A NIST Testbed Approach to Verifying mmWave Wireless Communication Signals

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Tucson, AZ

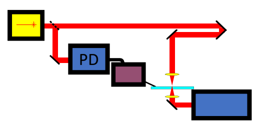
NIST Approach to mmWave Modulated-Signal Measurements

Traceability and uncertainty are hallmarks of NIST's approach to measurement verification

NMI Standards

Electrical Phase

NIST EOS
On-wafer CPW
~1 THz BW
<< 1 ps FDHM

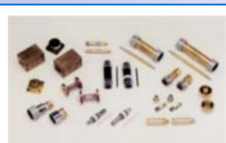


Power

NIST Power
Calorimeter

Impedance

NIST VNA Calibration Standards
Dimensional Metrology



Commercial products shown for illustrative purposes only.
Other products may work as well or better.

Transfer Standards

Photodiode
1.0 mm connector
Calibrated to 110 GHz
100 GHz BW

Power-Calibrated Signal Source
(e.g., swept sine)

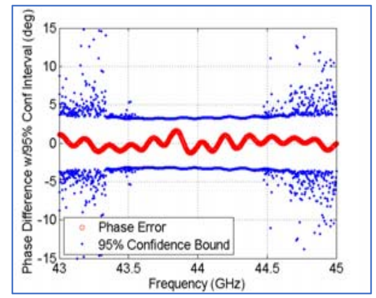
Calibrated VNA

Modulated-Signal "Testbed"

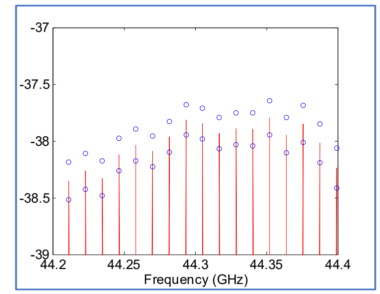
Traceable Oscilloscope
1.0 mm connector
Calibrated to 110 GHz

NIST Calibrated mmWave Modulated Signal Source
Calibrated to 94 GHz

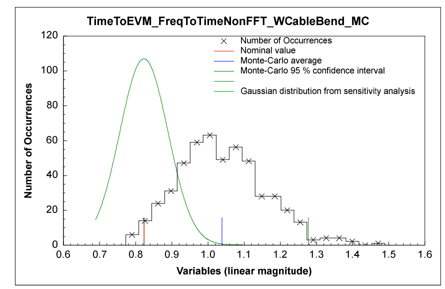
Signal measurements: With uncertainties



Phase Error < 3°



Magnitude Error < 0.3 dB



EVM Error ~ ±0.2%

[1] K.A. Remley, D.F. Williams, P.D Hale, C.M. Wang, J. Jargon, and Y. Park, "Millimeter-Wave Modulated-Signal and Error-Vector-Magnitude Measurement with Uncertainty," *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 5, pp. 1710-1720, May 2015.

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Modulated-Signal Testbed:

- A reference receiver measures (characterizes) a source
- A characterized source provides a known signal
- Users connect their receivers or DUTs to "known" signals to verify performance of their system

Traceable Oscilloscope
1.0 mm connector
Calibrated to 110 GHz

NIST Calibrated mmWave Modulated Signal Source
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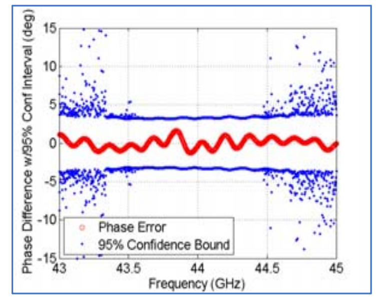
Signal measurements:
With uncertainties



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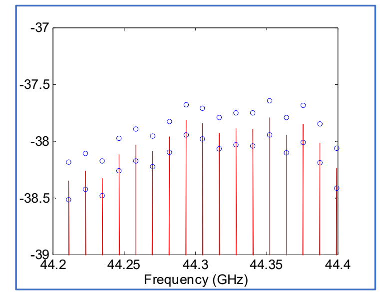

