CHANNEL-SOUNDER MEASUREMENT VERIFICATION AND UNCERTAINTY*

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Agenda

- Channel-Sounder Measurement Verification Procedures
  - Possible Options
    - Compare to theory
    - Conducted test of known simulated-channel artifact
    - Direct OTA comparison to VNA
  - ITS/NIST channel sounder comparison activity
- Uncertainties: a brief word

Channel Sounder Verification

Why verify?

- Ensure hardware provides accurate measurements
  - Calibrations, timing issues, etc.
  - Correction for system response (imperfect TX and RX hardware)
- Verify that post processing is correct
  - Path Loss, Delay, Angle of Arrival, Other metrics

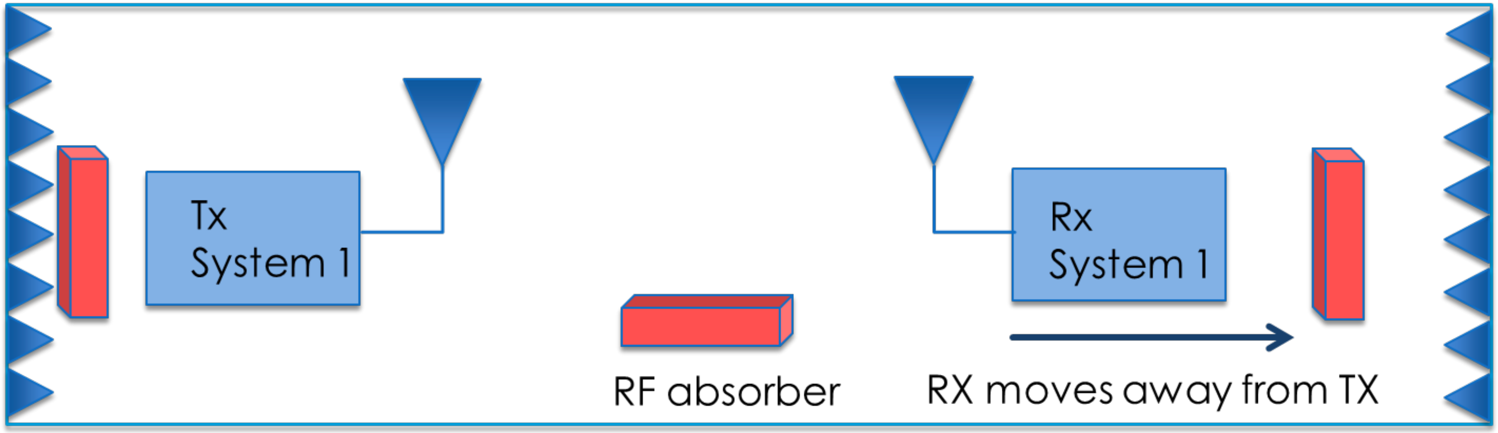
Verify by comparison to

1. **Theory** (e.g., Friis formula for path loss)
2. **Simulated-Channel Artifact** (conducted)
   - Portable: round-robin possible
3. **VNA** (“golden channel sounder”) (conducted or OTA)
   - Static environment
   - Examples:
     - mmWave Comparison
     - NIST/ITS 3.5 GHz Comparison

1. Verification by comparison to theory: Path Loss

- Orient the TX and RX antennas toward each other (if directional)
- Conduct LOS measurements starting a known distance apart with an increasing separation, starting at ¼ of 1/BW, with at least 10 distances.
  - The environment should introduce as few reflections as possible (an anechoic room or outdoors)
- Process data as normal and compare free-space path loss to theory

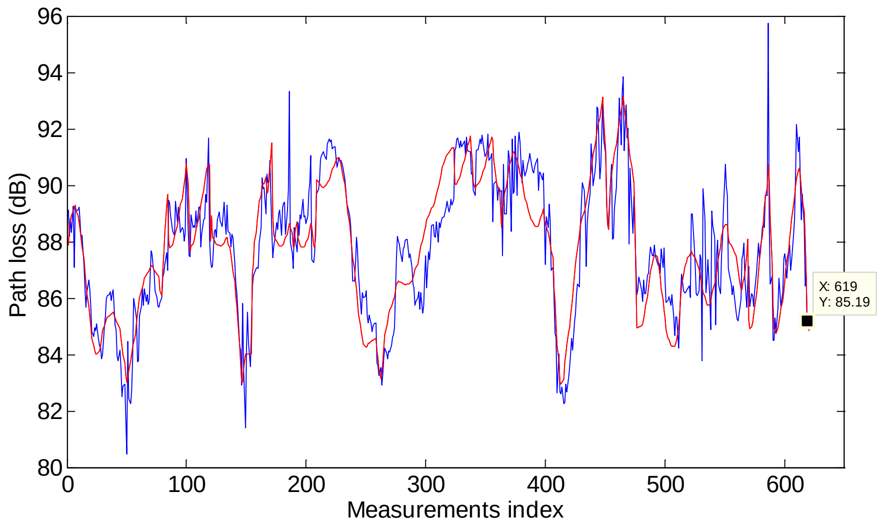
$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

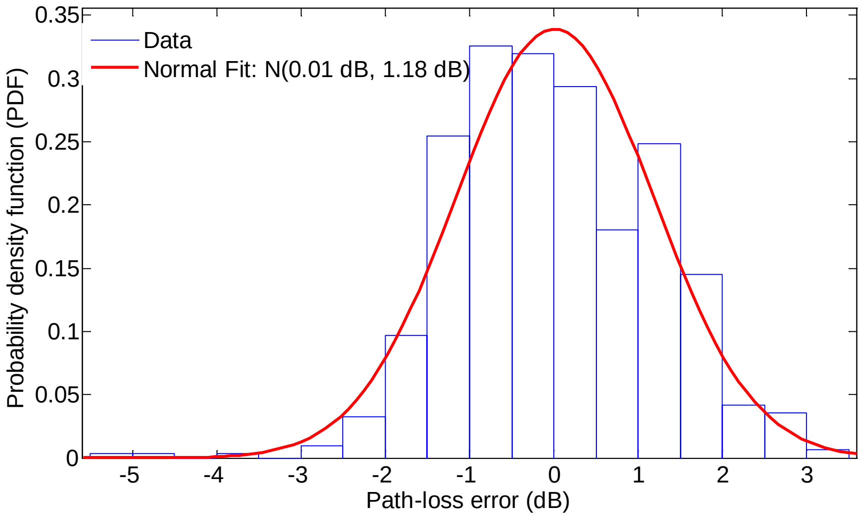


Alternate "In Situ" Verification Approach

- Verification in an open environment during actual measurements
- Example: NIST lobby area
- Measure path loss
- Compute "ground truth" from Friis transmission formula, plot error
- Compute path loss exponent (here 1.93)

