3GPP 5G NR System Design & Verification Solution

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Application Engineer/ Keysight Technologies

KEYSIGHT TECHNOLOGIES

Agenda

- Design Challenges for 5G Physical Layer Design Overview
- System Architecture Design
- Baseband RF Antenna Design
- Baseband RF Antenna Simulation Verification
- Early Emulation system for hardware test

5G Physical Layer Design Challenges

Baseband Design Challenges

- Standard compliance test
- Massive MIMO algorithm verification

RF Design Challenges

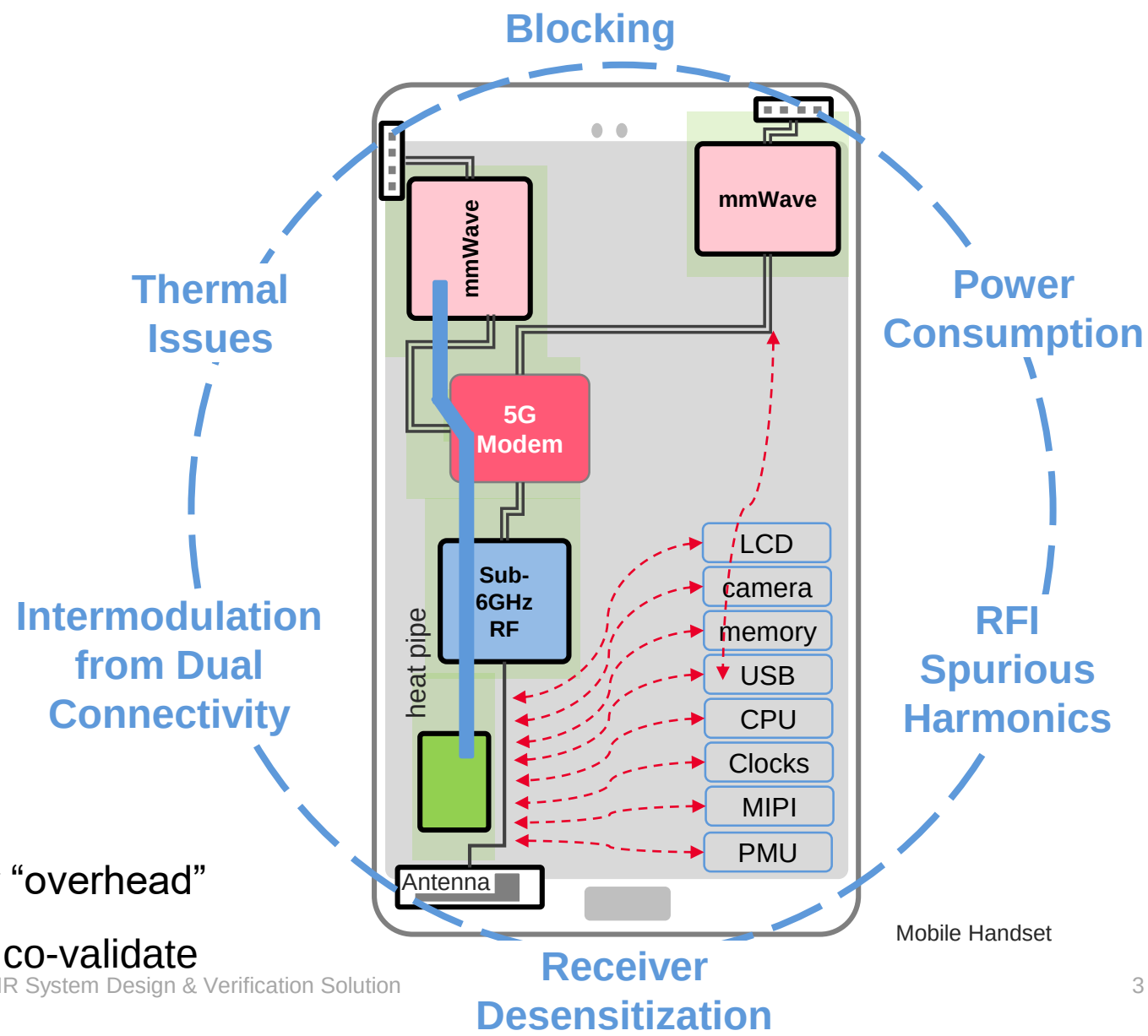
- Transceiver Design:
- Millimeter wave bands
  - Beamforming
  - Coupling Effect(multiple channel,RF/Antenna)
  - impedance mismatch

Antenna Design Challenges

- mm wave array antenna design
- OTA performance verification

System Integration Challenges

- Disjointed tool set
- One-directional, not predictive
- Low budget for “overhead”
- Difficult to co-validate