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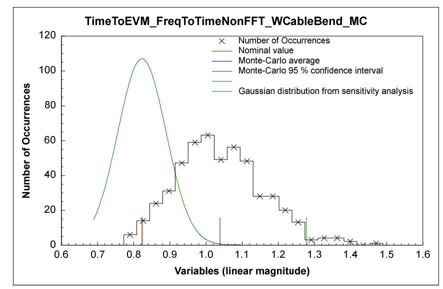

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Testbed Approach – User Step

Step 2: *User characterizes their acquisition instrument with transfer standards*

NMI's Transfer Standards

Electrical Phase

Power — From Step 1

Impedance

Traceable Oscilloscope
1.0 mm connector
Calibrated to 110 GHz

$$EVM_{Meas\ Trace\ Inst} = EVM_{Signal\ Scope} \pm \sigma^2_{Signal\ Scope}$$

NMI Calibrated mmWave Modulated Signal Source
Calibrated to 94 GHz

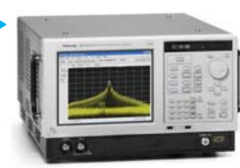
User's Transfer Standards

Electrical Phase

Power — From NMI

Impedance

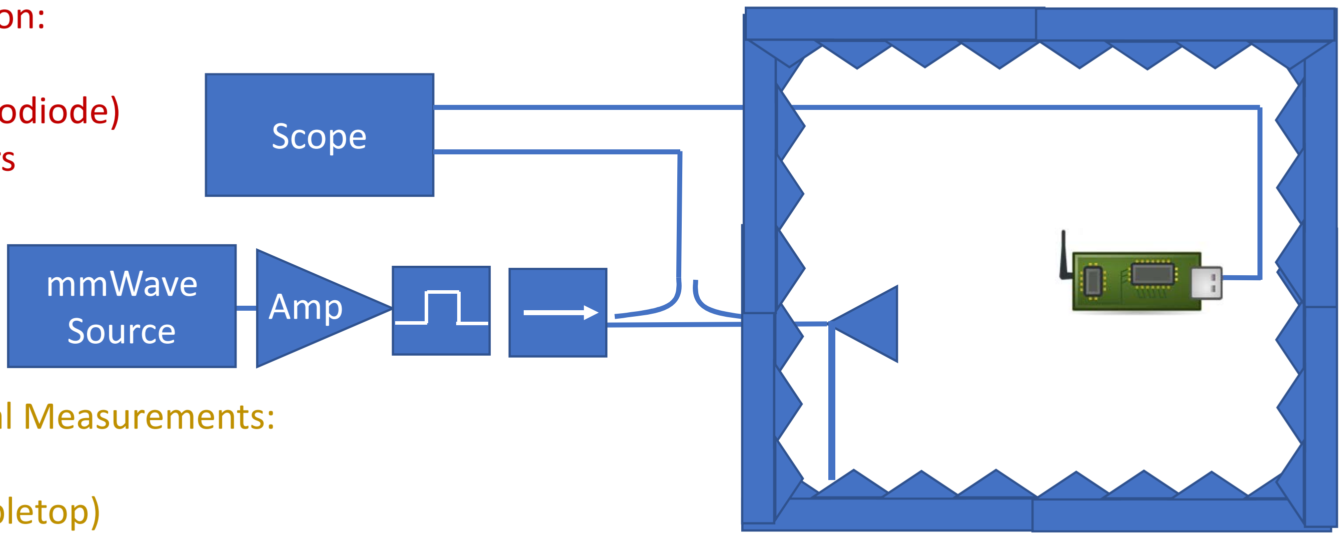
User Instrument
1.85 mm connector
Calibrated to 67 GHz



$$EVM_{Meas\ VSA} = EVM_{Signal\ VSA} \pm \sigma^2_{Signal\ VSA}$$

Simple Environment:
Anechoic Chamber and Spatial Fields

Scope Calibration:
- Power
- Phase (photodiode)
- S parameters
- TBD/TBC



Antenna Characterization:
- Antenna gain
- Antenna pattern
- Beamforming gain
- S parameters