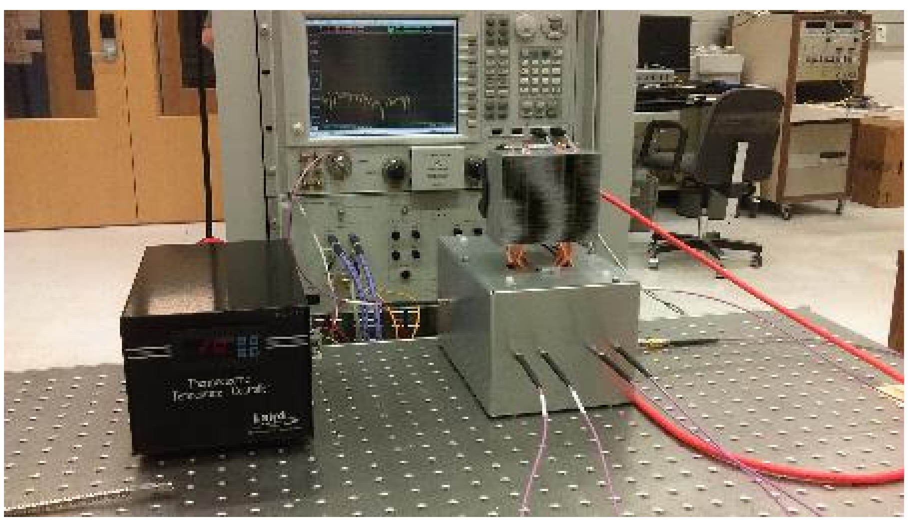
$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

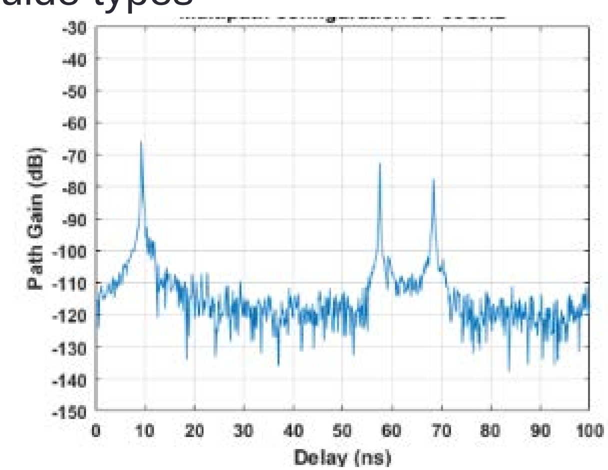


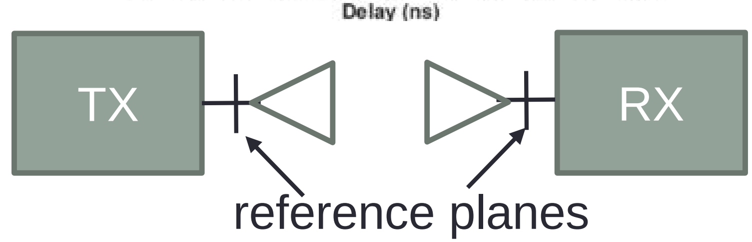


2. Multipath Verification Artifact

- Verify TX/RX performance: conducted measurement (no antenna)
- Artifact provides direct path plus up to two known multipath components
- Frequency range: anywhere between 10 - 67 GHz
- Temperature controlled
- Developed by NIST for 5G mmWave Channel Model Alliance
  - NIST provides adapters to other coax or waveguide types
  - NIST team to visit labs

