Propagation Measurement Workshop

July 7/14/21/28, 2016
1:00 p.m. to 2:00 p.m. (MST)

Institute for Telecommunication Sciences

Eric Nelson
Bob Johnk
Chriss Hammerschmidt
Paul McKenna

Context

- Spectrum sharing compatibility analyses demand more precise propagation models
- Propagation measurements are needed to refine existing models or develop new ones
- Recent rulemakings have spurred more measurements by government and private sector groups
- Confidence in other groups' measurements would dramatically increase model developers' access to useful data sets
- Data collection and processing techniques need to be well-understood, well-documented, and harmonized. If not, there is a risk of measurement/modeling silos developing

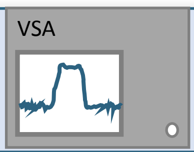
Workshop Motivation

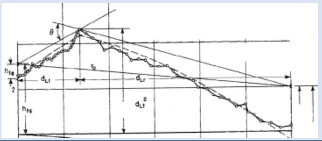
Increase propagation model developers' access to trusted measurement data by creating a forum to facilitate measurement system validation and information sharing

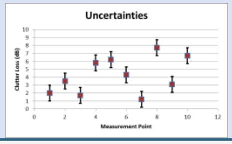
- Increase measurement data quality by sharing best practices
- Increase trust in shared data through system validation and demonstrated repeatability
- Improve understanding of test systems and test conditions through standardization (for each system type) and documentation of measurement systems and methods
- Promote information sharing by standardizing measurement data formats and defining and standardizing required metadata

Workshop Outline

Kick Off







- July 7, 2016 – Setting the Stage

  Presenters: Eric Nelson / Chriss Hammerschmidt

- July 14, 2016 – Design of a Measurement System – ITS Vector Signal Analyzer (VSA)-based System

  Presenter: Bob Johnk

- July 21, 2016 – Propagation Models and Overview of the Irregular Terrain Model

  Presenter: Paul McKenna

- July 28, 2016 – Uncertainties and Measurement Guidelines

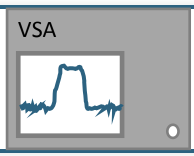
  Presenter/Moderator: Chriss Hammerschmidt

July 7, 2016 – Setting the Stage

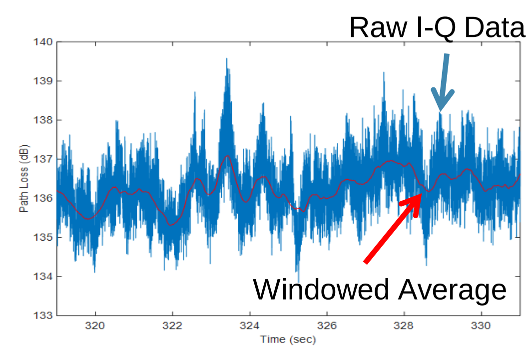
Kick Off

- Meeting Overview
- Background
- ITS/NIST CAC Research Collaboration
- ITS Propagation Measurements
- Possible System Testing
- Preparation for Future Meetings
- Contacts
- References
- Acronyms

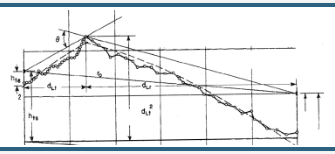
July 14, 2016 – Design of a Measurement System



- ITS VSA-based Measurement System Overview
- Data Processing Method
- System Verification Measurements



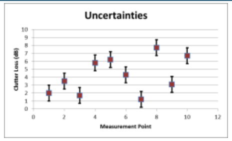
July 21, 2016 – Propagation Models and ITM Overview



- Types of propagation models
  - Free-space path loss
  - Empirical
  - Deterministic
  - Physical/Statistical Models
- Irregular Terrain Model (ITM)
  - What are the benefits of using ITM
  - What are valid parameters?
  - How does it calculate basic transmission loss?
  - How does it compare to other propagation models?
  - What role does it play in estimating clutter losses?

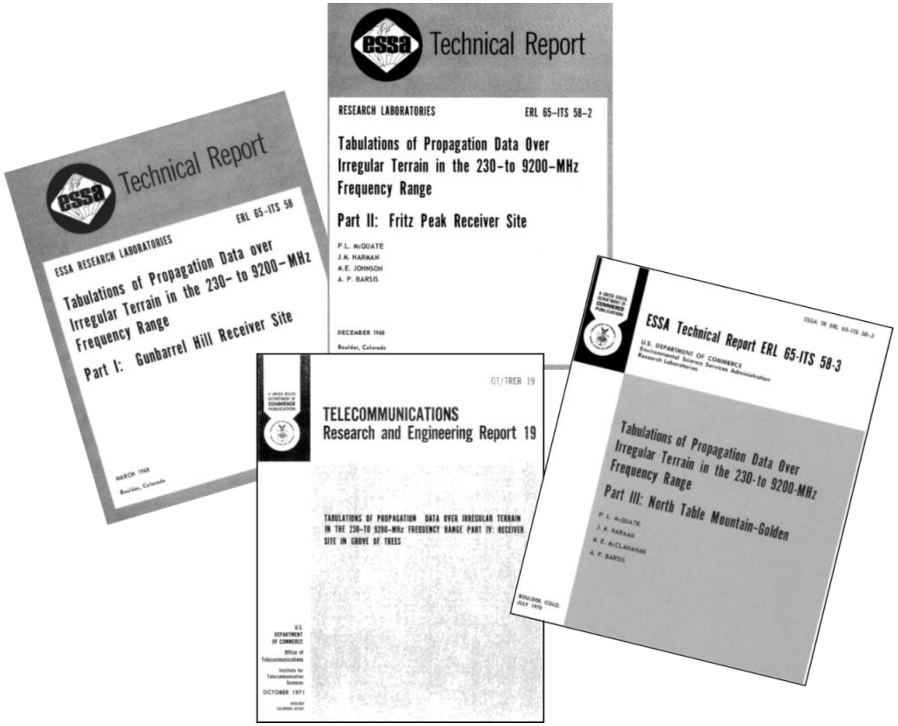
July 28, 2016 – Uncertainties & Guidelines

- Engineering tradeoffs & uncertainties
  - Antennas – directional vs. omnidirectional
  - System link budget
  - Terrain database
  - Geolocation
- Discuss measurement guidelines
  - Test planning/documentation
  - System validation
- Next steps



Background

- Major propagation measurement campaign 1960s-1970s — seminal results published as ITS reports
- Current need: Propagation measurements in the 3.5 GHz and AWS-3 bands to study aggregate interference into government systems
  - ITS began a new round of propagation studies in 2013
  - Investigation with NIST Statistical and Engineering Division (SED) in 2014



CSMAC Studies Prior to Advanced Wireless Service (AWS)-3 Rulemaking

- Commerce Spectrum Management Advisory Committee (CSMAC) Working Groups interference analysis
  - CSMAC Working Group analyses used conservative assumptions
    - No terrain (for air-to-ground analysis)
    - No antenna patterns (except in the case of aeronautical mobile telemetry systems)
    - No clutter* losses
  - Which led to large estimated protection distances (100s of km)
  - Further analysis needed to refine protection distances
- Industry participants sought to acquire real world information
  - Verify or refine CSMAC Analysis
  - Airborne measurements provide basis to understand interference potential
  - Developed test plan and conducted airborne measurements
  - Received input from Department of Defense (DoD) on test plan

*Clutter is defined as man-made structures or foliage in the radio propagation path

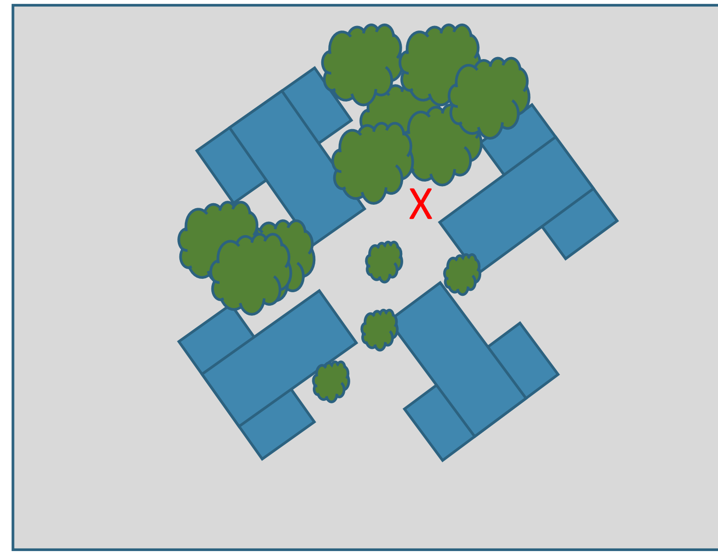
Analysis of Comsearch* Measured Airborne Data

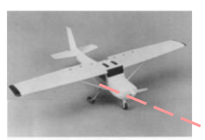
- Measurements to characterize aggregate UE uplink signal levels at several altitudes and flight paths
- Objective: Assess interference potential to federal aeronautical systems
- Measured uplink emissions in
  - 777-787 MHz (LTE)
  - 824-849 MHz (Cellular)
  - 1710-1755 MHz (AWS-1)
  - 1850-1910 MHz (PCS)

* Comsearch Government Solutions, LLC.