Modulated-Signal Measurements:
- Conducted
- Free-field (tabletop)
- Free-field (anechoic chamber)

Quantities of interest:
- RF signal: mag/phase and EVM (conducted)
- Signal at RX antenna: mag/phase and EVM (field)
- Off-axis EVM (spatial characteristics of field)
- Reference field

WLAN figure:
Google, not licensed

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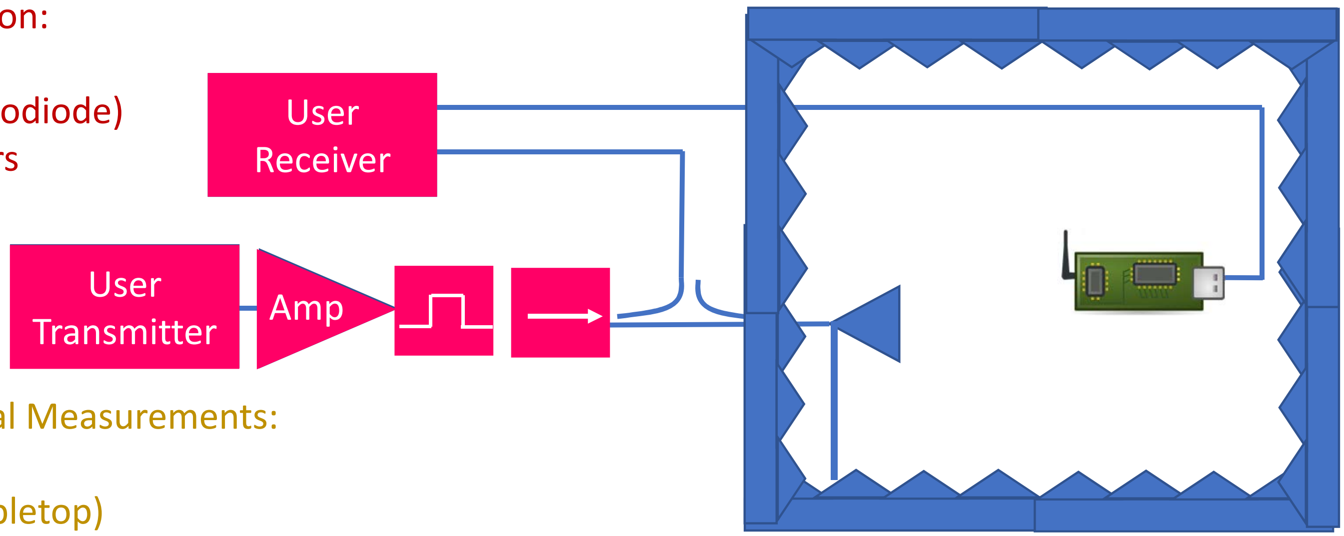