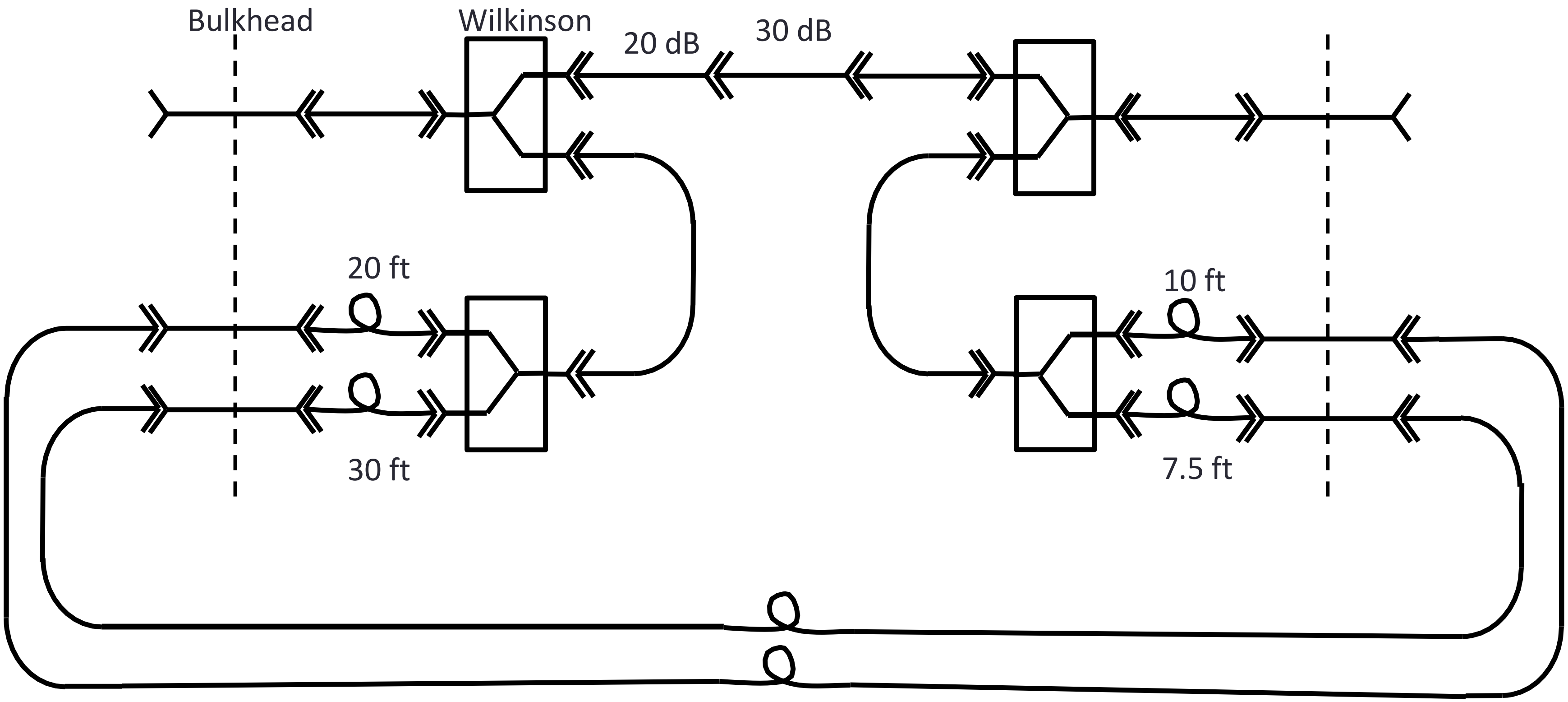




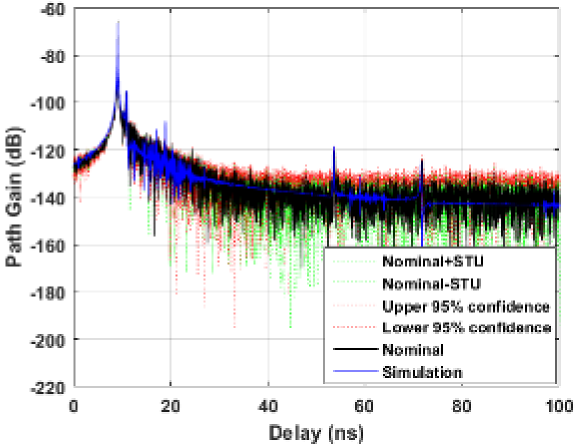


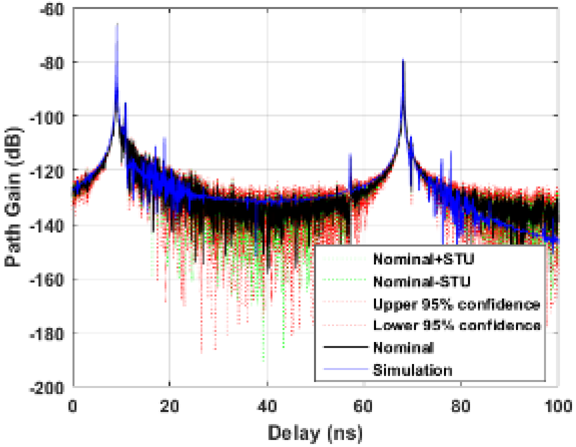
Multipath Verification Artifact: Schematic

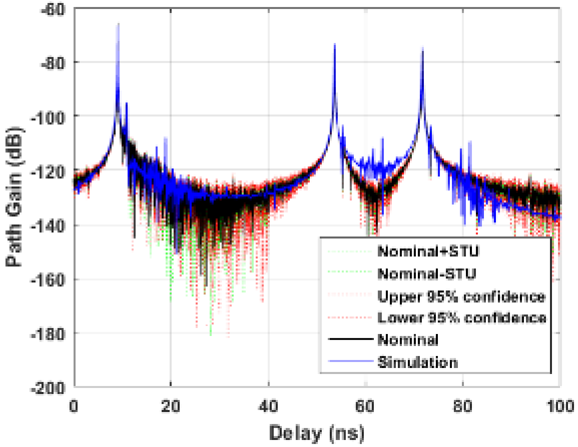
Cables can be reconfigured to provide various numbers, amplitude and multipath delays



NIST Artifact: VNA Characterization

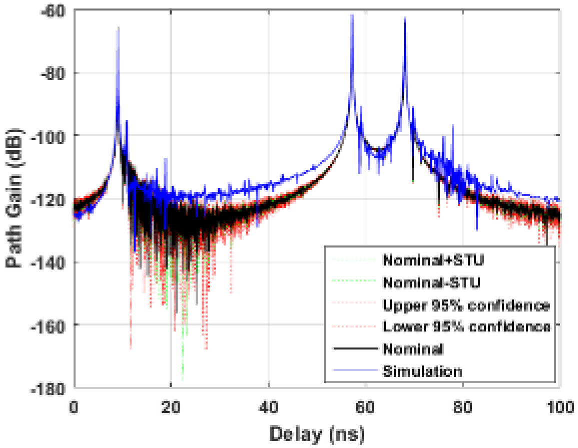






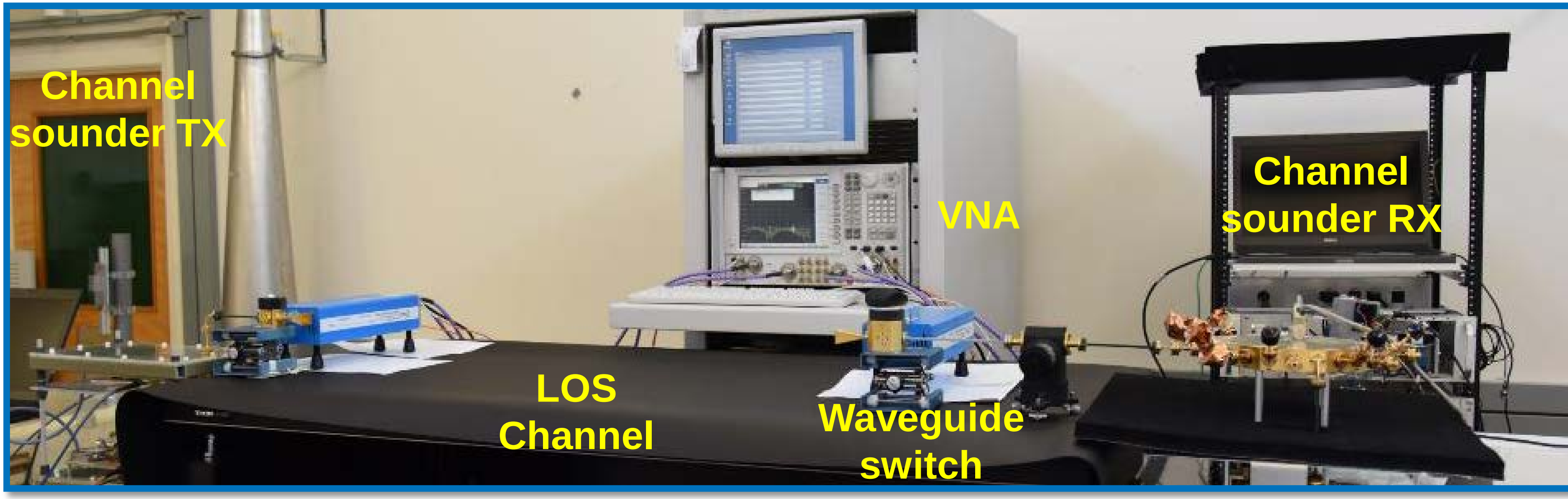
Artifact is reconfigurable:

- Various configurations, known multipath amplitudes:
- Up to four different delays
- With uncertainties



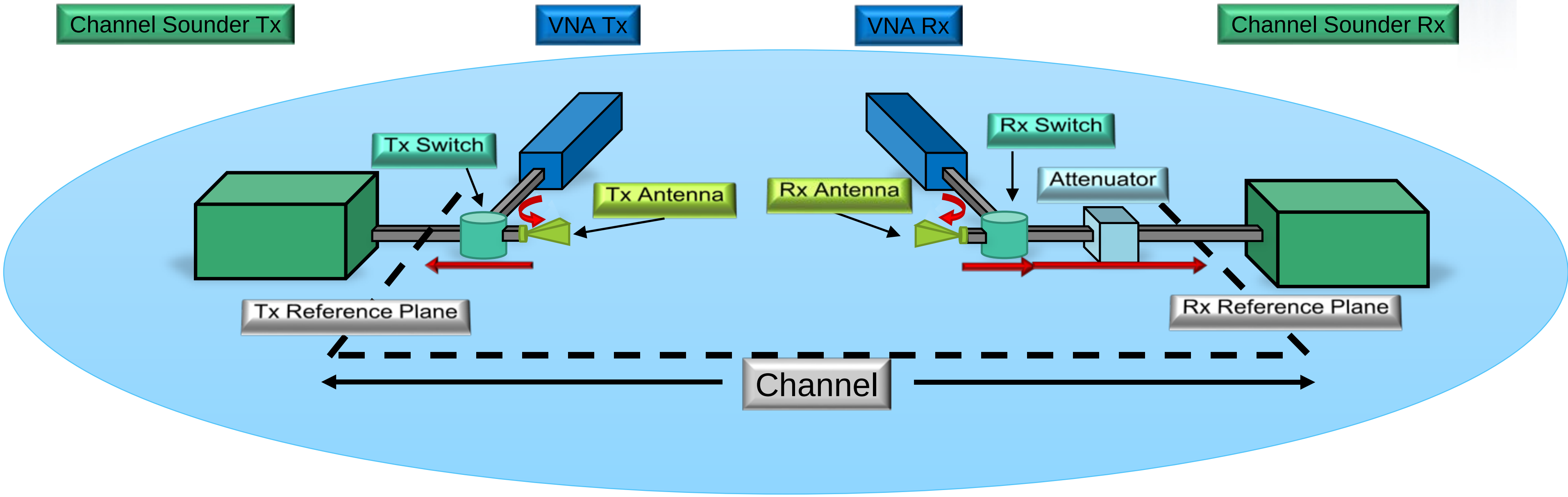
3. Comparison to VNA

- VNA serves as “golden reference” in controlled environment (lab)
- Compare sounder to VNA for same channel (using switch)
- Static environments only
- VNA uncertainties well established (e.g., NIST Microwave Uncertainty Framework)