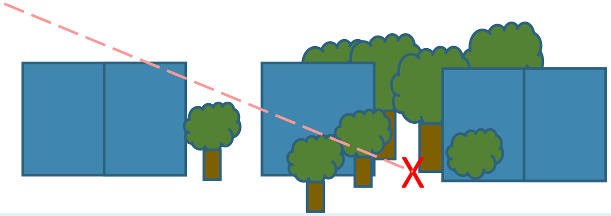
Additional Continuous-Wave (CW) Measurement Setup

- CW Transmitter:
  - Frequency: 1887.5 MHz
  - Power: 40 dBm (10 Watts)
  - Antenna Gain: 1.9 dBi
  - Antenna height: 1.8 m (6’) AGL
  - Antenna type: Omni-directional
  - Known transmitting location

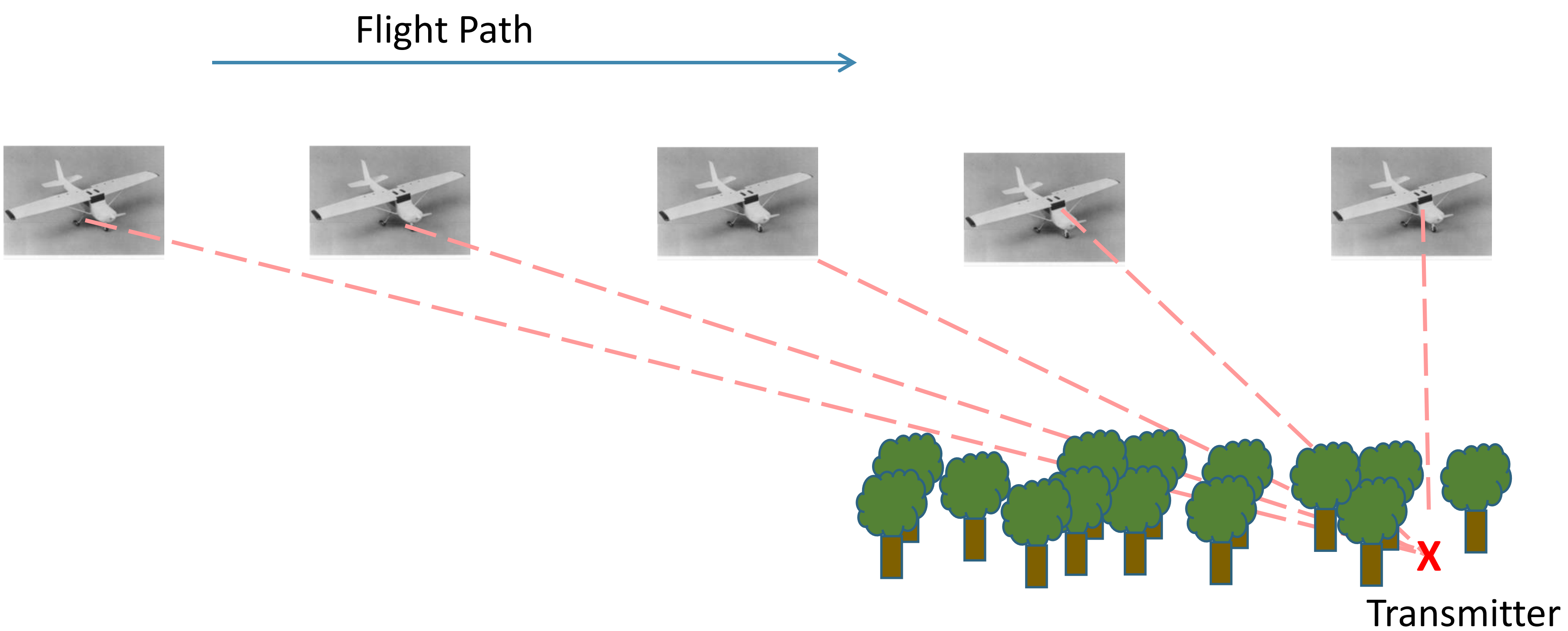




- CW Receiver:
  - Inside aircraft
  - Mean system noise floor: approx. -115 dBm
  - Antenna type: Omni-directional