Accelerate 5G Design with ADS SystemVue Empro

5G Library

Reference transmitter

1011010010
10010110…

System architecture study

Baseband Verification library as golden reference

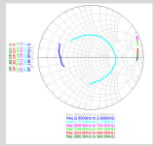
Spectrasys analysis for RF architecture design

Phase Array for antenna array

Baseband RF Antenna Design

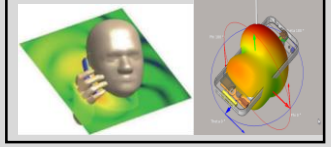
HDL

SystemVue



RF Circuit Design
RF Matching
RF+Em cosim

ADS



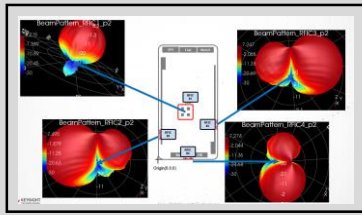
Empro

Baseband RF Antenna validation

Advanced Design System

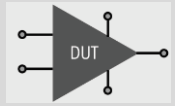
GoldenGate

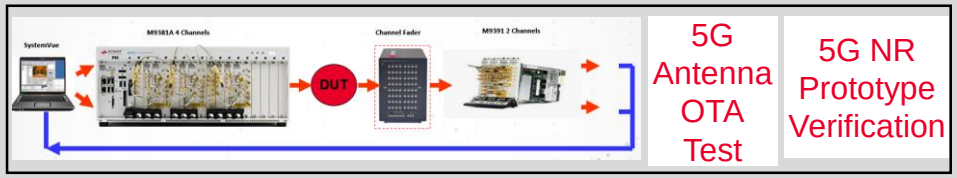
SystemVue



Conformance test template
5G Fading Channel Model
SystemVue ADS Cosim
ADS VTB
OTA for antenna verification

DUT validation with test equipment





5G Antenna OTA Test

5G NR Prototype Verification

5G Library

Reference receiver

1011010010
10010110…

BER
EVM

What You Can Do for 5G?

USING SYSTEMVUE, ADS, GOLDENGATE & EMPRO

1. Standard Waveform Creation and Analysis
2. Architecting RF Transceivers
3. Phased Array and Beamforming
4. Link Level Performance
5. 5G OFDM Based Real time FPGA Prototype for Massive MIMO Verification
6. High Band RF Matching
7. MM wave Transmitter Design
8. Phased Array Antenna Design
9. Advanced End-To-End Link/OTA Performance validation
10. Early RD Hardware Verification

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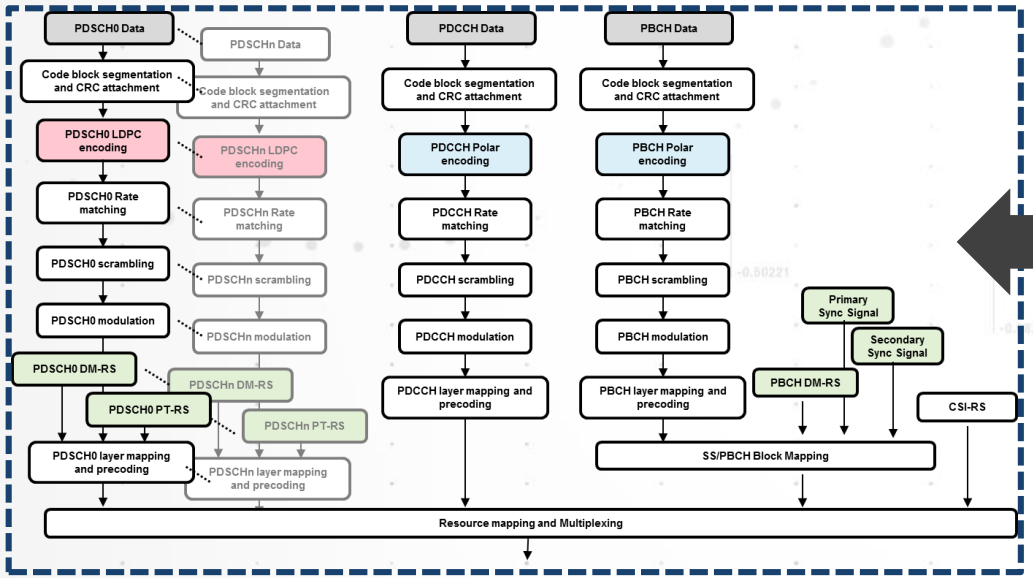
1. Standard Waveform Creation and Analysis

