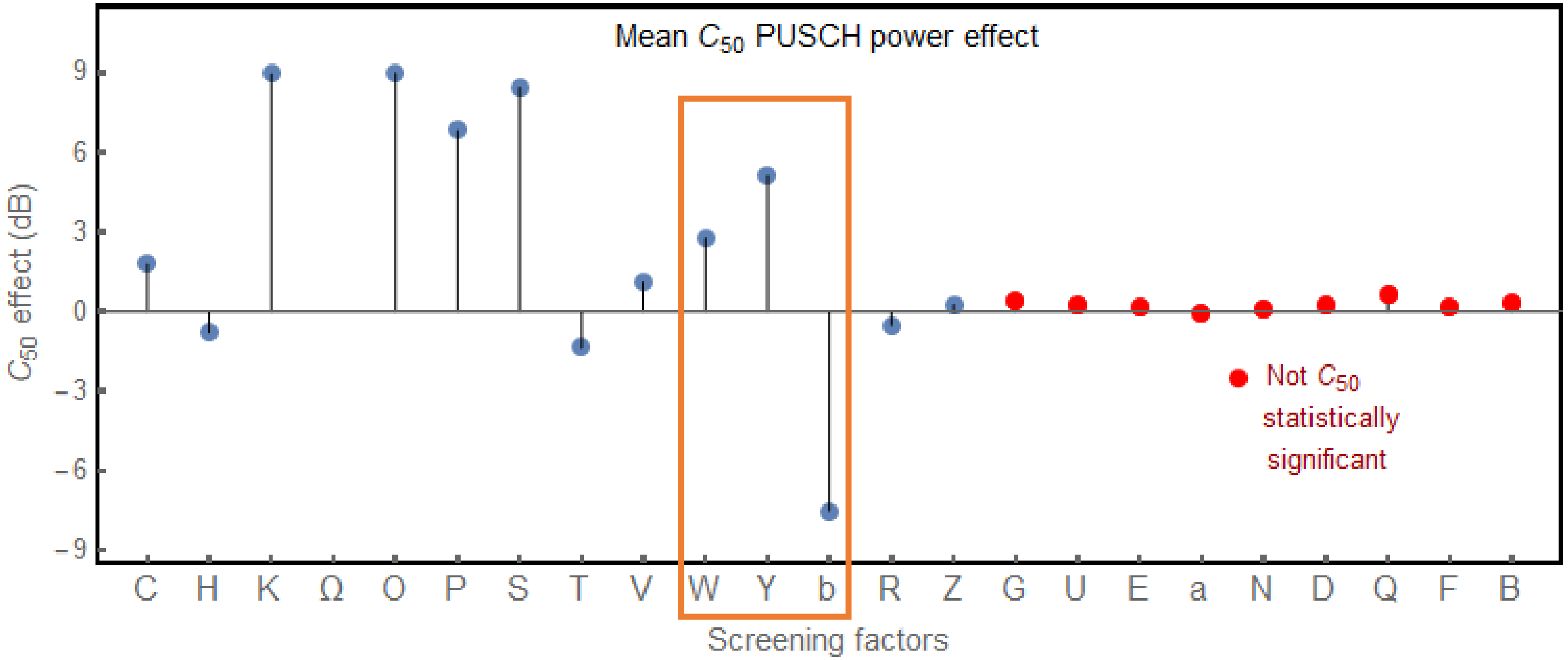
- ➢ Ensure main effects are uncorrelated
- ➢ Determine which factors have a significant impact (statistical analysis)

- 32-run design for eNB factors crossed with a 32-run for non-eNB factors
  - eNB design: resolution III orthogonal array
  - Non-eNB design: resolution IV fractional factorial design
- To minimize eNB factor changes, used a “split-plot” design
- Entire design repeated four times

# Factor-screening results

Results:

- 18 of 28 factors have a *statistically* significant impact.
  - *Practically* significant?
- Some surprises:
  - Link adaptation, Cell scheduling request periodicity, uplink outer scheduling
  - Influence from 2nd order effects?