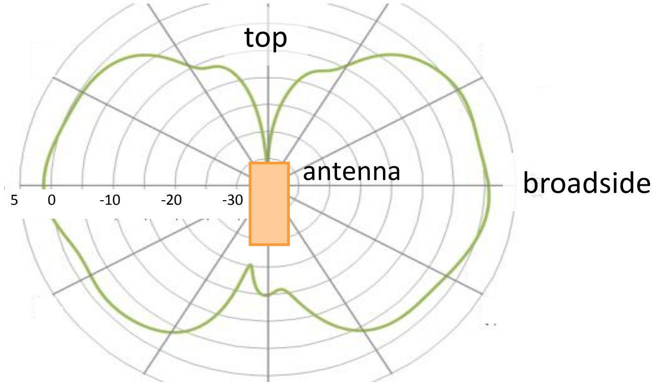


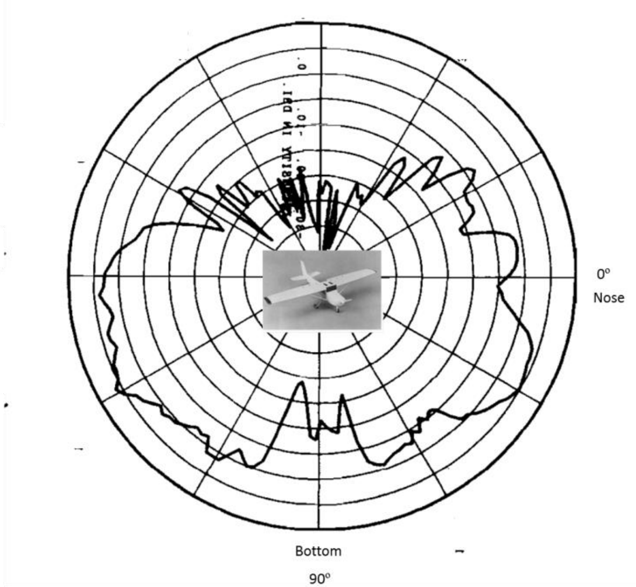
Clutter and the Radio Propagation Path



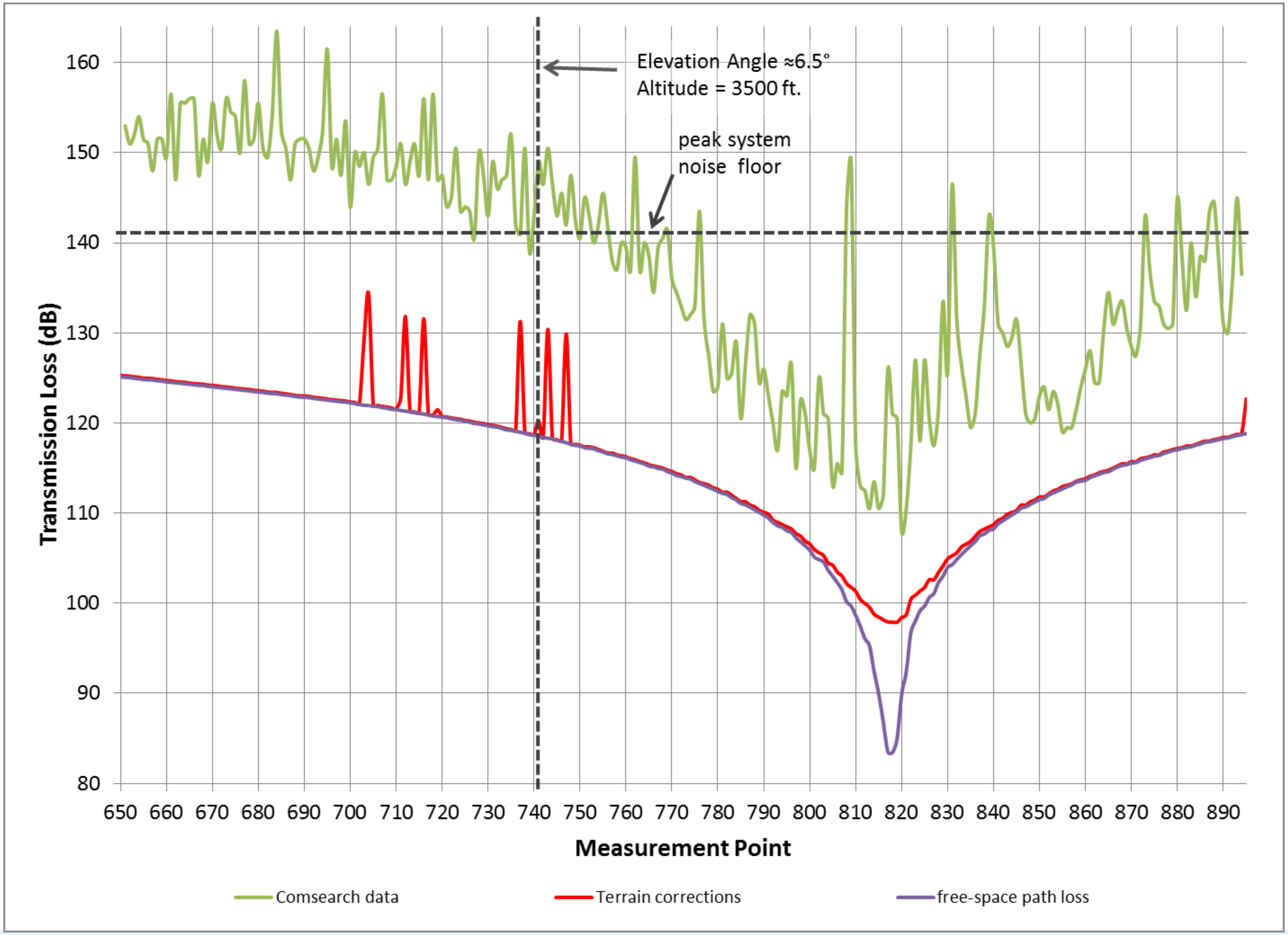
Analysis Needs

- Power (measured/calculated) at input to antenna
- Air-to-ground propagation model
  - ITU-R, P.528 – Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF, and SHF bands
  - IF-77 – ITS/FAA 1977 Propagation model (see references)
- Antenna Patterns for transmitting and receiving antenna





- Clutter loss model
  - ITU-R, P.833 – Attenuation in vegetation

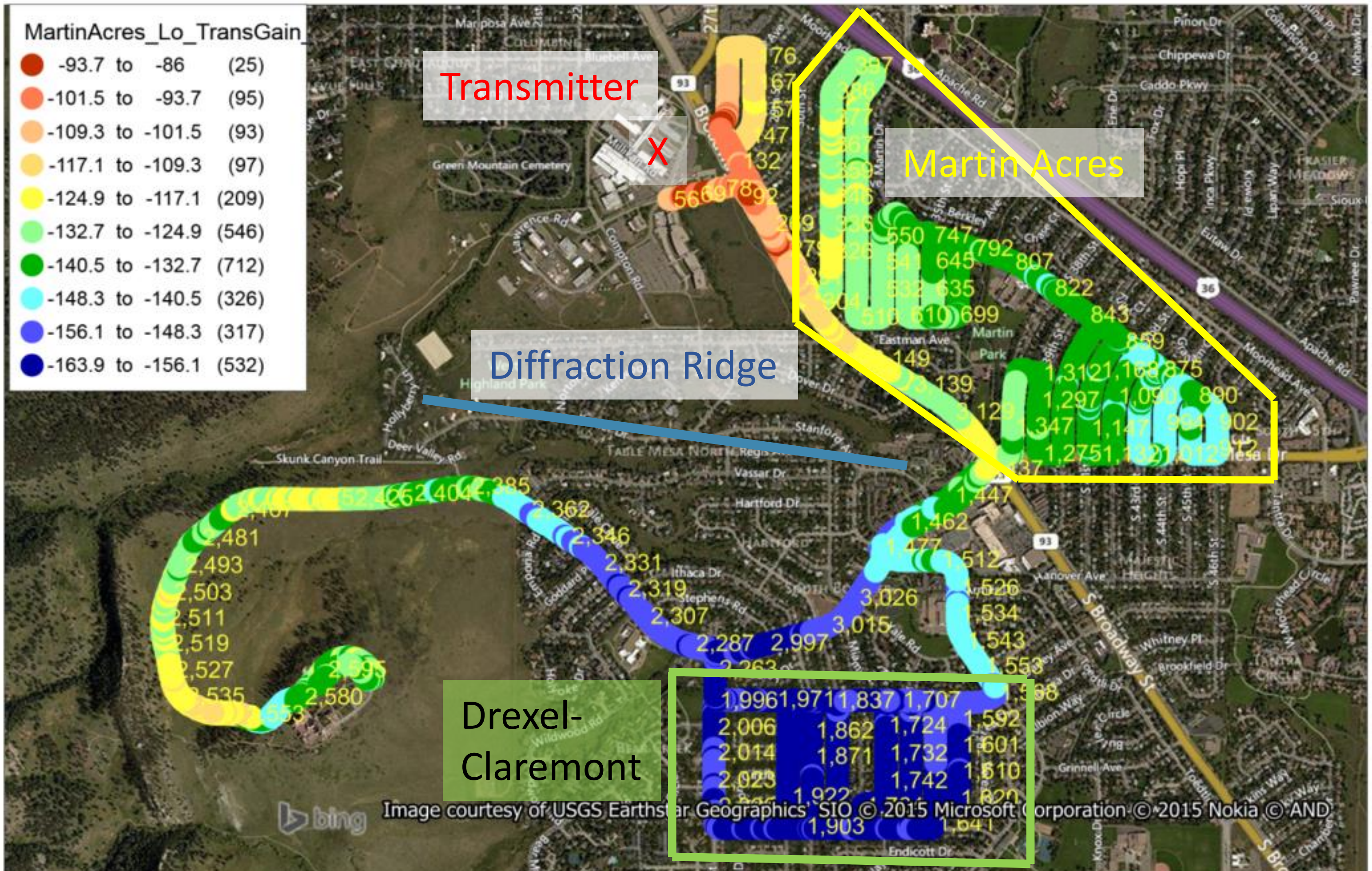


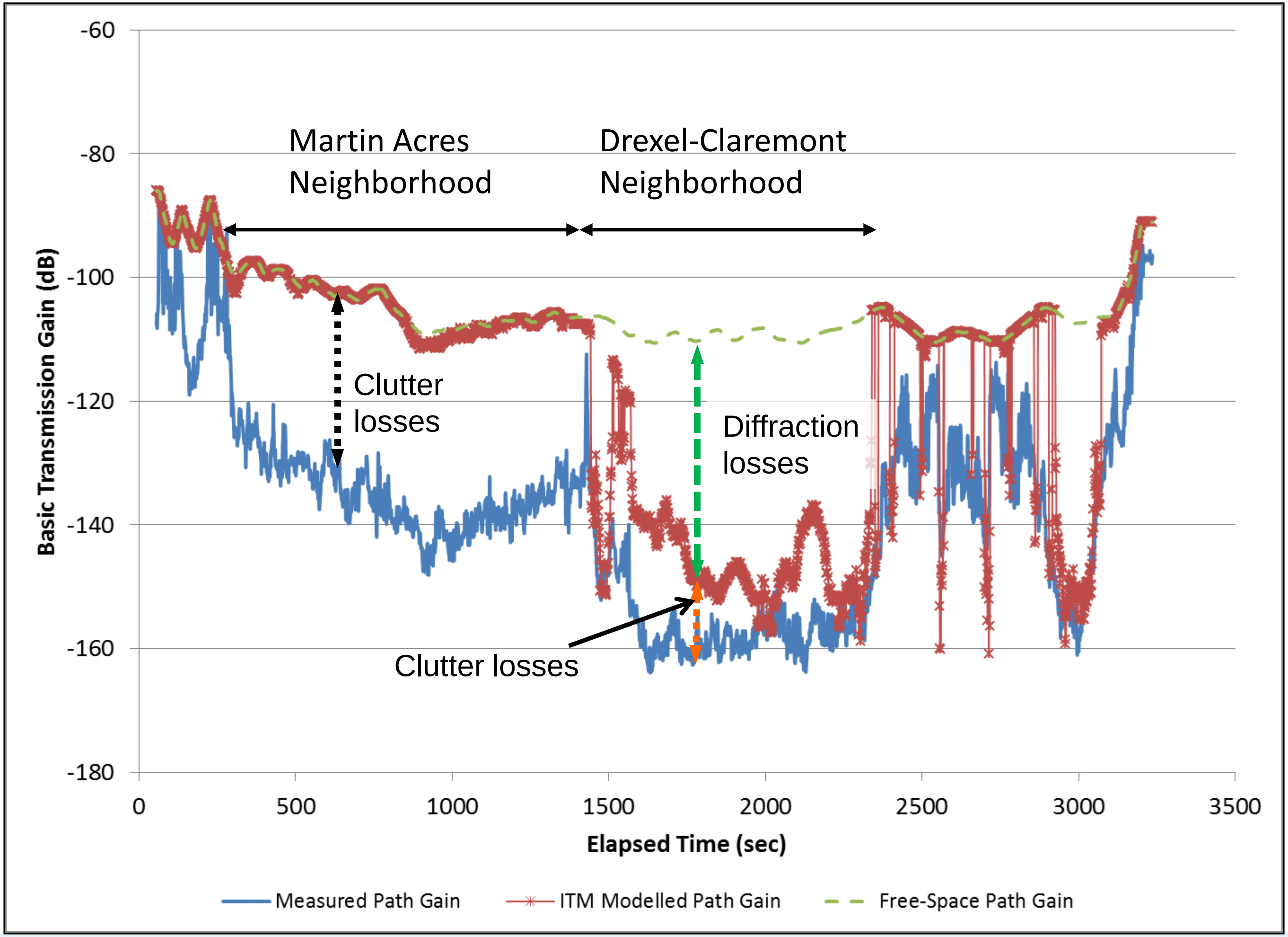
Elevation Angle ≈6.5°
Altitude = 3500 ft.
peak system noise floor
Transmission Loss (dB)
160
150
140
130
120
110
100
90
80
650 660 670 680 690 700 710 720 730 740 750 760 770 780 790 800 810 820 830 840 850 860 870 880 890
Measurement Point
Comsearch data
Terrain corrections
free-space path loss