Baseband: Trusted Algorithm Reference IP

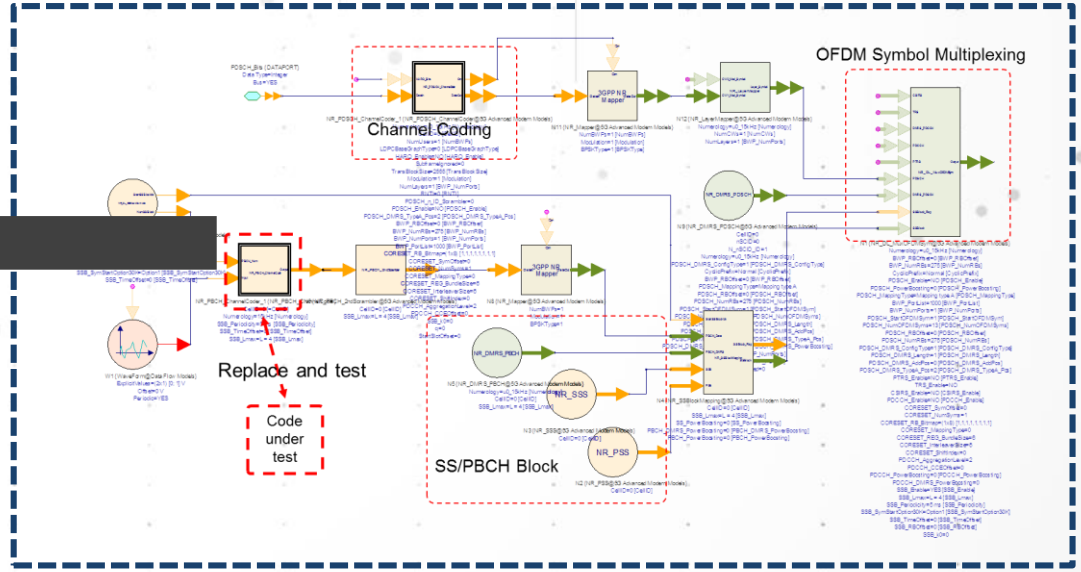
SystemVue

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



[NR Baseband Digital Signal Processing]

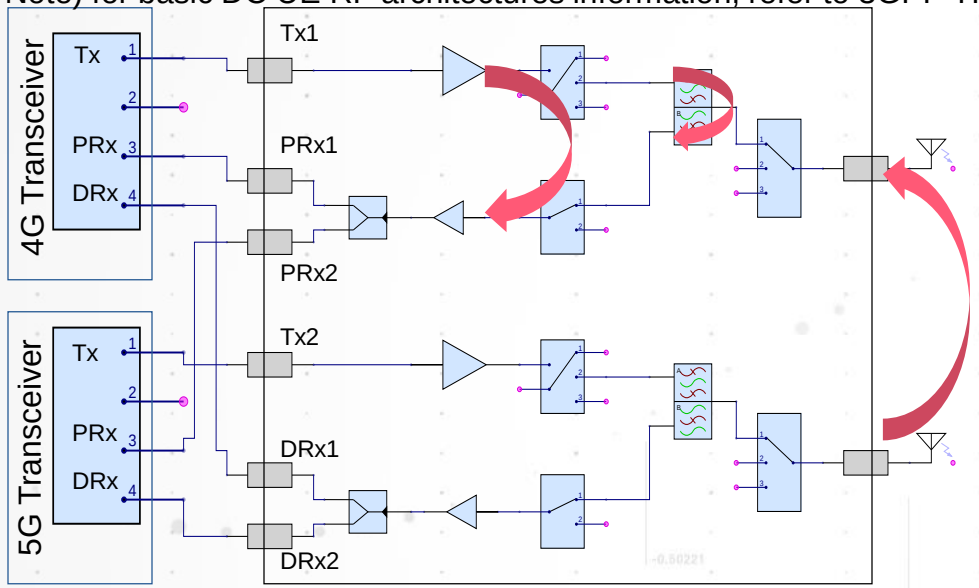


[Model Based Design for NR Baseband DSP]

