3GPP 5G NR System Design & Verification Solution

Application Engineer/ Keysight Technologies

WU Jiarui
5G Devices Design Challenge

- Architecture design
- Components, RF sub-system, Modules design
- NR (new radio) MODEM design
- Board design, SI/PI issue
- mmWave RF Transceiver design
- mmWave RF Beamforming IC design
- Phased array antenna system design

[Block diagram of 5G use equipment wireless system split-IF architecture]

## Keysight EEsof EDA Product Overview

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
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<tbody>
<tr>
<td>SystemVue</td>
<td>- ESL</td>
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<tr>
<td>ADS</td>
<td>- MMIC, RF Board, SiP, HSD</td>
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<tr>
<td>EMPro</td>
<td>- 3D EM</td>
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<tr>
<td>Genesys</td>
<td>- RF Board</td>
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<tr>
<td>GoldenGate</td>
<td>- RF Mixed Signal</td>
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<tr>
<td>IC-CAP</td>
<td>- Device Modeling GaAs, GaN, Custom Models Measurement</td>
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<tr>
<td>MBP</td>
<td>- Device Modeling Silicon</td>
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<tr>
<td>MQA</td>
<td>- Model Quality Assurance</td>
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<tr>
<td>A-LFNA</td>
<td>- Advanced Low-Frequency Noise Analyzer</td>
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<tr>
<td>WaferPro Express</td>
<td>- Wafer-level measurement and programming</td>
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<tr>
<td>HeatWave</td>
<td>- IC electro-thermal analysis</td>
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</table>
What You Can Do for 5G?

Using SystemVue, ADS, GoldenGate & EMPro

1. Standard Waveform Creation and Analysis
2. Link Level Performance
3. Architecting RF Transceivers
4. Over-The-Air(OTA) Simulation
5. Phased Array and Beamforming
6. Difficult System Engineering
7. Advanced End-To-End Link Performance
8. Multi-Radio Co-Existence
1. Standard Waveform Creation and Analysis

Support Standards

- 3GPP TS 38.211 - Physical Channels and Modulation
- 3GPP TS 38.212 - Multiplexing and Channel Coding
- 3GPP TR 38.901 - Study on channel model for frequencies from 0.5 to 100 GHz
2. Link Level Performance

A Glance of Future Diversity Case Including Beams
3. Architecting RF Transceivers

FR1 Dual Connectivity UE Architectures

Note) for basic DC UE RF architectures information, refer to 3GPP TR 37.863-01-01

Technical Issues:

- Complex 4G, 5G Transceivers and Multi-band RFFE(RF Front End) Design
- Dual Connectivity Simultaneous UL Produces IMD onto Active Receiver (Rx)
- Noise measurements in Rx band to estimate the impact of Tx excess noise
3. Architecting RF Transceivers

**mmWave Design Flow**

System level modeling using circuit level MMIC design data

- **Front End Schematic**
  - Load Pull – power and PAE
  - PA – Initial design with linear and non-linear simulation
  - Optimization Cockpit
  - Robust Statistical Design
  - X-Parameters

- **Back End Layout**
  - Layout & 3D view Momentum
  - DRC
  - LVS
  - Reticle Generation
  - Package and Bond wire effects / 3D EM simulation

Design software: Keysight SystemVue

complete MMIC design flow, Keysight ADS

image: Keysight, 28GHz transceiver module

3GPP 5G NR System Design & Verification Solution
Verification Method 1: Verification Test Bench

**In ADS / GoldenGate**

**Analog PA**

**VTB**

**SIMULATE LOCALLY INSIDE ADS**
Verification Method 2: Fast-Circuit-Envelope Model

SystemVue

Source

System Level Simulation

Black Box Behavioral Model

ADS/GoldenGate(on Virtuoso)

Circuit Design

Incorporating Memory Effect

CCDF

Spectrum

Time Domain signal

VSA

Including

EVM
Early R&D Hardware Testing - RF DUT

1. Download Signal
2. Capture Signal

Simulated Receiver
- Demodulator
- A/D Converter
- Baseband De-Coding

RF/IF AUD

SystemVue + VSA SW

MXG, ESG

MXA, PSA

Simulated RF Waveform

RF/RF BER

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4. Over-The-Air(OTA) Simulation

A Differentiator in Keysight OTA Solution

• OTA Tx & Rx
• Rotate array (with element patterns)
• Move probes (XYZ location & rotate probe pattern)
• Radiated near field and far field
• Dual-polarization & polarization mismatch
• Phase shift (narrowband) / time delay (wideband)
5G NR DL OTA Measurement Simulation
5. Phased Array and Beamforming

Antennas + Beamforming + Frequency Conversion

# of Antennas and PAs determines maximum EIRP

<table>
<thead>
<tr>
<th>Antenna element gain</th>
<th>Power summation gain</th>
<th>Beamforming gain</th>
</tr>
</thead>
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5G mmWave UE Conceptual Block

- Rx: T/R sw, VGA, PS, Combining, down-conversion
- Tx: T/R sw, PA, VGA, PS, Splitting, up-conversion

mmWave RFFE Functionality

- Rx: T/R sw, VGA, PS, Combining, down-conversion
- Tx: T/R sw, PA, VGA, PS, Splitting, up-conversion