Clutter Extraction Process

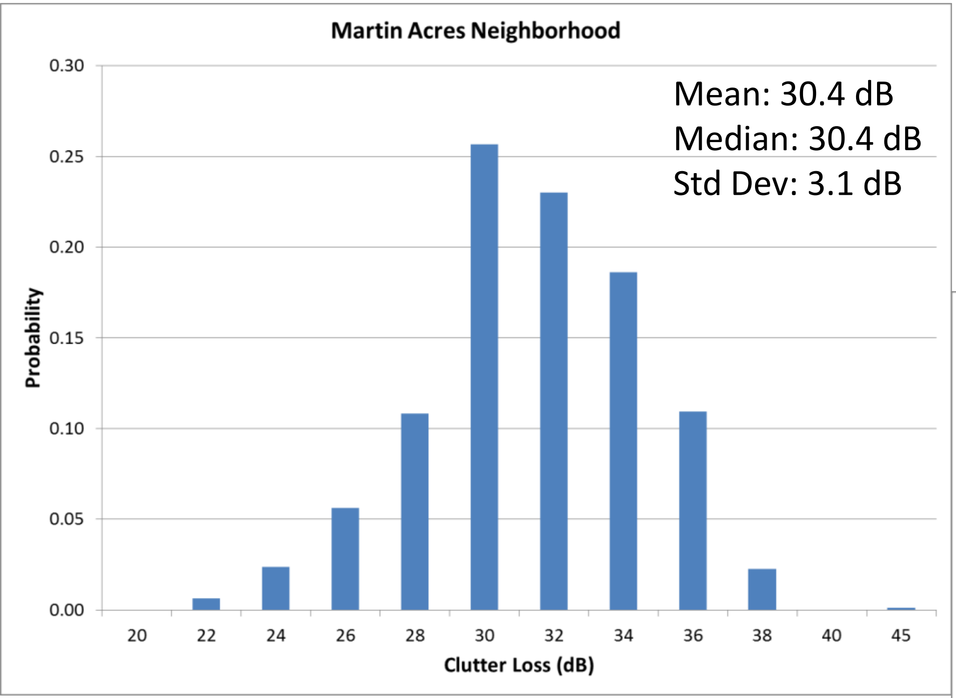
- Experimental design
- Measure antenna gains/cable losses/system losses
- Collect measured data
- Process data to extract path loss/gain
  - Correct for antenna gain/cable losses/system losses
  - Calculate path loss/gain
- Run the ITM model to obtain basic transmission loss/gain
  - ITM is run in point-to-point mode for each transmitting/receiver pair
- Subtract measured data from ITM model to obtain clutter/terrain loss
  - Need a proper implementation of ITM and a good terrain database

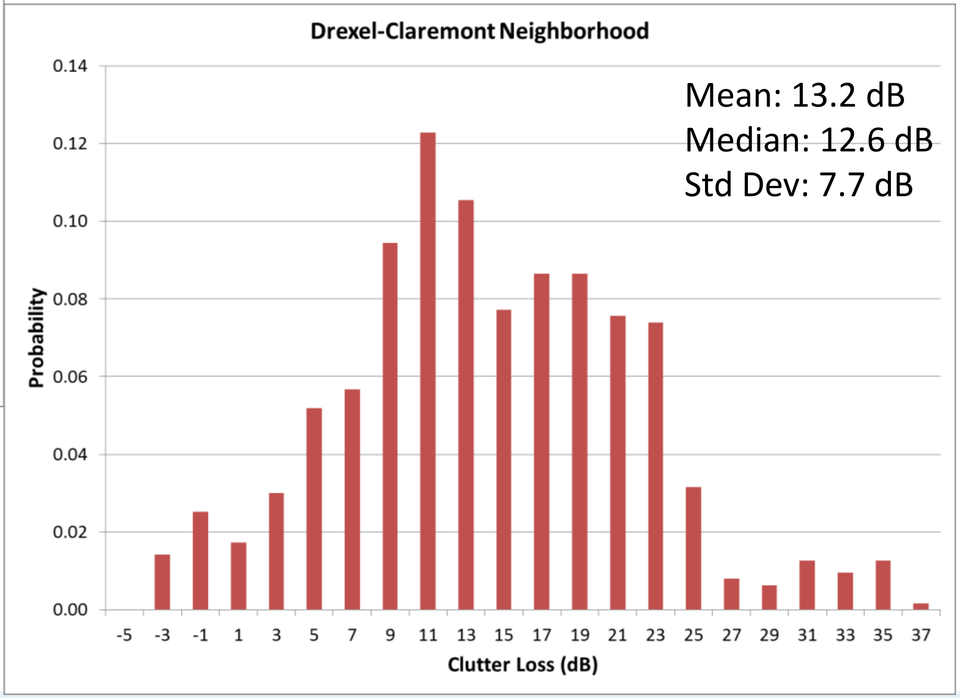
Propagation Measurements near Boulder Labs




-60
-80
-100
-120
-140
-160
-180
Basic Transmission Gain (dB)
0
500
1000
1500
2000
2500
3000
3500
Elapsed Time (sec)
Martin Acres Neighborhood
Drexel-Claremont Neighborhood
Clutter losses
Diffraction losses
Clutter losses
Measured Path Gain
ITM Modelled Path Gain
Free-Space Path Gain

Clutter Loss Results





ITS/NIST System Verification/Uncertainty Analysis

- System improvements
  - Component loss measurements using Vector Network Analyzer (VNA)
    - Replaced lossy cables with lower-loss cables
    - Shortened cable lengths
  - Antenna pattern gain measurements
    - Transmitting antenna
    - Antenna on van
      - Center of van vs. Antenna on van mast
- Measurements
  - 32 screening measurements to study environmental variable dependencies
    - Power, speed, clutter, elevation angle, traffic
  - Table Mountain in Boulder (clutter-free environment)
  - Martin Acres near laboratory
    - Power Spectral Analysis
    - Clutter model based on LiDar data

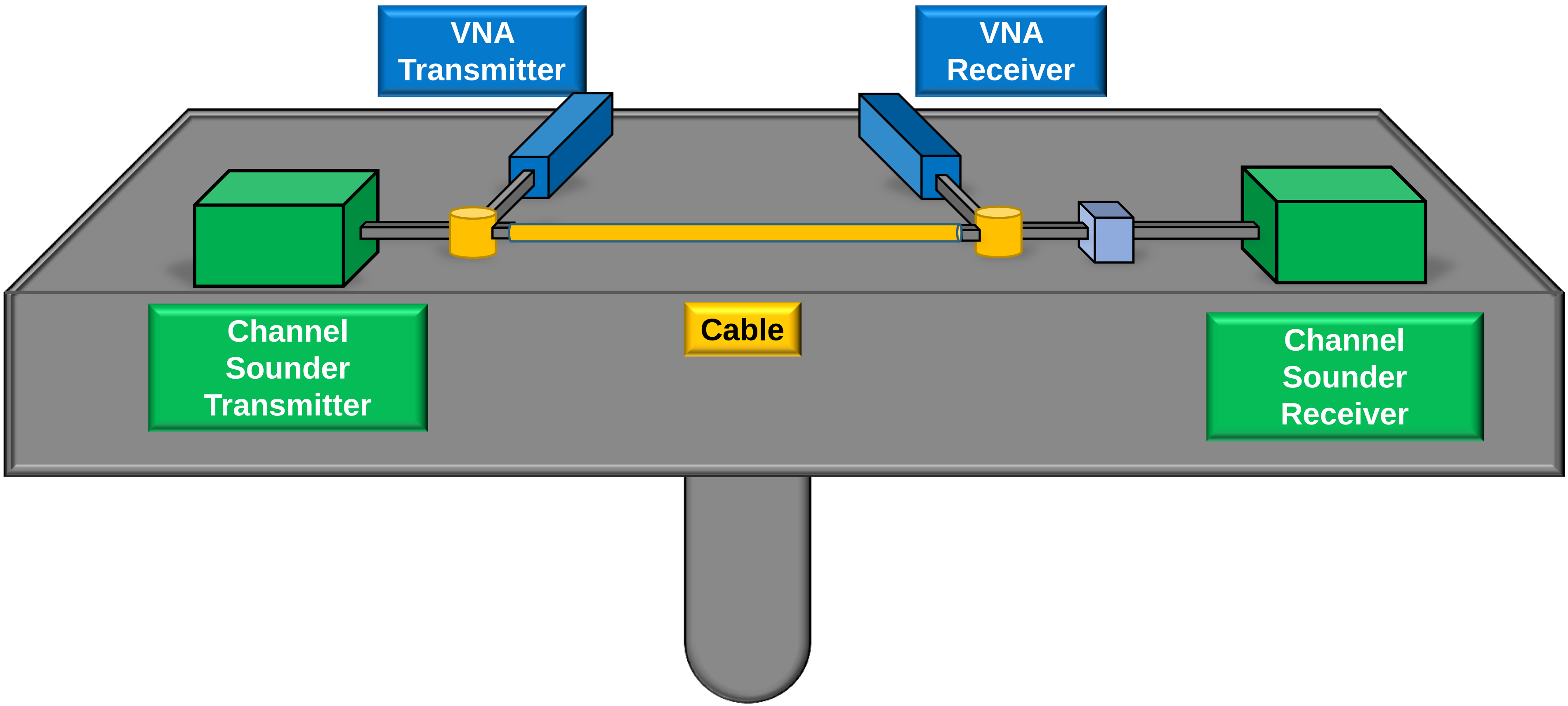
- Measurements (cont')
  - Downtown Denver
    - Three transmit locations
    - Two frequencies
    - Three regions (urban, suburban, residential)
    - Each region measured at least two times (at one frequency three times)
  - San Diego
    - Two transmit locations
    - Two frequencies
    - Three regions (urban, suburban, residential)
    - Each region measured at least two times
    - Static measurements
- Variability/uncertainty analysis
- Remaining issues
  - GPS positioning errors
  - Propagation model Improvements
  - Uncertainty/variability – new Propagation Working Group with NIST