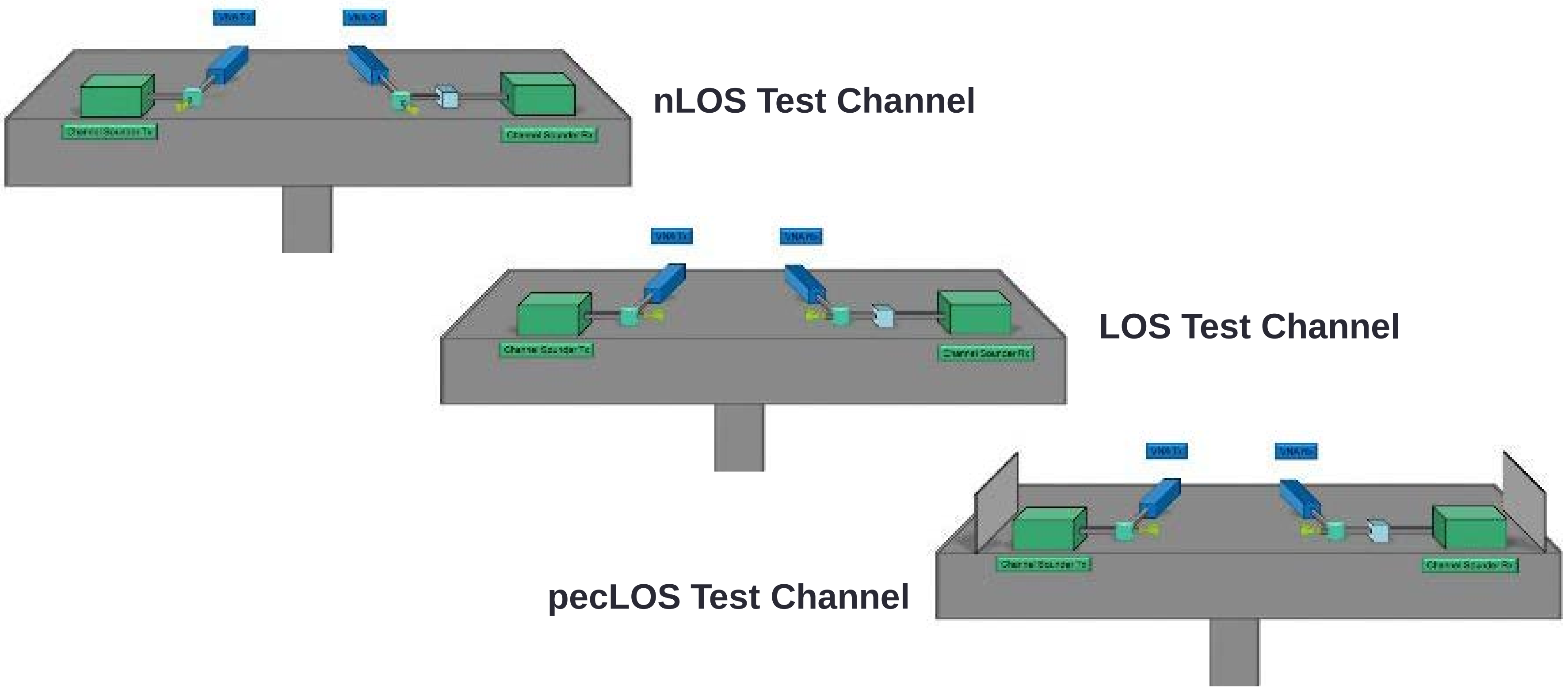
Set-up and Reference Planes

"Channel" includes Antennas, Switches, and Attenuator



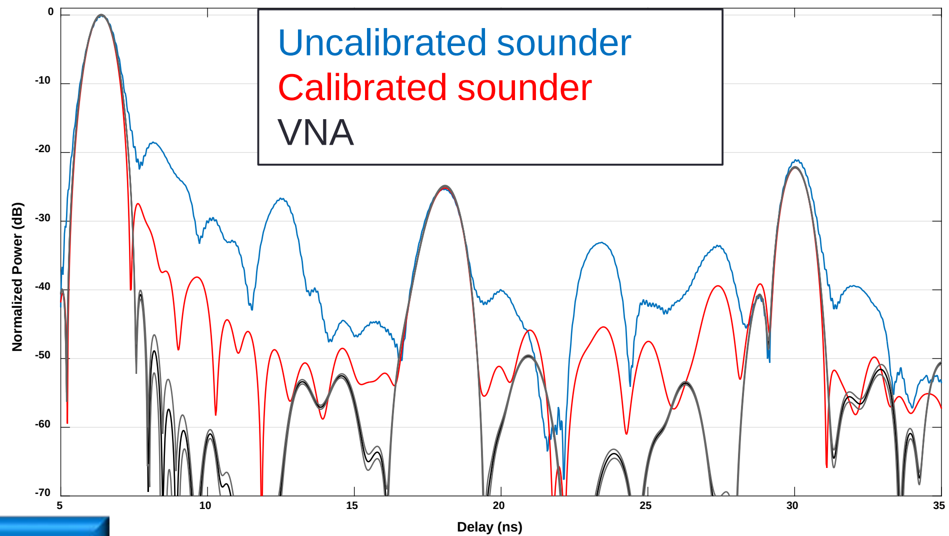
Multiple Test Channels

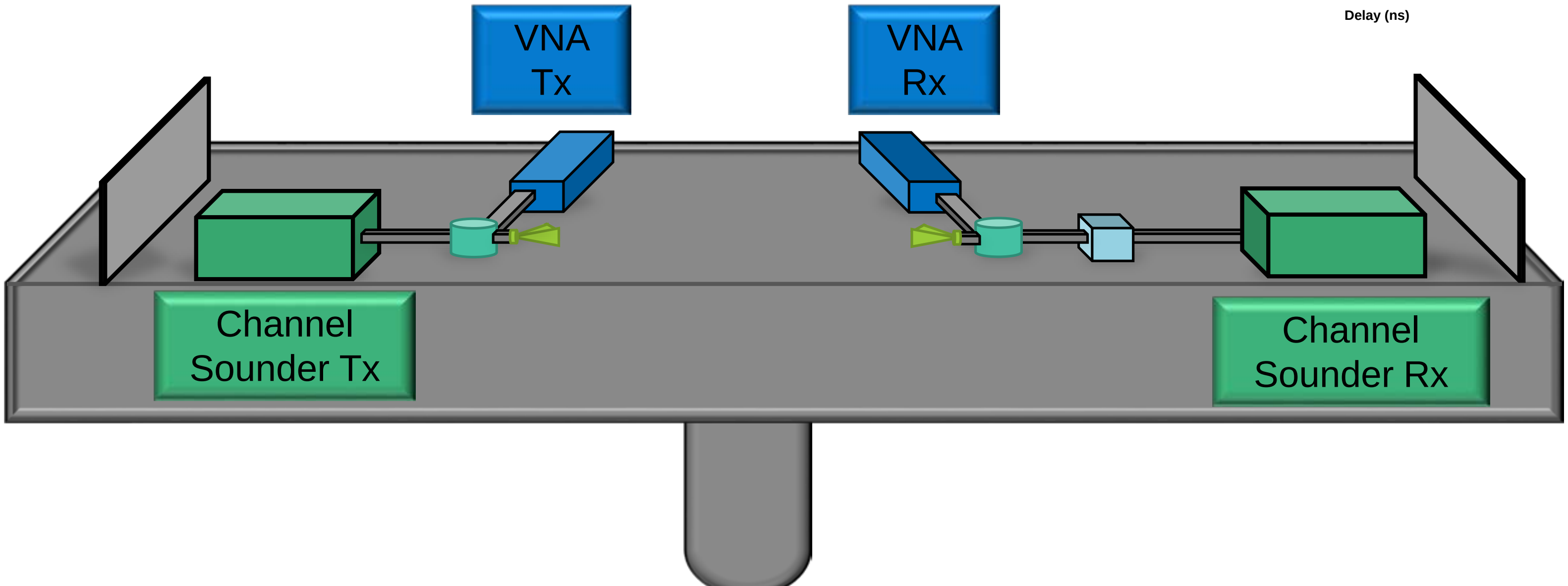
- Channel sounders and VNA measure same channel at (nearly) the same time: Switches maintain antennas+channel
- Dembedding procedures move reference place



Example Comparison Measurement

- Metal plates create known multipath
- PDP computed from both sounder and filtered VNA data
- Note higher noise floor for sounder, need for calibration





Compare Channel Parameters

Channel Sounder		RMS Delay Spread (ns)	Number of Multipath Components
nLOS M_{th} = -20 dB	VNA	9.83 ± 0.52	16
	Calibrated sounder	8.9	19
	Uncalibrated sounder	9.5	18
LOS M_{th} = -20 dB	VNA	0.314 ± 0.001	1
	Calibrated sounder	0.301	1
	Uncalibrated sounder	0.389	3
pecLOS M_{th} = -27 dB	VNA	2.52 ± 0.04	4
	Calibrated sounder	2.78	4
	Uncalibrated sounder	2.96	6