- Parameter
  - Freq: 4.4 GHz
  - Pwr: 7 dBm
  - LO Freq: 23.5 GHz
  - PH: -30°
- Antenna
  - NumBits: 6
  - Quantization: Number of Bits (Uniform)
  - SideLobeLevel: -20 dB
  - Window: Taylor
  - NumAnts: 1
  - CalcMode: Auto
- Array
  - BeamPhi: 0°
  - BeamTheta: 0°
Characterization of mmWave Components

Array Antenna

Mutual Coupling

- Ideal coupling matrix: non-physical coupling based on the distance between the elements
- S-parameters: generated from electromagnetic simulation, real measurement. This is a physical basis and much more accurate
- Active impedance: various depends on array configuration, spacing between elements, and phase shift applied at each element
- Antenna element patterns
Characterization of mmWave Components
Phase Shifter / Digital Attenuator

Phase shifter 22.5° unit: circuit level design using TriQuint pHEMT process

[ component level characterization to system level beam quality analysis ]
# Simulation vs Measurement Results

## 8x8 28GHz URA rf Beamformer RF-IF converter

<table>
<thead>
<tr>
<th>Beam Direction</th>
<th>3dB Beamwidth (deg)</th>
<th>First Null Left (deg)</th>
<th>First Null Right (deg)</th>
<th>First Sidelobe Left (dB)</th>
<th>First Sidelobe Right (dB)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Sim</td>
<td>Meas</td>
<td>Sim</td>
<td>Meas</td>
<td>Sim</td>
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<tr>
<td>0 degree</td>
<td></td>
<td></td>
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<tr>
<td>30 degree</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>14.5</td>
<td>14.0</td>
<td>14</td>
<td>13</td>
<td>50</td>
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<tr>
<td>-30 degree</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>14.5</td>
<td>14.5</td>
<td>-50</td>
<td>-50</td>
<td>-14</td>
</tr>
</tbody>
</table>
Phased Array Antenna Design -- EMPro
EMPro – 3D EM Simulation (FDTD)

8*8 (0.8 lambda spacing)
4 K80 GPU
4min, 40s

16*16
4 K80 GPU
27min, 46s
Planar Antenna: ADS Momentum 8x8 patch array

Direct EM solution, with weighted signal excitation in post-processor
Transmitter

single pass sub-network
EM Co-Sim: 1x4 Transmitter Array in ADS/Momentum

System / Circuit / EM Co-simulation and beam steering

Phase shifters for Beamsteering

Manual gain taper for sidelobes
6. Difficult System Level Engineering

SIMULATION-BASED DPD
(predictive)

MEASUREMENT-BASED DPD

Digital Pre-Distortion

PA Model Extraction (Memory and Non-linear effect)

External Trigger

Attenuator

N5182 MXG or E8257D PSG as external modulator

M9330A AWG if > 100 MHz

I, Q

RF DUT

M9392A PXI VSA (>140MHz)

or N9030A PXA (<140 MHz)

RF DUT

N5182 MXG or E8257D PSG as external modulator

Simulate

Model

External Trigger

Digital Pre-Distortion

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7. Advanced End-To-End Link Performance

Dual Polarized MIMO and Beamforming

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

Antenna pattern files
- Complex vector components: Mag(Etheta, Ephi), Ang(Etheta, Ephi)
- PhaseCenter_Yes: antenna position information from pattern files
- PhaseCenter_No: antenna position information from user definition

3GPP mmW wireless channel model

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
8. Multi-Radio Co-Existence

**FR1 Transceiver Modeling in Frequency Domain**

- **b3 DL source**
  - @Victim Frequency
  - Receive power @-95dBm

- Transmit IMD signals jump into the receiver

- **Simultaneous UL Tx:**
  - b3 UL @ 1740 MHz
  - n78 UL @ 3575MHz

- **IF Frequency**
  - @210 MHz

- **Non-linear PA creates IMDs**

- **Band b3 and n78 transmitters**

- **Band b3 receiver primary path @ 1835MHz**
Transmitter Intermodulations

**Downlink Band**
- 1805MHz ~ 1880MHz

**Uplink Band**
- 1710MHz ~ 1785MHz

IMD’s landing on b3 receive frequency 1835MHz

n78 Uplink Signal
- 3575MHz

IMD product @ 3480 MHz, self-interference for the TDD band?

b3 Uplink Signal
- 1740 MHz

n78 TDD Band
- 3300MHz ~ 3800Mhz

b3 Uplink Band
- 1710MHz ~ 1785MHz

b3 Downlink Band
- 1805MHz ~ 1880MHz

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Customer Example

5G NR UE FR2 Radiated Receiver Characteristics

* Channel configuration information:

FRCTable = 22, Frequency = 28000 MHz, Numerology = 3, Subcarrier Space = 120 kHz, Bandwidth = 50 MHz, MCS = 4, PDSCH_NumRBs = 32

* Throughput performance analysis model:

throughput fraction = 80.85 %

* 5G NR Downlink System Model:

5G NR Waveform

3GPP TS 38.521, Annex A DL Reference Measurement Channel

Design Revision: V1.0, 2/4/2019

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Summary

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  • Multi-Radio Co-Existence

World’s first compliant 5G NR Verification Library with OTA