ITS/NIST CAC Research Collaboration

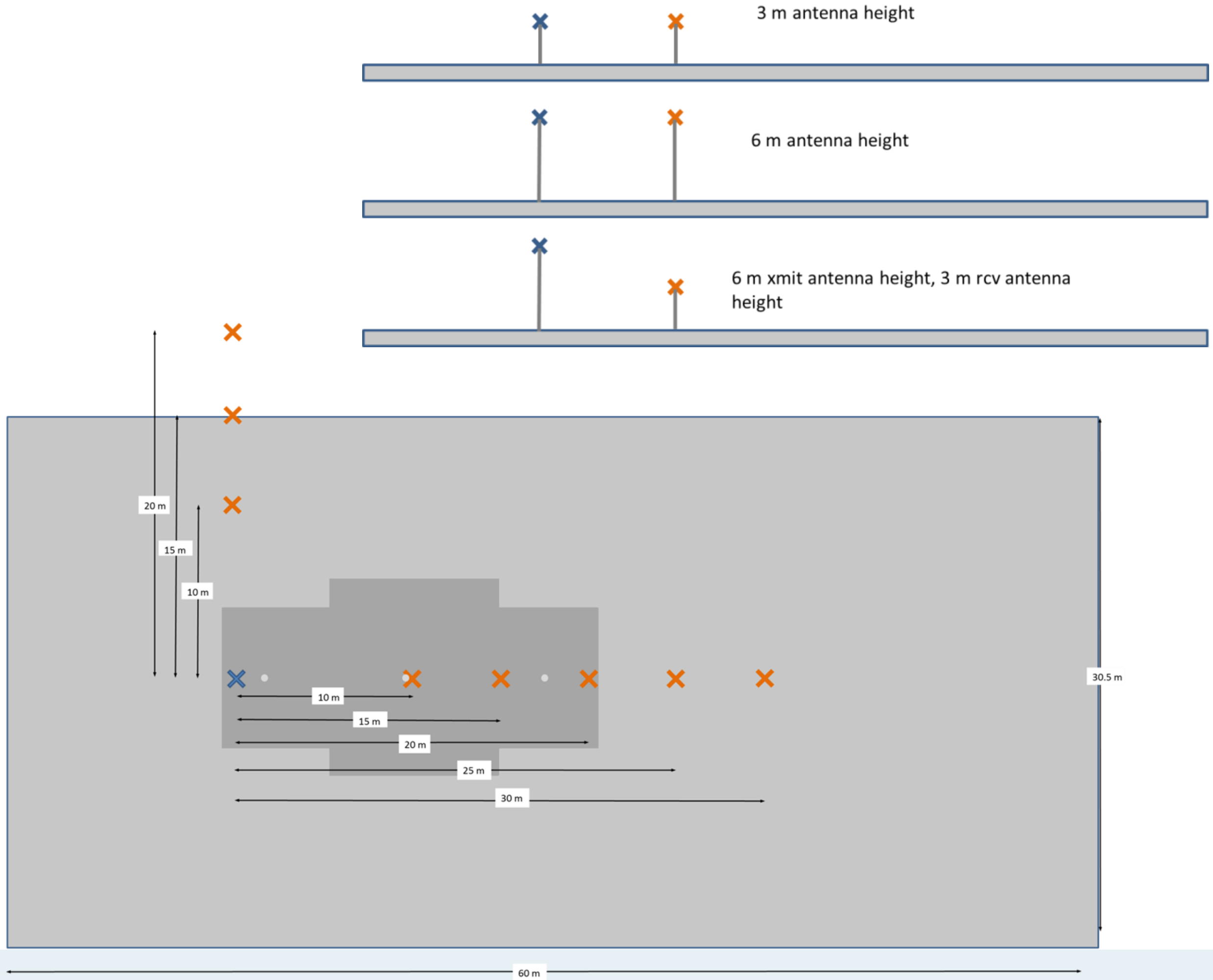
Objective: Use modern metrology tools, such as the NIST Microwave Uncertainty Framework (MUF), to place modern propagation (channel) measurements and models on a sound metrological foundation

- Compare measurements for four channel sounders
  - **Phase I**: Intercomparison of channel sounders in a conducted environment
  - **Phase II**: Intercomparison of channel sounders on an open-area test site (OATS) – controlled external environment
  - **Phase III**: Mixed-path propagation study with one antenna on the OATS and one antenna off the OATS
  - **Phase IV**: Field testing at Table Mountain facility
- Improve models based on measurements
- Improve computational processing algorithms

ITS/NIST CAC Research Collaboration Conducted Measurements



ITS/NIST CAC Research Collaboration
OATS Facility



ITS/NIST CAC Research Collaboration – Table Mountain Field Test Site

ITS Clutter Loss Measurement Project

San Diego, CA

Denver, CO

Washington, D.C.

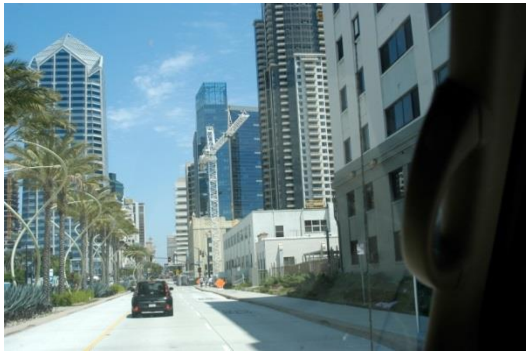
Los Angeles, CA

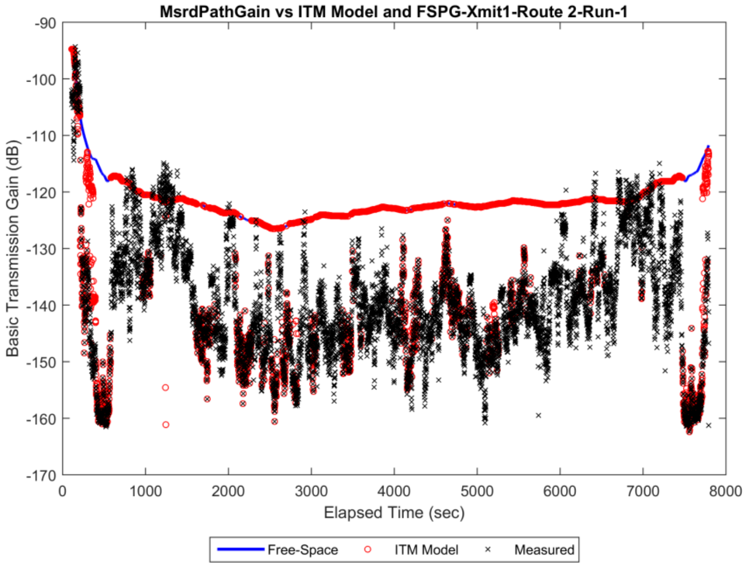
Location	Frequency Bands (MHz)	Transmitting Locations
San Diego, CA	1) 1755-1780 2) 3500	1) Point Loma 2) Navy Sub Base
Denver, CO & Boulder, CO	1) 1755-1780 2) 3500	1) Hackberry Hill 2) Diamond Hill 3) DMNS† 4) Green Mountain 5) Commerce Labs
Washington, DC	1) 1755-1780 2) 3500 (static)	1) Alexandria 2) St. Eliz. Campus 3) Ashburn
Los Angeles, CA	1) 1755-1780	1) Angels Pt 2) Griffith Park* 3) Point Mugu*