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# Notable Results

# Network settings make a difference

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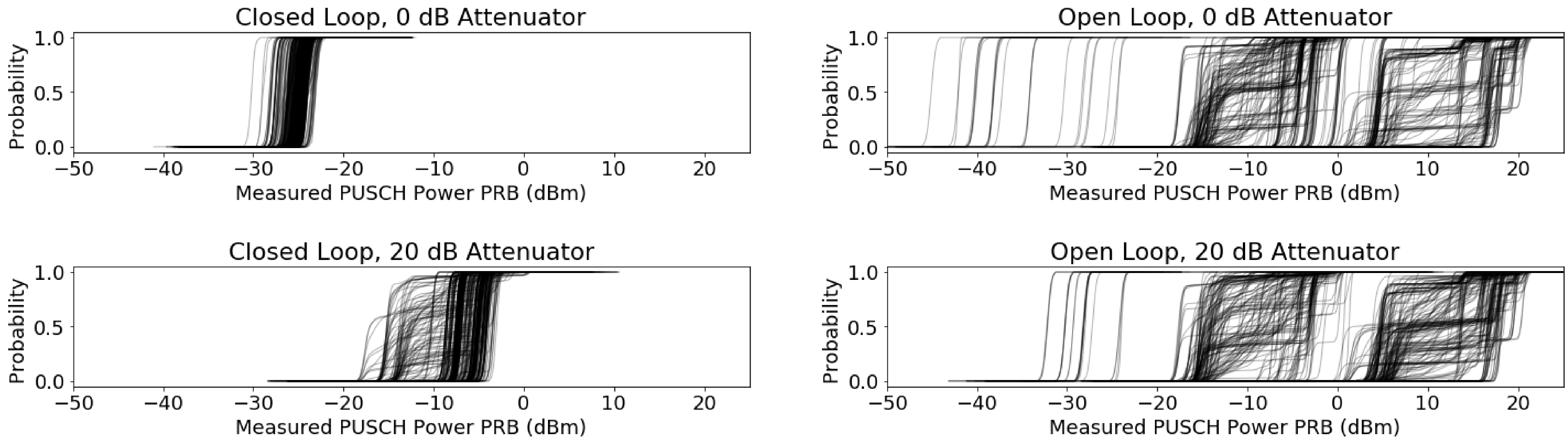
Example: Power control

- Open loop: UE decides; closed loop: eNB decides
- Closed loop could enable better prediction of UE behavior → more deployments
- Follow-up experiments to support upcoming DoD recommendations (FY19)




