A NIST Testbed Approach to Verifying mmWave Wireless Communication Signals

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NIST Approach to mmWave Modulated-Signal Measurements

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

Signal measurements: With uncertainties

Phase Error < 3°  Magnitude Error < 0.3 dB  EVM Error ~ ±0.2%


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

Transfer Standards
- Photodiode
  - 1.0 mm connector Calibrated to 110 GHz 100 GHz BW

Modulated-Signal “Testbed”
- Traceable Oscilloscope
  - 1.0 mm connector Calibrated to 110 GHz
- Calibrated VNA
- NIST Calibrated mmWave Modulated Signal Source Calibrated to 94 GHz

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

Signal measurements: With uncertainties
- EVM Error ~ ±0.2%
- Phase Error < 3°
- Magnitude Error < 0.3 dB


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Step 2: User characterizes their acquisition instrument with transfer standards

NMI’s Transfer Standards
- Electrical Phase: From Step 1
- Power: From NMI
- Impedance

User’s Transfer Standards
- Electrical Phase
- Power: From NMI
- Impedance

EVM<sub>Meas Trace Inst</sub> = EVM<sub>Signal Scope</sub> ± σ<sup>2</sup> Signal Scope

EVM<sub>Meas VSA</sub> = EVM<sub>Signal VSA</sub> ± σ<sup>2</sup> Signal VSA

NMI Calibrated mmWave Modulated Signal Source
Calibrated to 94 GHz

User Instrument
1.85 mm connector
Calibrated to 67 GHz

Traceable Oscilloscope
1.0 mm connector
Calibrated to 110 GHz
Simple Environment: Anechoic Chamber and Spatial Fields

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

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
Simple Environment: Anechoic Chamber and Spatial Fields

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

**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
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
Reference Modulated Fields
• Known signals emanating from characterized antennas
• Received signals: separate instrument/antenna nonidealities from channel characteristics
• Unconstrained environments (statistical model)
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](chart1.png)

Magnitude error over 200 MHz

![Phase error over 2 GHz](chart2.png)

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

![EVM uncertainty over 1.3 GHz](chart3.png)

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