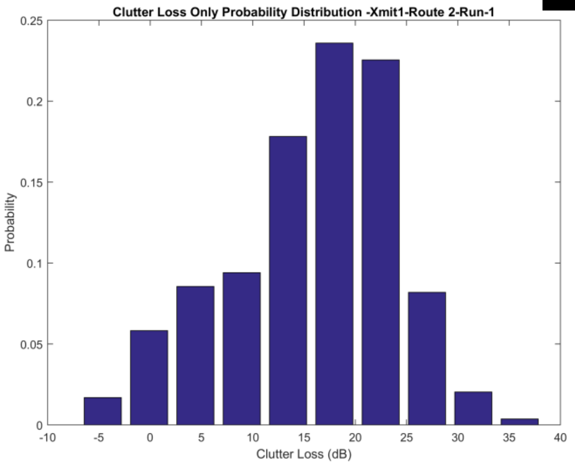
† Denver Museum of Nature and Science
*Future Measurement Campaigns

San Diego, CA

Point Loma



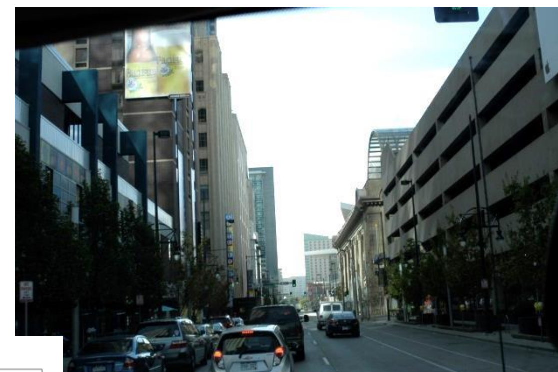


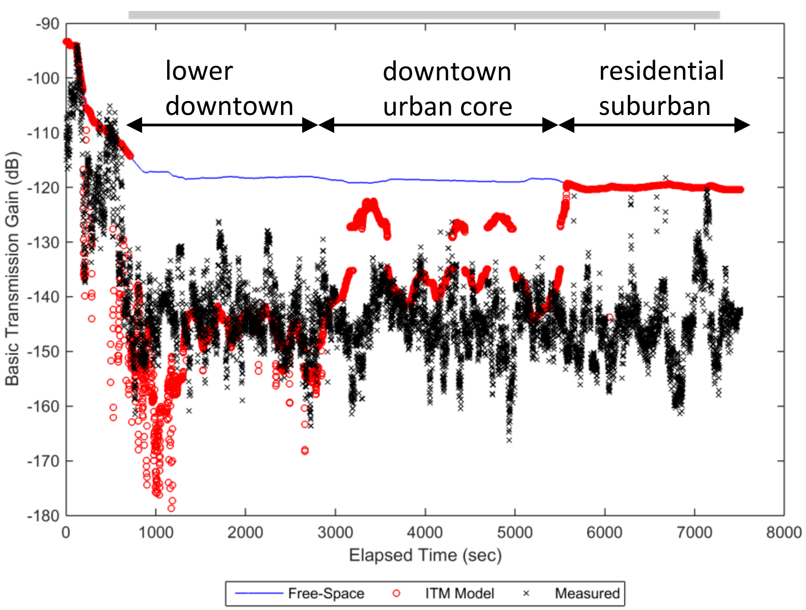


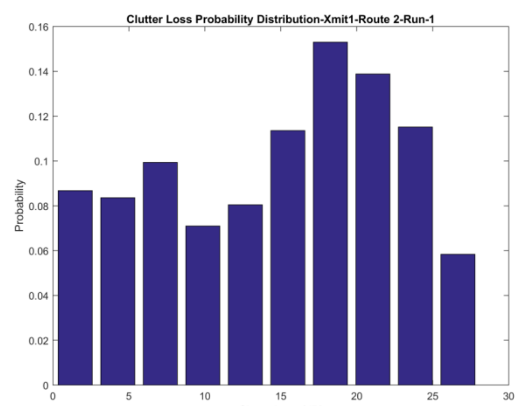
Mean clutter losses: ~15 dB in downtown urban area

Denver, CO

Hackberry Hill



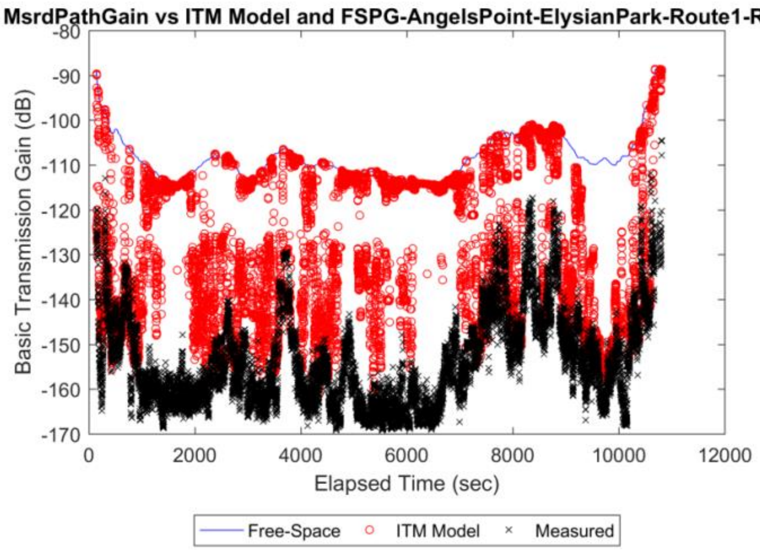


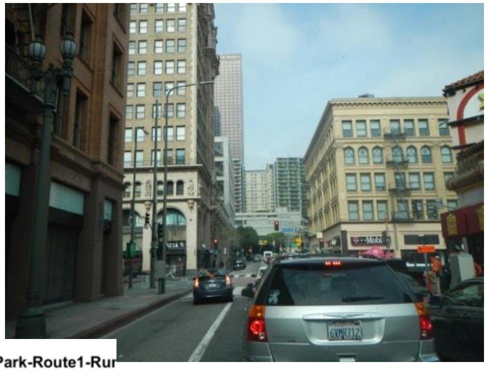


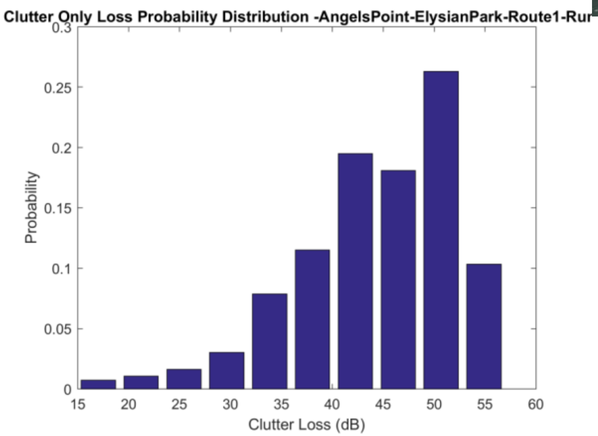
Mean clutter losses:
~15 dB in downtown urban core