*Preliminary data

# Is self-reported power reliable?

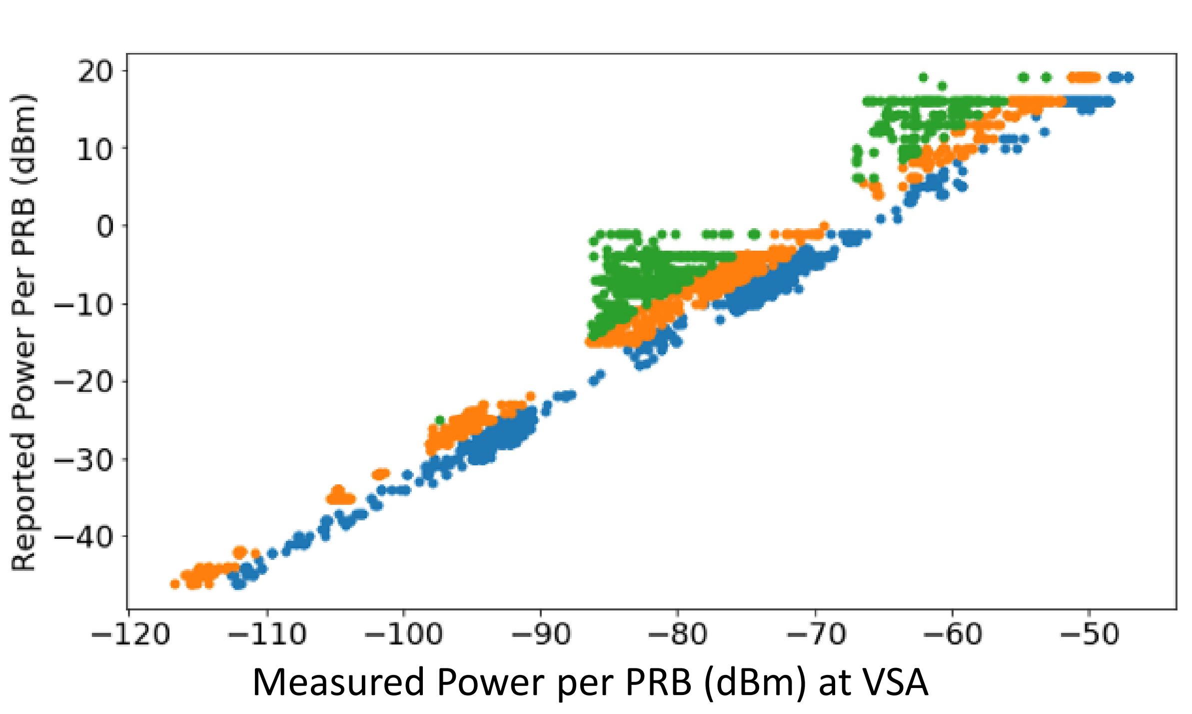
- Substantial body of work predicated on the UE's self-reported power
  - It's accuracy has never been assessed.

- Region 1 – good agreement
- Region 2 – moderate agreement
- Region 3 – poor agreement

- In some scenarios, the UE reported power was a poor metric of the actual radiated power