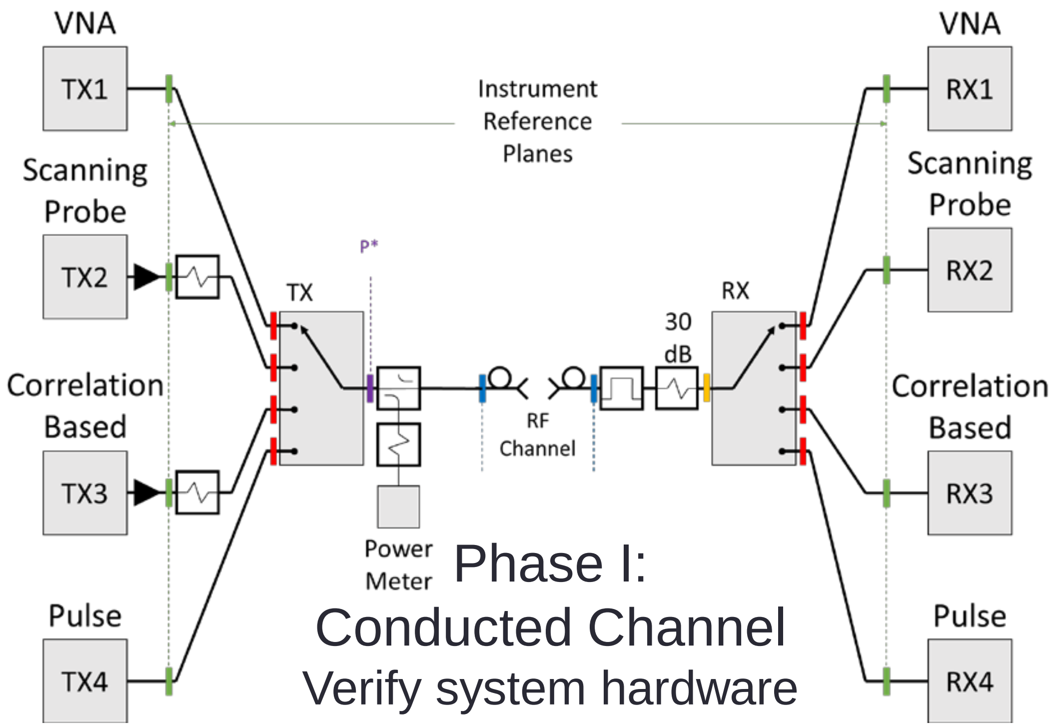
- VNA: Frequency response filtered to match sounder's PN filter
- "M_{th}" threshold applied to PDP

ITS/NIST Channel Sounder Comparison Study

Four channel sounders: switches maintain channel conditions

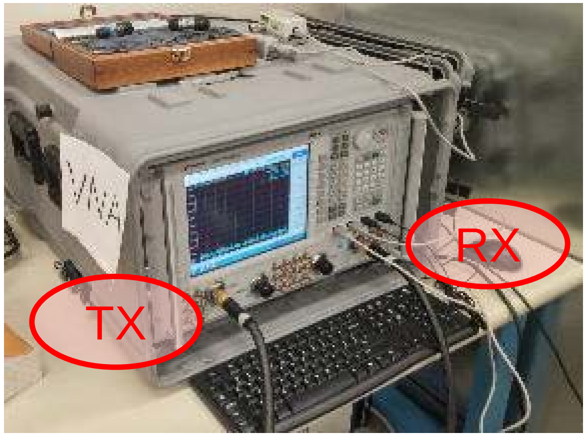
Verify by comparison to VNA:

1. Three two-way comparisons
2. Move VNA reference plane to observe “pristine” sounder output
3. Compare measurements of Simulated-Channel Artifact

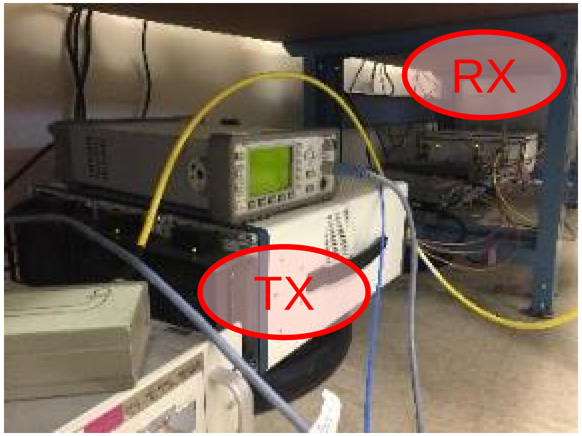


Phase I:
Conducted Channel
Verify system hardware

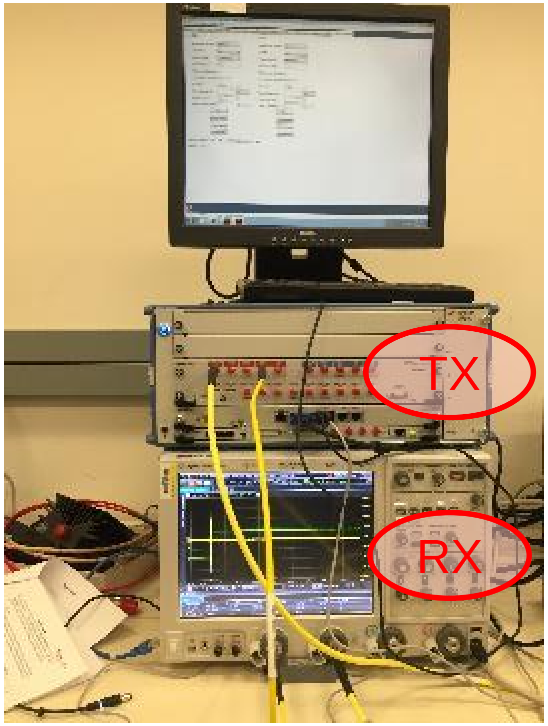
Four Channel Sounders*



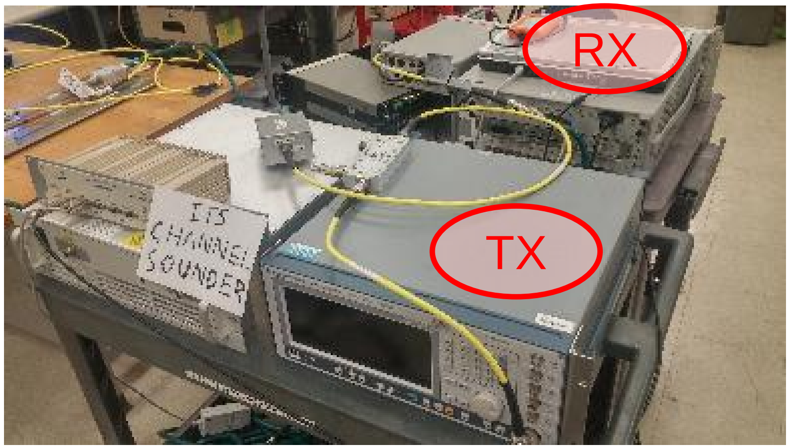
Vector Network Analyzer



Correlation-Based
(AWG + Digitizer)