Los Angeles, CA

Angels Point



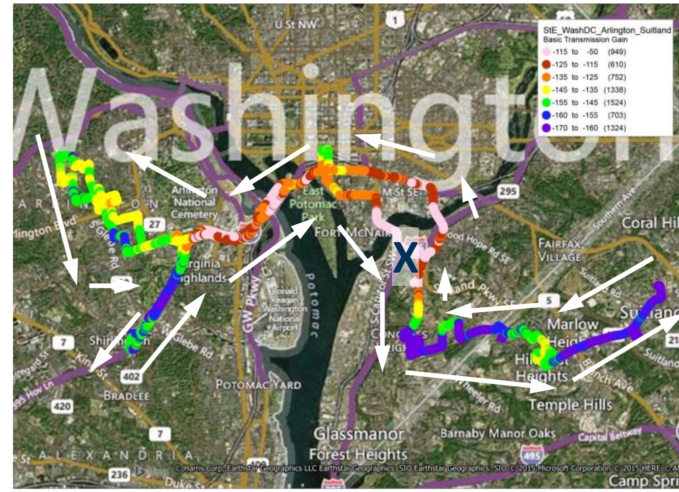


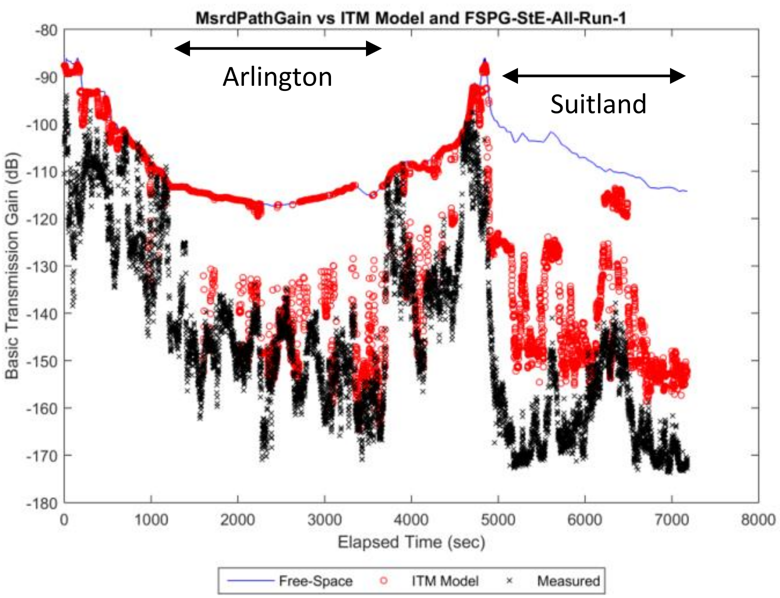


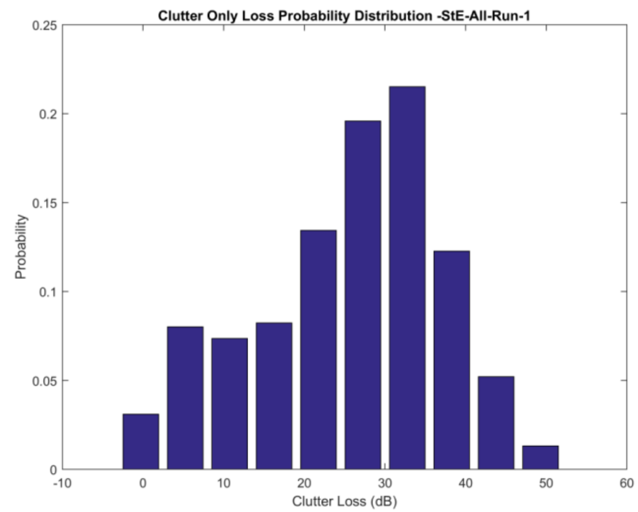
Mean clutter losses: ~43 dB in downtown urban area

Washington, DC

St. Elizabeth Campus







Mean clutter losses: ~30 dB in suburban area

Observations

- Washington, DC higher propagation loss than expected – buildings closely spaced, narrow streets, lots of vegetation
- Interior of Downtown Los Angeles higher propagation loss than expected (surprising because of wide streets)
- Propagation into region beyond downtown Denver highly shielded by downtown buildings – site-specific, end-point clutter corrections vs. whole path clutter corrections
- Different urban areas showing differing amounts of clutter loss. Time for ray-tracing models?
- Resolution and accuracy of terrain databases very important

ITS Lessons Learned

- Choose antenna carefully – highly directional antennas can lead to problems in the processed data
- Document system carefully and don't change it on the fly
- Manufacturer's specifications are not always accurate
- Site surveys are very important – get the lay of the land
- Always bring duplicate equipment
- Process the data while on site – hard to go back
- Measure the system noise floor
- Elevation Angle and Azimuth with respect to receiving area important
- Pictures are helpful to document measurement area
- Studies need to be done on reciprocity of transmitter in clutter vs. receiver in clutter

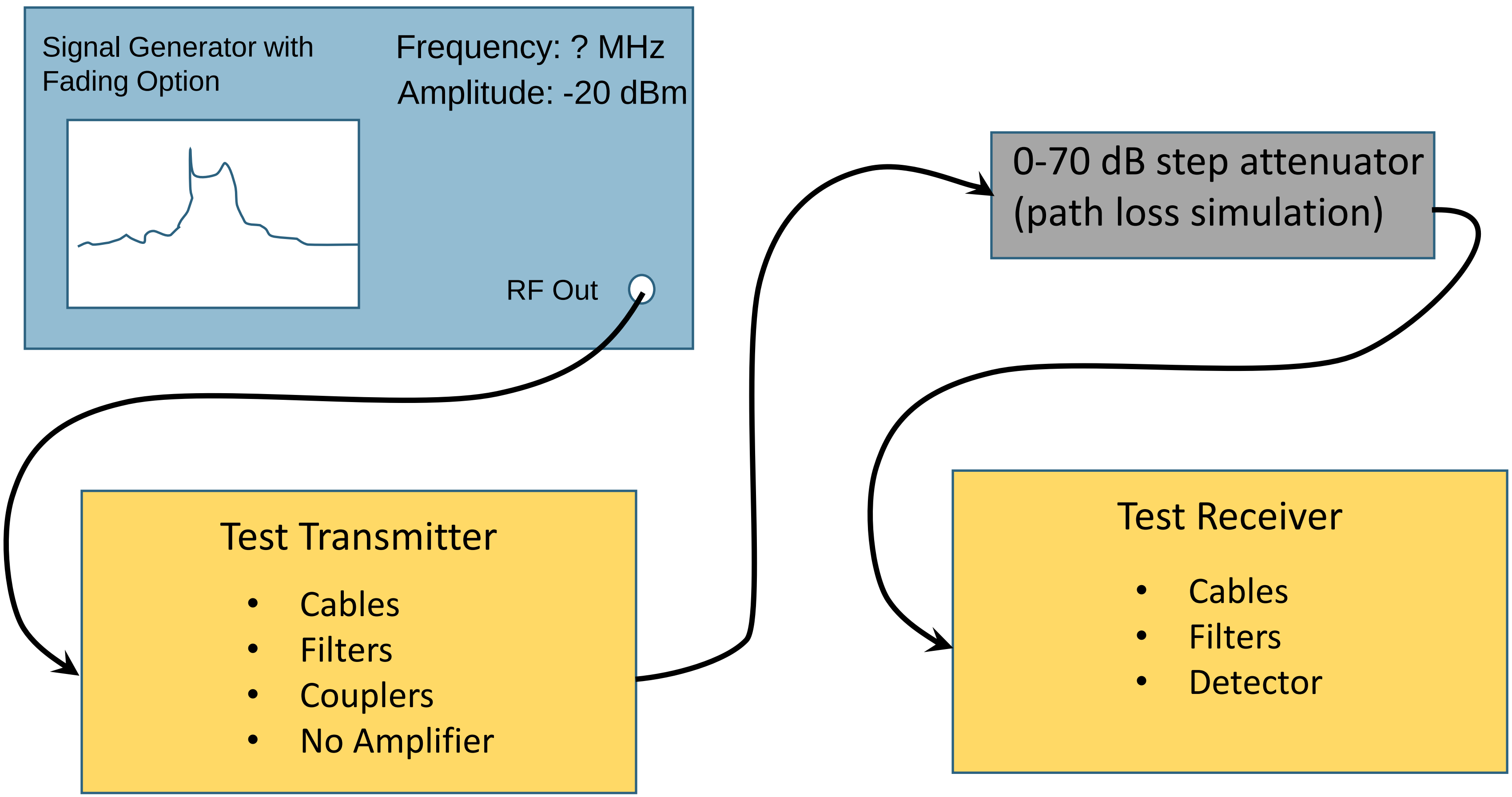
Possible System Test Setup

Bench Top Testing

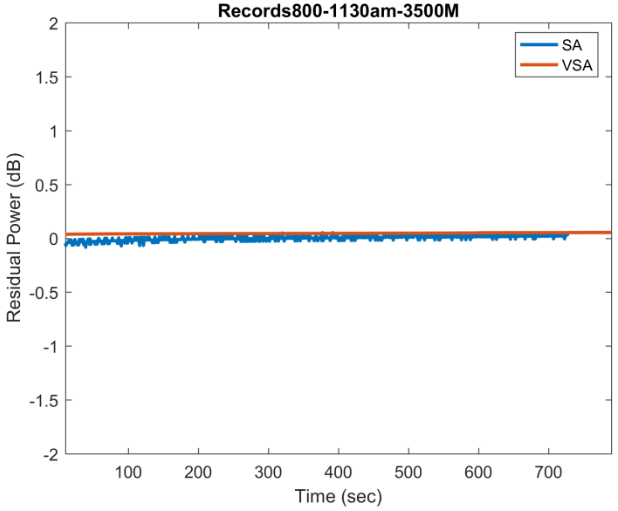
Fading Simulator Settings

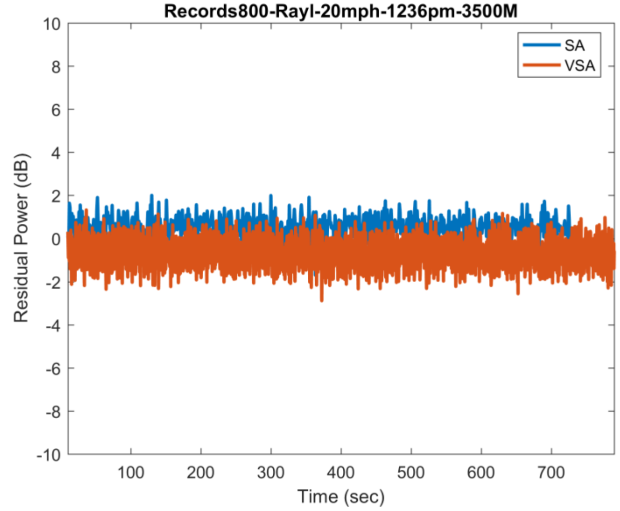
- CW signal
  - 0 dB path loss
  - 70 dB path loss
- Rayleigh fading signal
  - 0 dB path loss
  - 70 dB path loss
  - 20 mph, 50 mph
- Rician fading signal
  - 0 dB path loss
  - 70 dB path loss
  - 20 mph, 50 mph
  - 10 dB power ratio
  - Doppler shift