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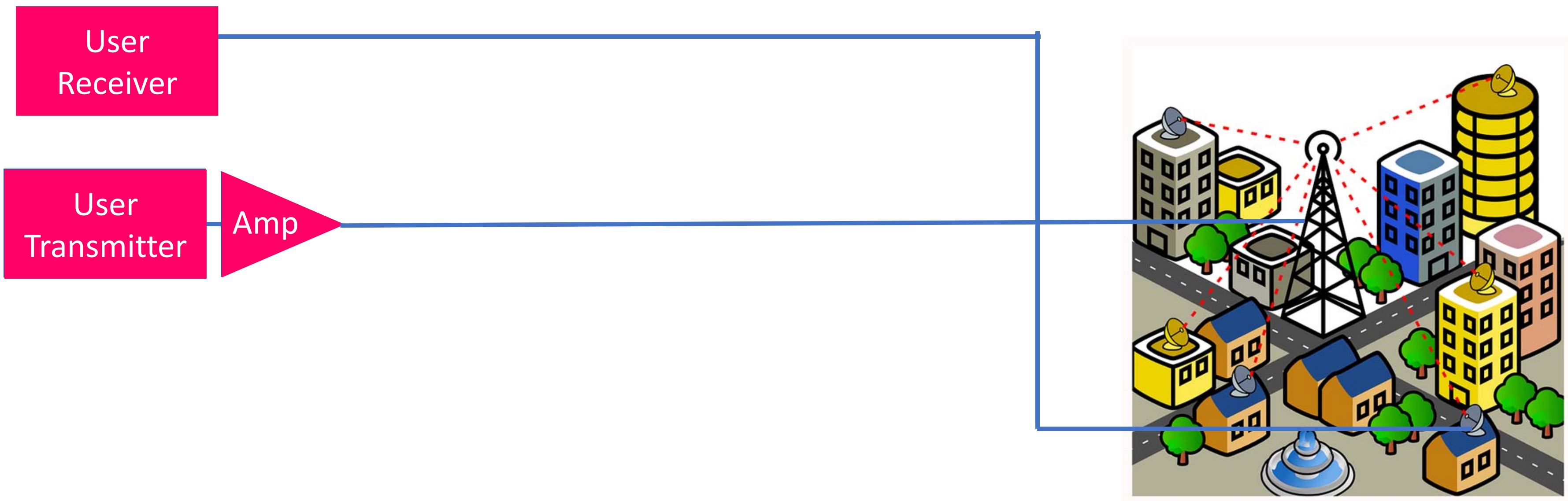
Extension to More Realistic Settings

Reference Modulated Fields

- Known signals emanating from characterized antennas
- Received signals: separate instrument/antenna nonidealities from channel characteristics
- Unconstrained environments (statistical model)

Figure available from Google for download, not licensed

Extension to More Realistic Settings



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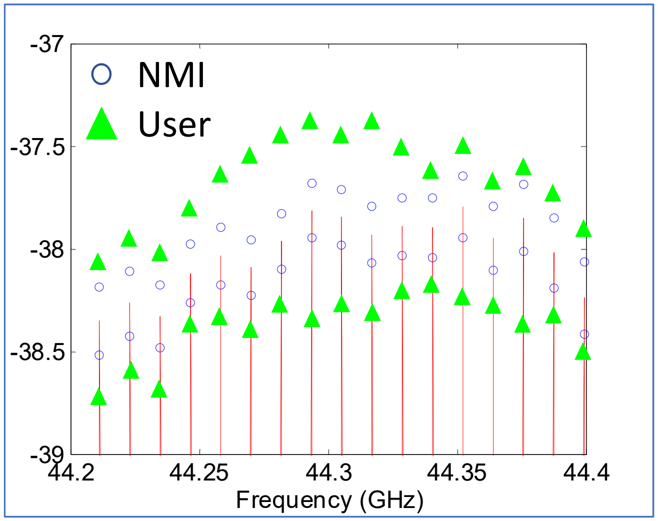
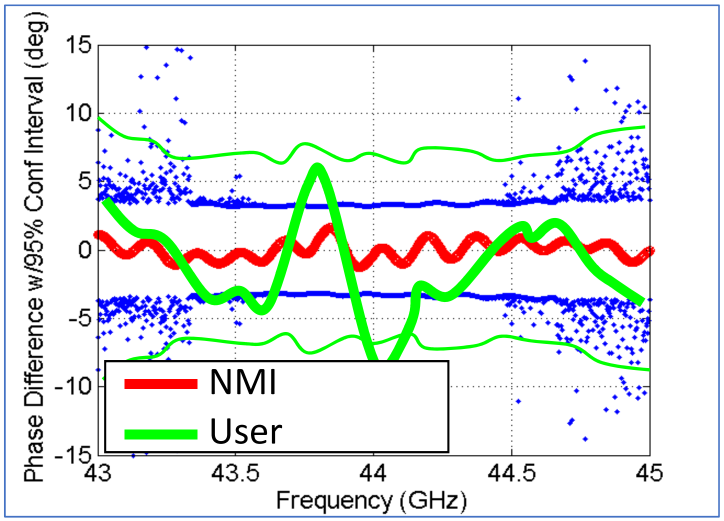
What the Traceable Testbed Approach Accomplishes