Direct Pulse
(AWG + Scope)

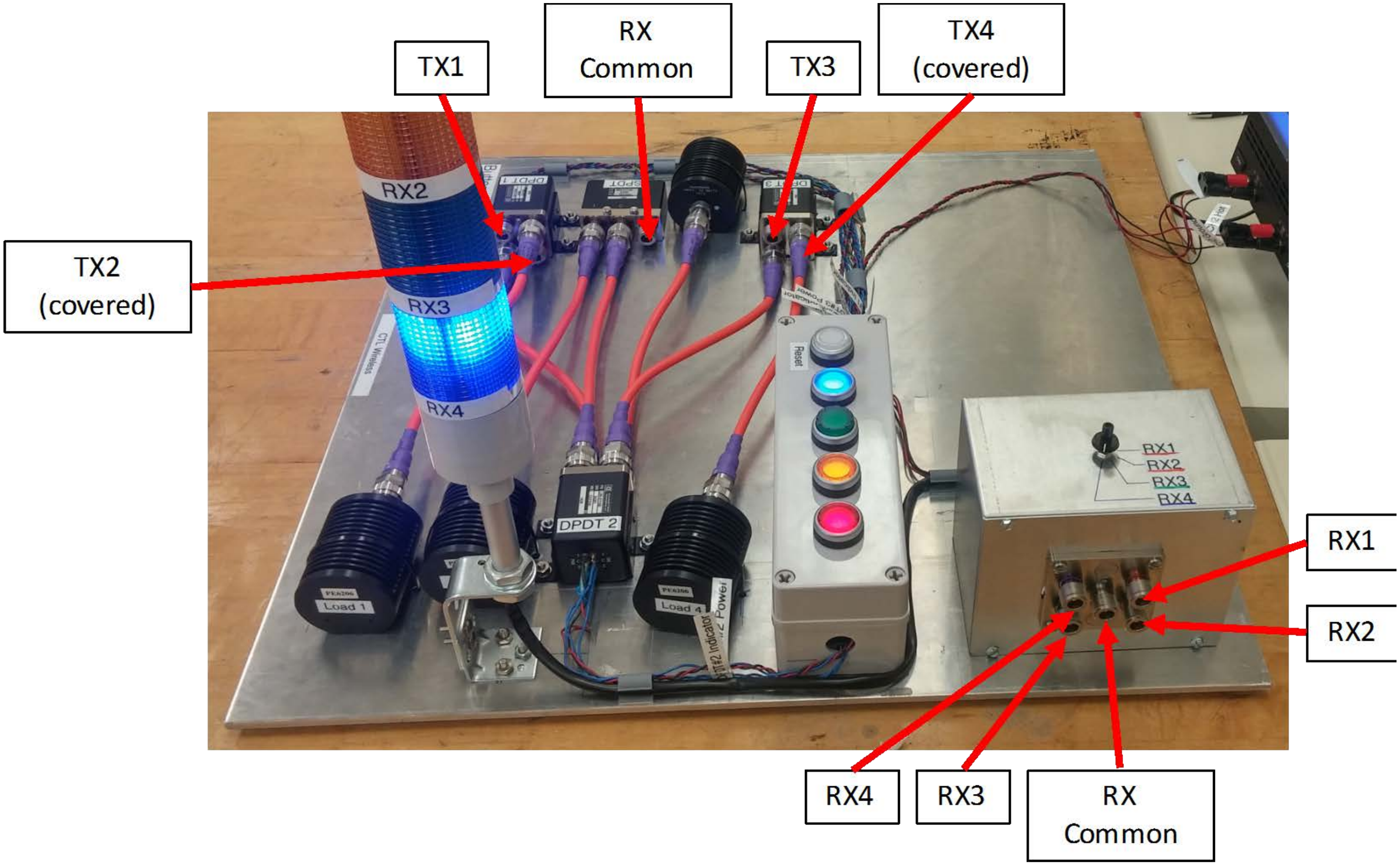


Scanning Probe
System (Signal
Generator + VSA)

*Illustration of products and product names does not imply endorsement by NIST.
Other products may work as well or better.

Switch Matrix Maintains Channel Conditions

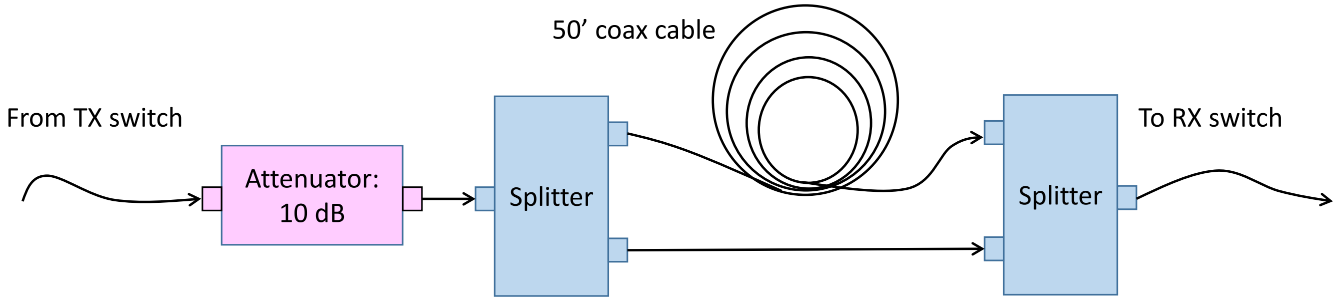
- Eliminate connection repeatability uncertainties
- Sequentially enable testing of all four sounders

