7 Key Measurement Challenges

Signal Quality
mmWave, Waveform, Fidelity

Lots of Channels
MIMO & Beamforming

Channel
Characterizing & Emulating

Life Beyond Connectors
Over-the-Air

Performance on the Network
Network Emulation

Connect Design & Test
Components & Systems

Field & Drive Test

Protocol R&D
RF/RRM DVT
Functional KPI

Design
Simulate
Validate
Connect
Test
Design & Test in the Past

A simple, left to right flow

Measure devices

Simulate performance

Measure the prototype
Design & Test Requirements Are Growing Exponentially

<table>
<thead>
<tr>
<th>5G NR</th>
<th>Wireless Coexistence</th>
<th>EMI/EMC and Regulatory Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>20x more conformance tests than 4G</td>
<td>Wi-Fi, Bluetooth® GPS, FM radio, 4G, 5G, NFC, RFID, Qi</td>
<td>20+ IEC &amp; European (EN) standards</td>
</tr>
</tbody>
</table>
PathWave enables agile and connected workflows

Design  Simulate  Validate  Connect  Test

www.keysight.com/find/pathwave
PathWave Design Tools

COMMUNICATIONS, DEFENSE, AND POWER PRODUCT DESIGN TOOLS

System
- ESL
- DSP, FPGA
- RF architecture

Component
- RF & uW
- High-speed digital
- Power electronics

Physics
- EM
- Thermal
- Device modeling

Integrated design, validation, and test

VSA
# Microwave Subsystem Lineup Analysis

**Version:** 5.0 CM 05-09-94

**Customer:**

**Product:** DKUK219

**Date:** ******

**Temp Range:** 40.0°C to 85.0°C

**Bandwidth:** 12.20 - 12.70 GHz

**Input PWR LE:** -38.00 dBm

## Unit Performance

<table>
<thead>
<tr>
<th>TEMP (°C)</th>
<th>GAIN (dB)</th>
<th>NF (dB)</th>
<th>ICP (dBm)</th>
<th>CNTRL (dB)</th>
<th>DLL (dBm)</th>
<th>Noise (dBc)</th>
<th>G_Rat (dB)</th>
<th>I_zc</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40.0°C</td>
<td>52.00</td>
<td>2.36</td>
<td>20.84</td>
<td>13.68</td>
<td>12.15</td>
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<td>106</td>
<td>493.9</td>
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<td>26.0°C</td>
<td>52.00</td>
<td>3.17</td>
<td>20.21</td>
<td>12.43</td>
<td>11.51</td>
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<td>106</td>
<td>460.0</td>
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<td>85.0°C</td>
<td>52.00</td>
<td>3.98</td>
<td>19.60</td>
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<td>10.92</td>
<td>-30.86</td>
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### Circuit Module Information (25°C)

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<th>Circuit Block</th>
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<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>ICP (dBm)</th>
<th>CNTRL (dB)</th>
<th>DLL (dBm)</th>
<th>Noise (dBc)</th>
<th>G_Rat (dB)</th>
<th>I_zc</th>
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<tbody>
<tr>
<td>0641 LNA</td>
<td>A1</td>
<td>8.00</td>
<td>2.00</td>
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<td>0.01</td>
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<td>0640 Gain block</td>
<td>A2</td>
<td>9.00</td>
<td>3.50</td>
<td>28.00</td>
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<td>0.01</td>
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<td>0.20</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>0640 Gain block</td>
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<td>9.00</td>
<td>3.50</td>
<td>28.00</td>
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<td>0.01</td>
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### Circuit Module Information (5°C)

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<td>27.70</td>
<td>8.00</td>
<td>2.50</td>
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<tr>
<td>0640 Gain block</td>
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<td>3.50</td>
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<td>3.50</td>
<td>28.0</td>
<td>8.40</td>
<td>4.10</td>
</tr>
</tbody>
</table>
RF System Design Tip: Use Better Component Models

Examples of RF Component Models

• When it comes to models…
  • Many can be potentially useful
  • Some are better than others
  • None are perfect

• There are many options for modeling RF components:
  • S-parameters
  • S2D, P2D
  • X-parameters
  • Circuit models (SPICE, transmission lines, etc.)
  • Other behavioral models (Volterra, intermod tables, built-in, etc.)
  • Language-based models (Verilog-A, etc.)
  • Others that I’m leaving out?