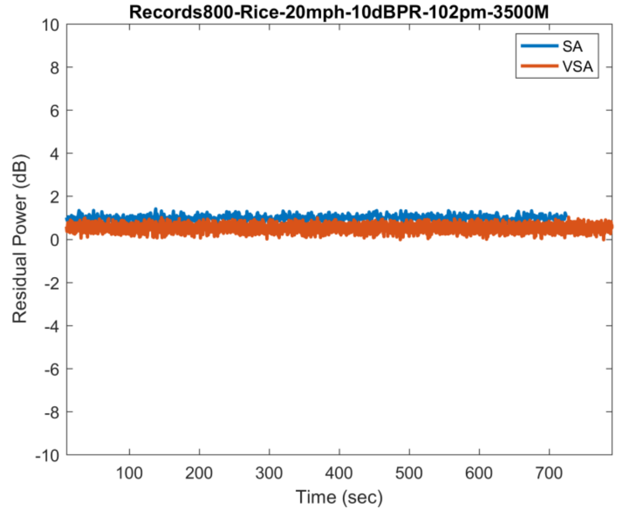
Bench-top System Verification Testing



Post-processed Measurement Data







CW Signal
- 0 dB simulated path loss

Rayleigh fading signal
- 0 dB simulated path loss
- 20 mph

Rician fading signal
- 0 dB path loss
- 20 mph
- 10 dB power ratio
- No Doppler shift

Proposed Reference Field Test Sites

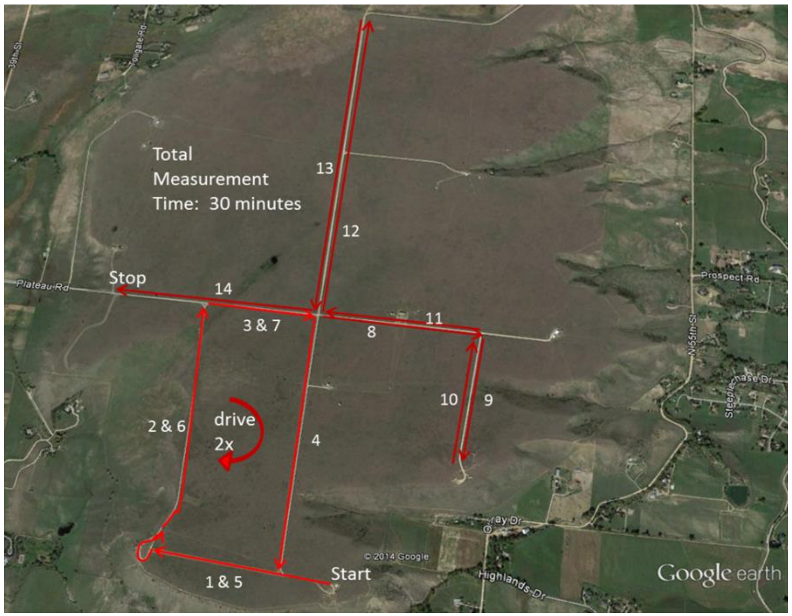
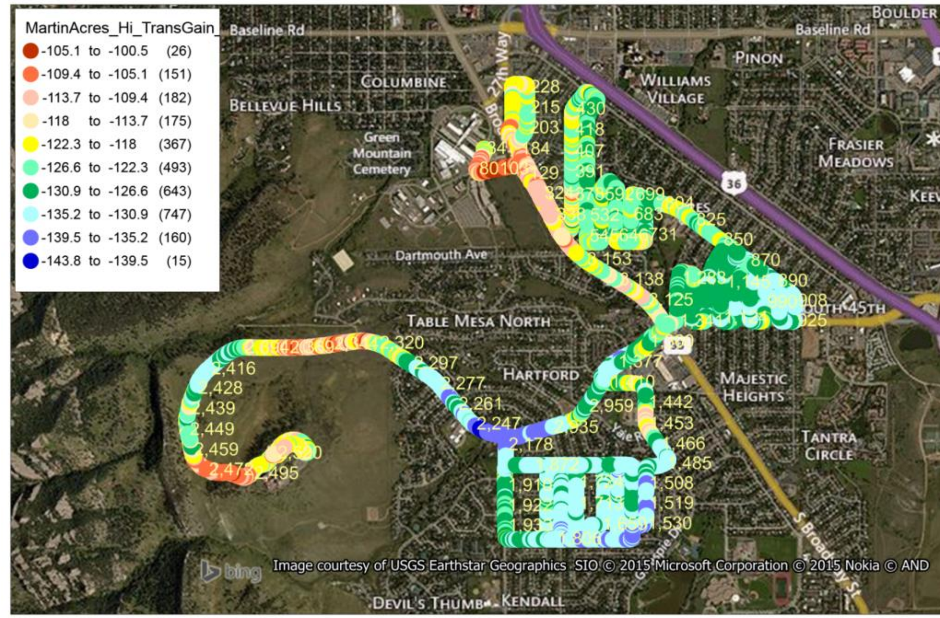


Table Mountain
(uncluttered environment)



Martin Acres
(cluttered environment)

Vision

- System verification testing
  - Bench-testing at ITS
  - Reference faded waveforms (for participants with access to vector signal generators that lack a fading option)
  - Intercomparison testing at previously measured locations
  - Field testing at reference test sites in Boulder, CO
- Shared understanding of system architectures, measurement techniques, post-processing algorithms, and data analysis
- Lessons learned
- Measurement guidelines
- Open data repository of community accepted measurement data

Preparation for Future Meetings

- Document the details of your measurement system (Due date: July 14, 2016)
  - System schematic with link budget
  - Data post-processing algorithm
  - Describe system verification testing
    - Antenna measurements
    - Receiver system
    - Post-processing software
- Develop a list of previous or currently planned propagation measurements (Due date: July 21, 2016)
  - e.g. if you are going to San Diego, would you like a set of our measured coordinates so that we can compare data?
- Develop a list of lessons learned (Due data: July 28, 2016)
  - This will be shared with the group via e-mail

Contacts:

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- Bob Johnk: bjohnk@its.bldrdoc.gov
- Paul McKenna: mckenna@its.bldrdoc.gov
- Lee Pucker: Lee.Pucker@WirelessInnovation.org

Reference Documents

- P.L. McQuate, J.M. Harman, A.P. Barsis, Tabulations of Propagation Data over Irregular Terrain in the 230- to 9200- MHz Frequency Range Part 1: Gunbarrel Hill Receiver Site, NTIA Technical Report ERL 65-ITS 58, March 1968.
- P.L. McQuate, J.M. Harman, M.E. Johnson, A.P. Barsis, Tabulations of Propagation Data Over Irregular Terrain in the 230-to 9200-MHz Frequency Range Part 2: Fritz Peak Receiver Site, NTIA Technical Report ERL 65-ITS 58-2, December 1968.
- M.E. McClanahan, A.P. Barsis, Tabulations of Propagation Data Over Irregular Terrain in the 230- to 9200-MHz Frequency Range Part 3: North Table Mountain-Golden, NTIA Technical Report ERL 65-ITS 58-3, July 1970.
- P.L. McQuate, J.M. Harman, M.E. McClanahan, Tabulations of Propagation Data over Irregular Terrrain in the 230-TO 9200-MHz Frequency Range Part 4: Receiver Site in Grove of Trees, NTIA Technical Report OT/TRER 19, July 1971.

Reference Documents

- Commerce Spectrum Management Advisory Committee, Working Group 5 Final Report 1755-1850 MHz Airborne Operations, September 16, 2013.
- G.D. Gierhart, M.E. Johnson, The IF-77 Electromagnetic Wave Propagation Model, NTIA Sponsor Report FAA-ES-83/3, September 1983.
- K. J. Keeping, J. C. Sureau, 'Scale Model Pattern Measurements of Aircraft L-Band Beacon Antennas,' Lincoln Laboratory, Project Report ATC-47, FAA-RD-75-23, April, 1975.
- A.G. Longley, P.L. Rice, Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain: A Computer Method - 1968, NTIA Technical Report ERL 79-ITS 67, July 1968.

Acronym Definitions

- ACTS – Air Combat Training System
- AGL – Above Ground Level
- AWS – Advanced Wireless Services
- CAC – Center for Advanced Communications
- CSMAC – Commerce Spectrum Management Advisory Committee
- CW – Continuous-Wave
- DoD – Department of Defense
- FAA – Federal Aviation Administration
- ITM – Irregular Terrain Model
- ITS – Institute for Telecommunication Sciences
- ITU-R – International Telecommunications Union Radiocommunication Sector
- LTE – Long Term Evolution

Acronym Definitions

- MUF – Measurement Uncertainty Framework
- NIST – National Institute of Standards and Technology
- OATS – Open Area Test Site
- PCS – Personal Communications Service
- SA – Spectrum Analyzer
- SED – Statistical Engineering Division
- SHF – Super High Frequency
- VHF – Very High Frequency
- UHF – Ultra-High Frequency
- VNA – Vector Network Analyzer
- VSA – Vector Signal Analyzer