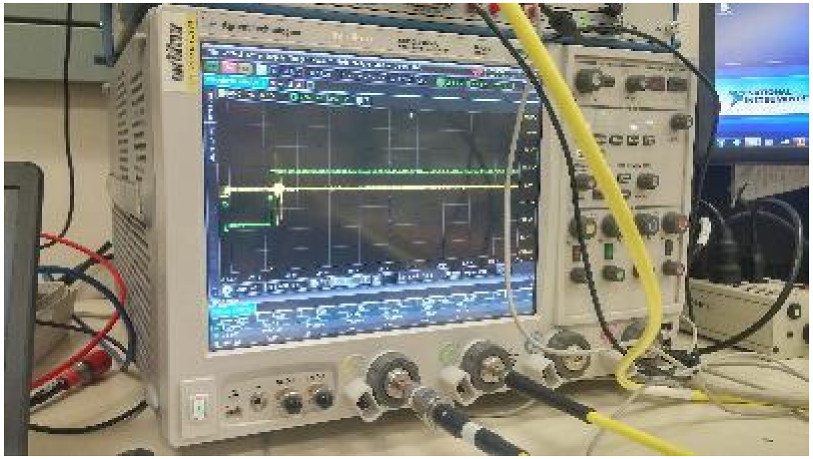


Conducted Tests: Check System Hardware

Simulated Channel tests both Path Loss and RMS Delay Spread

1. Direct path
2. “Reflected” path simulated by long cable

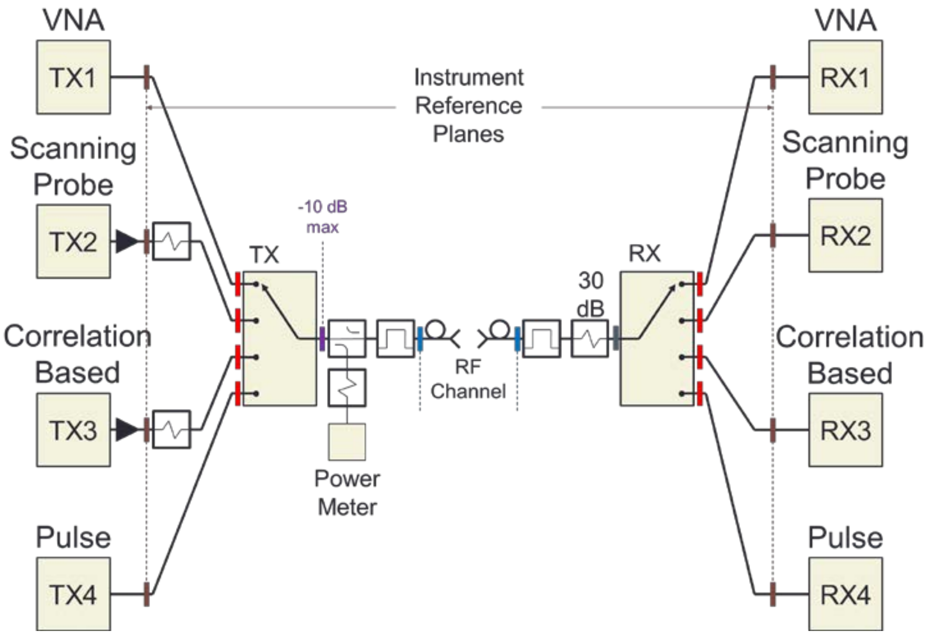




ITS/NIST Channel Sounder Comparison Study

Initial Results:

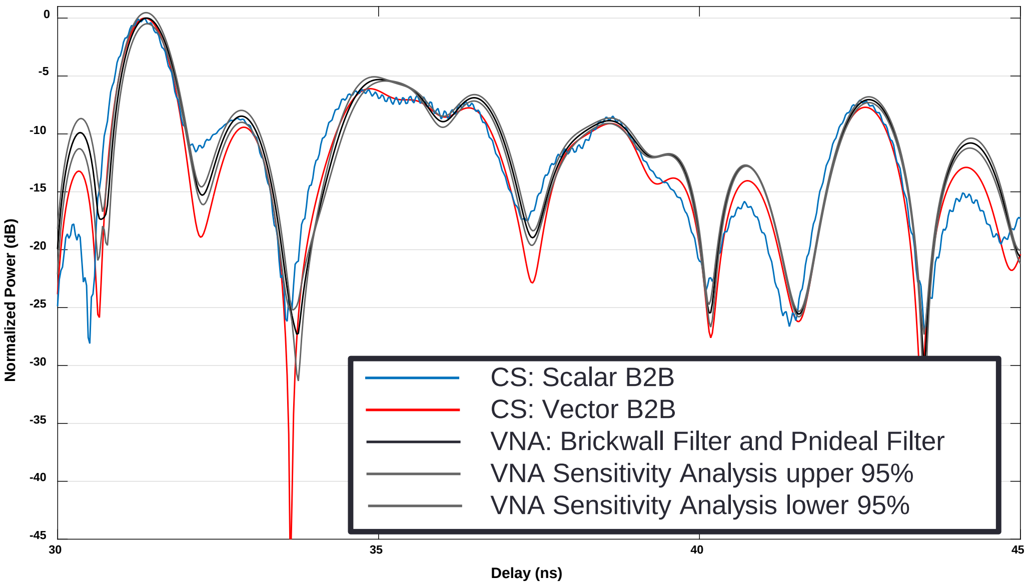
1. Measurement campaign started week of Aug. 2
2. Data analysis in process
3. Anticipated output: best-practice document



Measurement Uncertainties

- Uncertainties rarely included with channel measurements
- Goal is to make accurate, easy to use
- NIST Microwave Uncertainty Framework:
  - Propagate uncertainties through to channel metrics
- Full channel sounder uncertainty analyses in process

- VNA: 2 GHz Brick Wall Filter
- Power normalization to 0 dB
- CS time shifted to VNA peak value time
- Pnideal Filter applied



Conclusion

- Measurement verification can be done in many ways
  - **Theory** (e.g., Friis formula for path loss)
  - **Simulated-Channel Artifact** (conducted)
  - **VNA** (“golden channel sounder”) (conducted or OTA)
- Comparison to reference instrument with uncertainties improves confidence in measurement
- Suggested practice:
  - System hardware verification first
  - Channel measurements second
  - Incorporate measurement uncertainties when available
  - Transfer uncertainties to key wireless metrics