• Sys-parameters

Mixer model based on intermod table
5G mmWave Transmitter Design

**RF Architecture Simulation**

Types of models used in system-level simulation:
- Behavioral models (built-in)
- Sys-parameters
- S-parameters
- X-parameters

**IQ modulator IC:**
- Local oscillator isolation to the mixers
- Phase noise performance
- IQ imbalance
- Frequency-dependent behavior

**Amplifiers:**
- Gain, noise figure, OP1dB, OPSAT, OIP3, OIP2

**Filter bank and switches:**
- Cover wide frequency range
- Return (impedance mismatch) loss
- Insertion (dissipative) loss

**Balanced amplifiers:**
- Common at mmWave with 90-degree hybrid couplers
- More immune to load pull effects
Example Design – 5G mmWave Receiver

ARCHITECTURE SIMULATION USING ACCURATE MODELS

RF: 28 GHz, BW: 3 GHz
IF1: 6 GHz, BW: 9 GHz
IF2: 1 GHz, BW: 40 MHz

X-microwave
X-parameters
S-parameters

Keysight
Sys-parameters

Behavioral
5G Receiver Prototype

Built using COTS parts and X Microwave prototyping plate

Off-the-shelf parts:
- Analog Devices, Inc.
- Avago Technologies
- Marki Microwave, Inc.
- Mini-Circuits
- Qorvo, Inc.

- RF: 28 GHz, BW: 3 GHz
- IF1: 6 GHz, BW: 9 GHz
- IF2: 1 GHz, BW: 40 MHz
- L01: 22 GHz
- L02: 7 GHz

Shielded high frequency parts
EVM Results for the 5G Receiver Prototype

MEASURED VS SIMULATED WITH 16QAM AT INPUT POWER -50 DBM
Phased-Array Modeling

INCREASING THE ACCURACY OF SYSTEM-LEVEL PHASED ARRAY

Use mix of built-in behavioral blocks, S-, X-, and Sys-parameters

28.5 GHz

RF splitter
Amplitude taper
Phase shifters
X-parameter-based power amplifiers

Extracted data from electromagnetic simulation
1. Element/array far-field pattern
2. S-parameters include coupling effects (can actively analyze changing input impedances)
Addressing 5G Physical-Layer Design Challenges

Model-based design for:

- Exploring technologies and architectures
- Analyzing system performance for various use cases
- Uncovering potential issues early on

- Power consumption
- RFI spurious harmonics
- Intermodulation from dual connectivity
- Thermal issues
- Blocking
- Receiver desensitization
- RFI spurious harmonics
- Power consumption
- Intermodulation from dual connectivity
- Thermal issues
- Blocking
Modeling a Real-World 5G Scenario

3GPP TS 38.901
- Polarization type: dual
- Polarization modeling method: Model-2
- Polarization angle [0,90]
- XPRIndB: cross-polarization ratio

Antenna pattern files
- Complex vector components: Mag (\(E_{\theta}, E_{\phi}\)), Ang (\(E_{\theta}, E_{\phi}\))
- PhaseCenter_Yes: antenna position information from pattern files
- PhaseCenter_No: antenna position information from user definition

Scenario #1
- Number of stream (PDSCH_DMRS): 2
- # of mmWave module: 1

Scenario #2
- Number of stream (PDSCH_DMRS): 1
- Diversity combining: maximal ratio combining
- # of mmWave module: 1

Scenario #3
- Number of stream (PDSCH_DMRS): 2
- Diversity combining: Switching (selective)
- # of mmWave module: 2
Multi-Radio Coexistence

- Non-standalone (NSA) mode: LTE and NR radio co-exist
- Simultaneous LTE + NR transmission = serious IMD issues
- Hundreds of 5G band configurations can be analyzed to determine IMD and NF
- Then, NF data for the receiver can be used for link-level simulation

IMD product affects receiver sensitivity
Over-The-Air (OTA) Simulation

- Why radiative test (OTA)?
  - In FR2, not enough space to make cable connections to all antenna elements
  - K and V connectors are expensive
  - How do you measure beam direction in conducted test? It's not the right approach! Need OTA!
- Are you going to do all this without a simulation-based study?

- 3GPP TS 38.141 - NR; base station (BS) conformance testing
- 3GPP TS 38.521 - NR; user equipment (UE) conformance specification

Combining Simulation & Test

CREATE & COMBINE WAVEFORMS & NOISE, VIRTUALIZE MISSING HARDWARE

WAVEFORMS

Custom OFDM, 5G, LTE, MIMO, EW, defense

Throughput-coded BER DPD

Noise, multipath, interferers, clutter, targets

Missing hardware Missing test coverage

VIRTUAL SYSTEMS