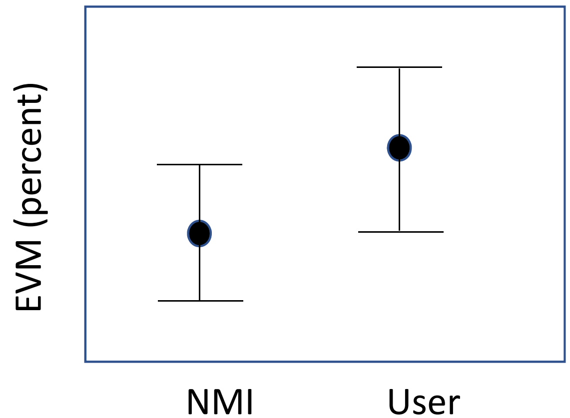
- No need to make assumptions to de-embed user instrument
- Allows comparison of systems over various metrics and conditions:



Magnitude error over 200 MHz



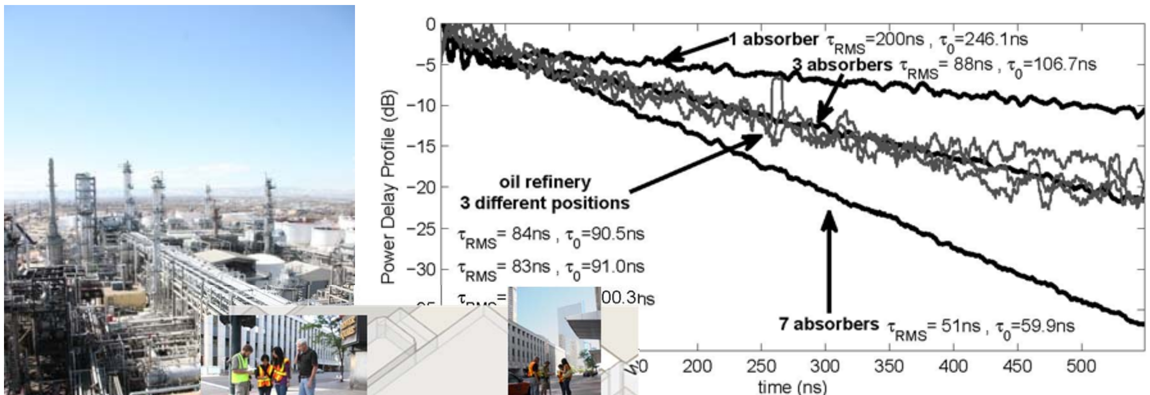
Phase error over 2 GHz
(with 95% confidence bounds)