- Good news! The UE never over-estimated power

- Impact: Adds confidence to existing measurements; informs modeling



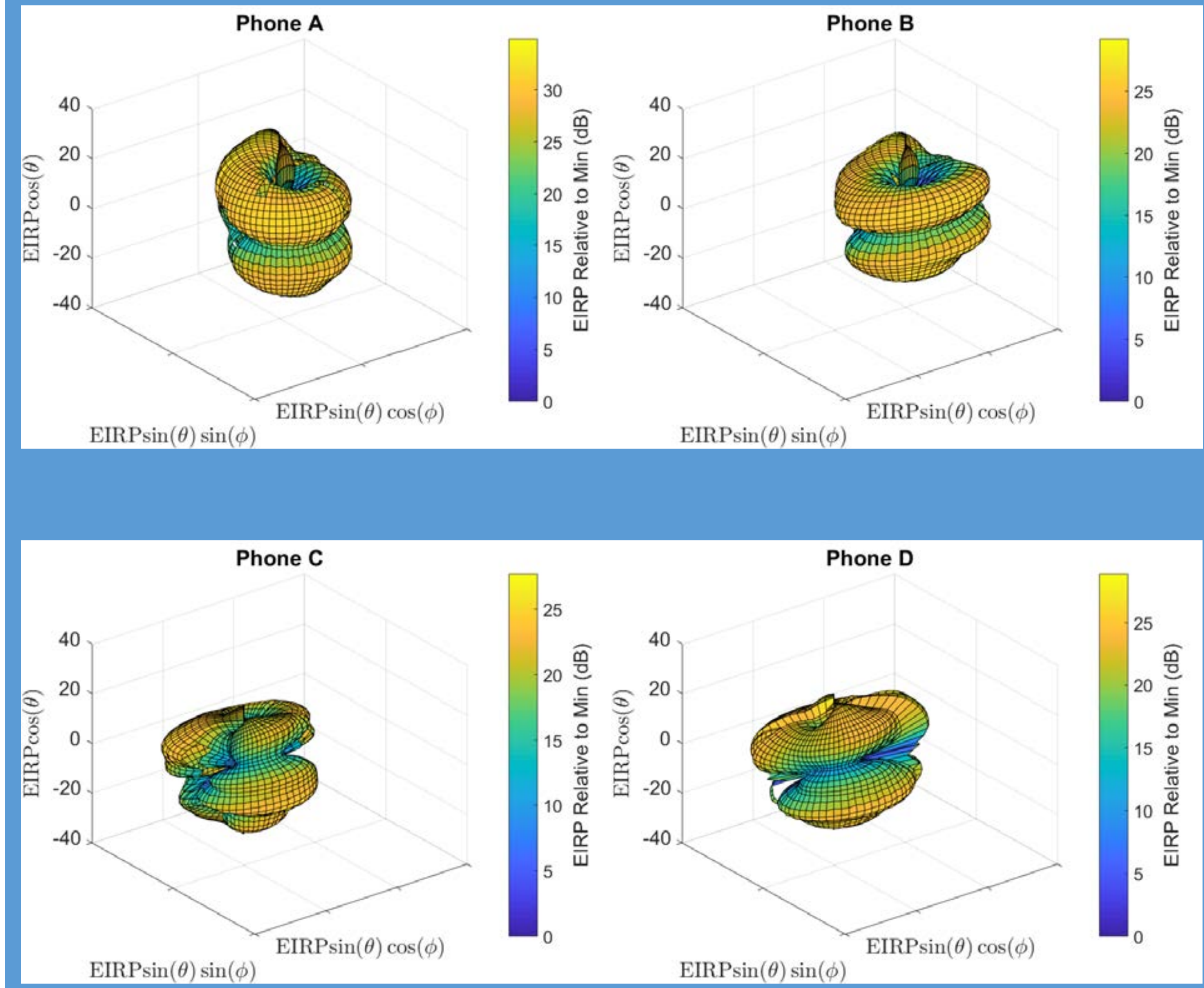

*Preliminary data

# Not all UEs are the same

- Measurements conducted on 5 different types of UEs, spanning cost, physical size, operating system, and generation/age

- Challenging assumptions
  - All UEs radiate the same?
    - Not quite

- Results can be directly incorporated into revised interference models

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# Summary

- Goal: Trusted spectrum testing leads to more informed decisions on spectrum use
  - Work has direct and broad impacts
  - Spin-offs feed back into CTL's core priorities
- Measurement data will increase confidence in decisions made by DoD
  - Getting to green
  - Impacts: More effectively predict UE emissions; enable more efficient use of spectrum
- Challenging common assumptions
  - UE radiation pattern
  - UE emissions behavior
- Next: Experiment to investigate emissions under closed-loop power control

# NASCTN Project (EAFB): LTE Impacts on AMT


Melissa Midzor
NASCTN

Adam Wunderlich
NASCTN



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https://www.nist.gov/ctl/nasctn

# Test Team and Collaborators

Programmatics:

Program Manager - Melissa Midzor (NIST/CTL)

Contracts - Linda Derr (NIST/CTL)

Project Manager - K. Hartley (MITRE)

Project support - I. Stevens (NIST/CTL Assoc)

Test Leads:

Technical Lead - B. Young (MITRE)

Data Science Lead - A. Wunderlich (NIST/CTL)

Chief Engineer - D. McGillivray (NIST/CTL)

In-Situ Waveform Captures:

Capture Lead - F. Sanders (Sr. Fellow) (NTIA/ITS)

Spectrum and Propagation Division Chief - E. Nelson (NTIA/ITS)

Deputy Spectrum Manager - K. Dudley (NASA/LaRC)

Communications Engineer - L. Joyce (NASA/LaRC)

AMT Susceptibility Test:

Lead - M. Krangle (MITRE)

Design of Experiments - T. Mull (MITRE)

Test Automation - S. Lefebre (MITRE)

Test Engineers - E. Briggs, A. Paranay, A. Knight (MITRE)

Laboratory Waveform Captures:

OTA Measurements - R. Horansky (NIST/CTL)

LTE Implementation - A. Kord, J. Coder (NIST/CTL)

# Project Goals

AWS-3 Auction led to compressed operations of Aeronautical Mobile Telemetry (AMT) systems:

- Operate in “upper L-Band” 1755-1850 MHz → now 1780-1850 MHz
- However - AMT infrastructure remains unchanged

Current Test Specification

- Written by the Defense Department’s Range Command Council Telemetry Group
  - Inter Range Instrumentation Group (IRIG) Protocols
  - Does not currently address new waveforms (LTE).