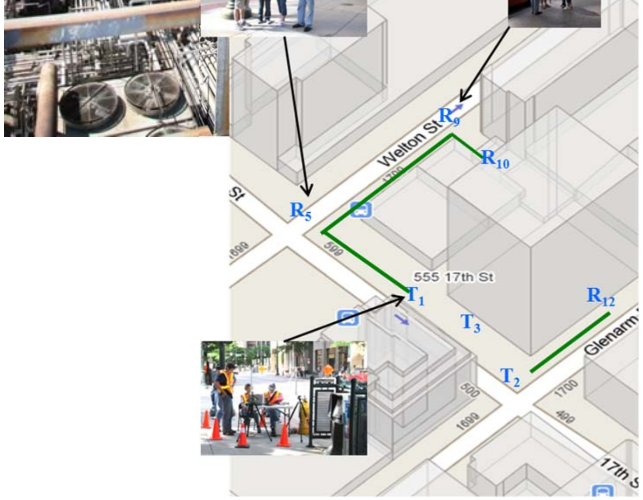


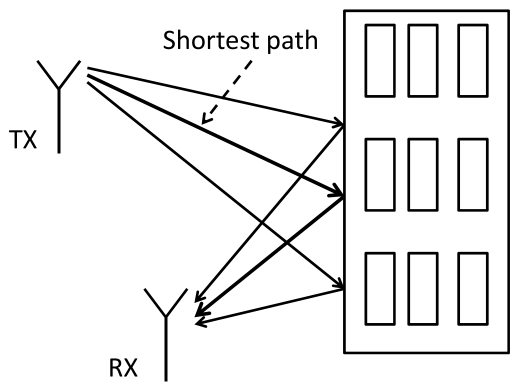
EVM uncertainty over 1.3 GHz

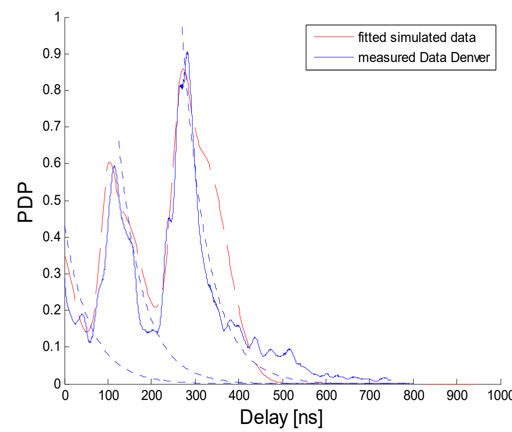
The approach is based on rigorous propagation of uncertainties from fundamental to more complicated, realistic set-ups

Reverberation Chambers for Isotropic or Reflective Environments: Time Response



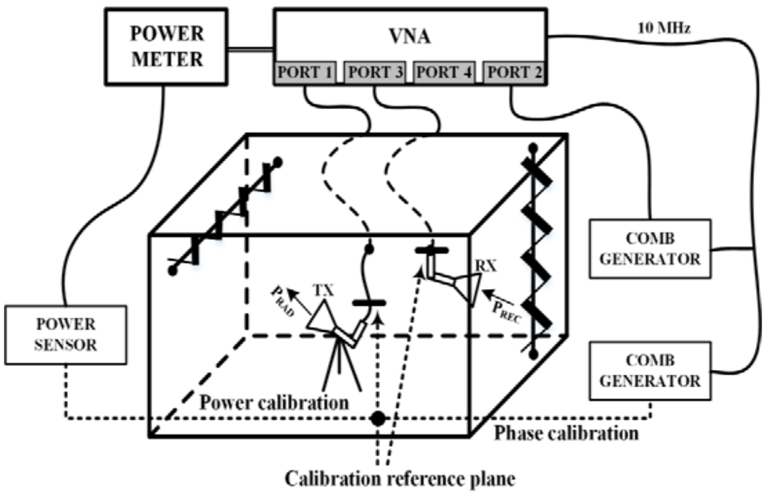






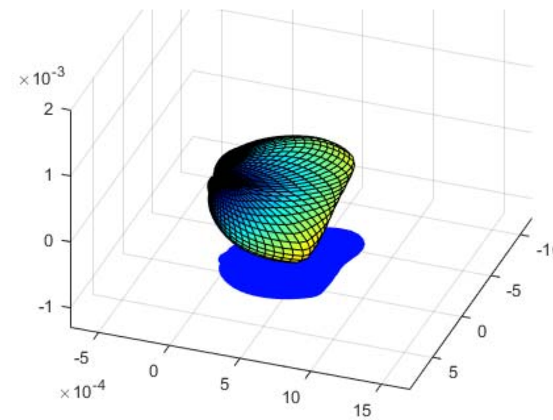
Future Directions: Traceability for Spatial Measurements of mmWave Signals in Reverberation Chambers

Loaded Reverberation Chamber



- Total Radiated Power
- Total Isotropic Sensitivity

Hybrid Chamber



- Angle of Arrival
- Beam-Forming Gain

NVNA Calibration:

- Power
- Phase (comb generator)
- S parameters