NASCTN Project Goals:

- Develop a set of compatible methodologies for susceptibility testing, waveform capture, and environment scanning
- Validated data to support potential changes in AMT operations to prevent possible harmful interference from LTE emissions and improve the test space
- Enable other ranges with AMT systems to perform testing with improved methodology, and appropriate scenarios and waveforms

# NASCTN 3 Part Test Approach

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## Sensitivity and Susceptibility Testing

- Test sensitivity to various VSG produced signals
- Test susceptibility to captured and generated LTE waveforms

## Generate Waveforms (Library)

- Develop & measure various radiated test scenarios
- Curated Data Set - a "Library of LTE – Uplink waveforms" that can be leveraged for current and future tests

## Collect In-Situ LTE waveforms

- Capture LTE signals in a variety of AMT environments
- Informs Testing settings and scenarios
- Informs and adds to "Library"

**Develop compatible methodologies that support future tests, variety of Ranges, and enable community contributions to data**

# Receiver Sensitivity & Susceptibility Testing

NIST

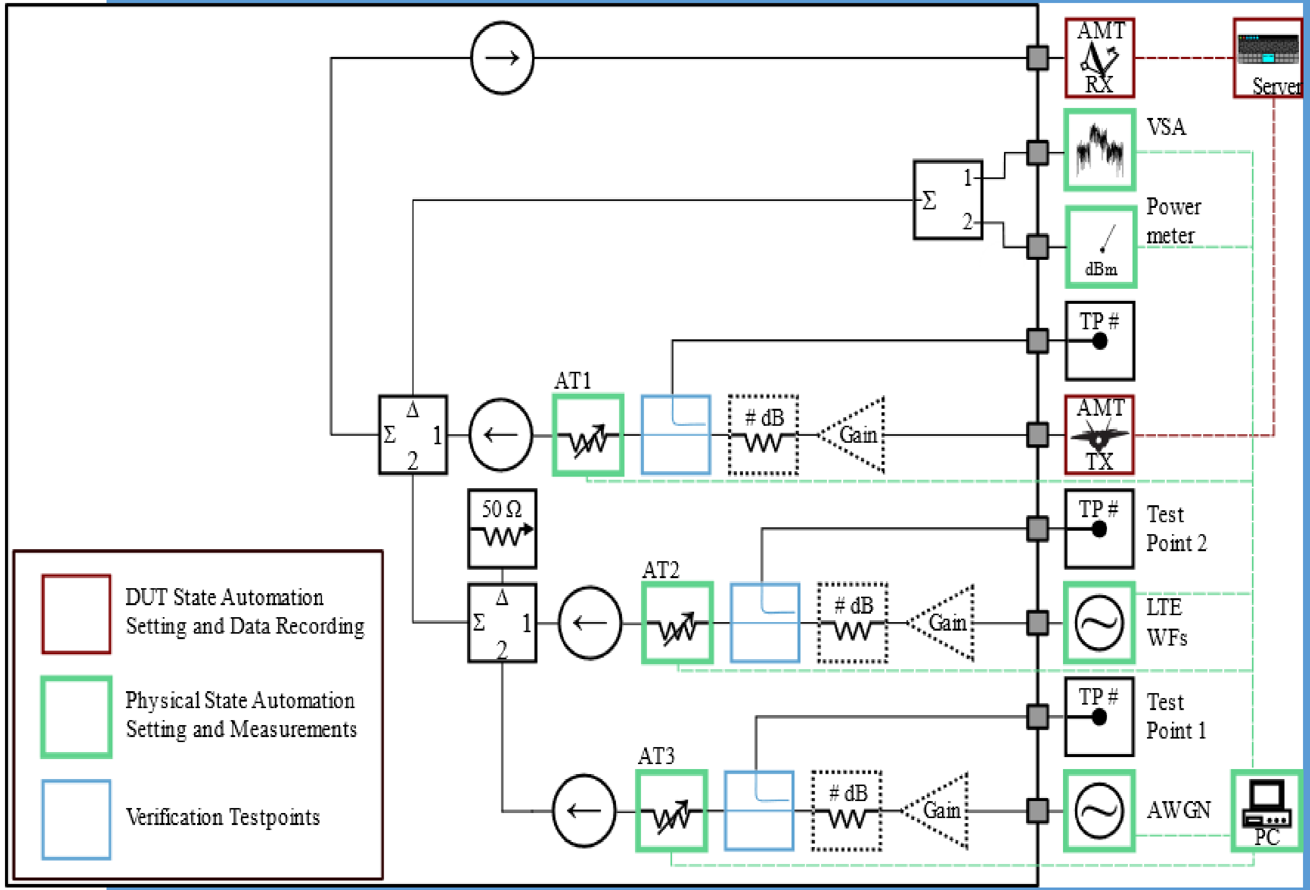
Parallel Testbeds:

1. CTL – Boulder CO: Testing
2. MITRE – Bedford MA: Automation and independent verification

Twin copies allow for test optimization and rapid implementation of lessons learned -> parallelized design changes

Developing use cases for

- Design of Experiments
- Subsequent data analysis



# Waveform Generation and Capture

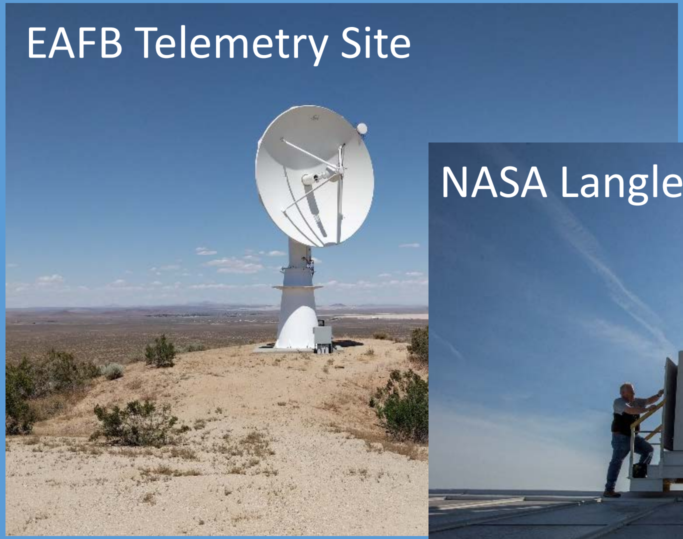
Library of LTE Waveforms for use in susceptibility testing

Anechoic Chamber - Generation

- Near Field, 2 UEs attached to an eNB (base station).
- Leverages Aggregate LTE  testbed
- Controlled Test environment

Ranges (Over the Air) - Collect

- Far Field captures at two test ranges:
    - Edwards AFB,
    - Provide different population centers and environments





# Current Status and Next Steps

Community Review (Test Plan Workshop) Feb 26th

- Attendees: **70+** attendees from DSO, TRMC, AT&T, Verizon, Novatel, T-Mobile, Ligado Networks, NTIA (ITS and OSM), Telemetry equipment vendors, APL, Alion Sciences, MITRE, others

Team Kick-Off: March 26-27

Pre-Site Surveys: Edwards Air Force Base June 30th. NASA Langley scheduled July 18.

Test Beds build and automation being developed.

Significant interest from Community Review and DoD conferences indicate methods will benefit multiple ranges and spectrum communities.

# Questions?