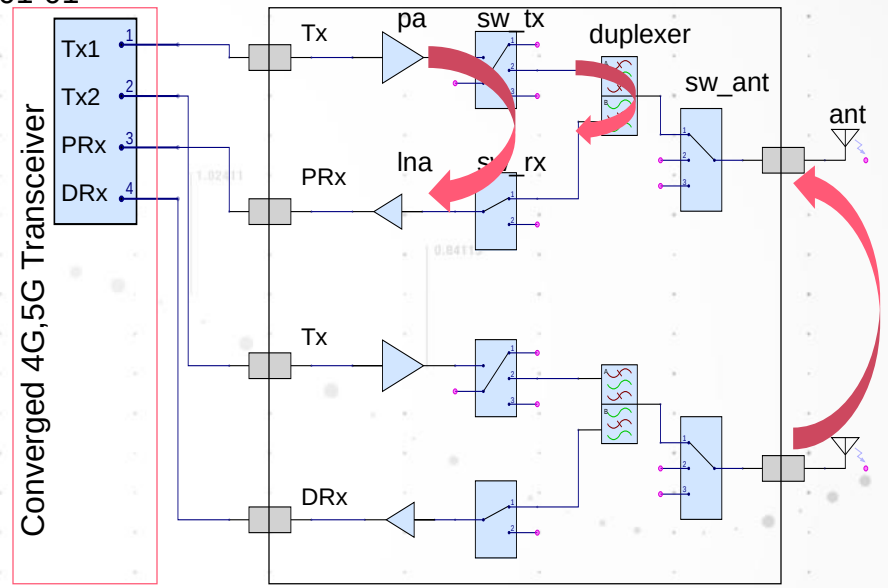
2. Architecting RF Transceivers

FR1 Dual Connectivity UE Architectures

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



[Separate 4G, 5G Transceivers, Dedicated UL PA]



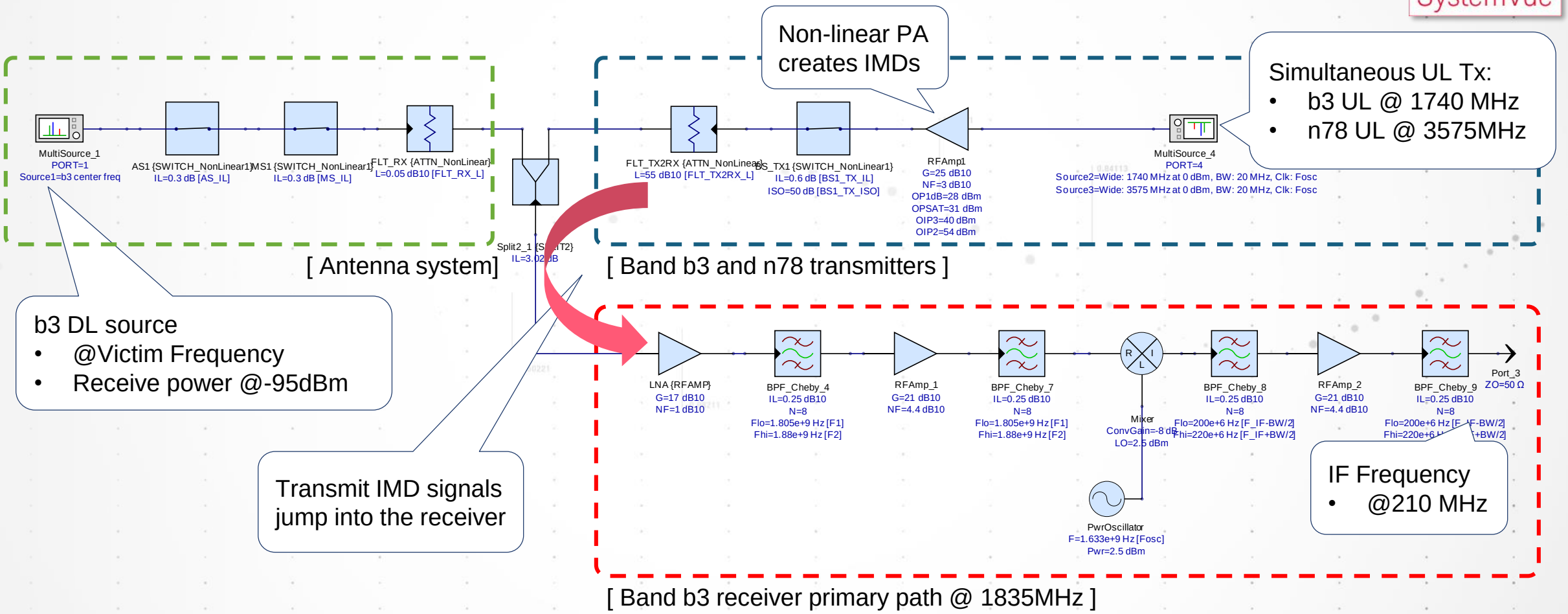
[Converged 4G, 5G Transceivers, Dedicated UL PA]

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

2. Multi-Radio Co-Existence

FR1 Transceiver Modeling in Frequency Domain



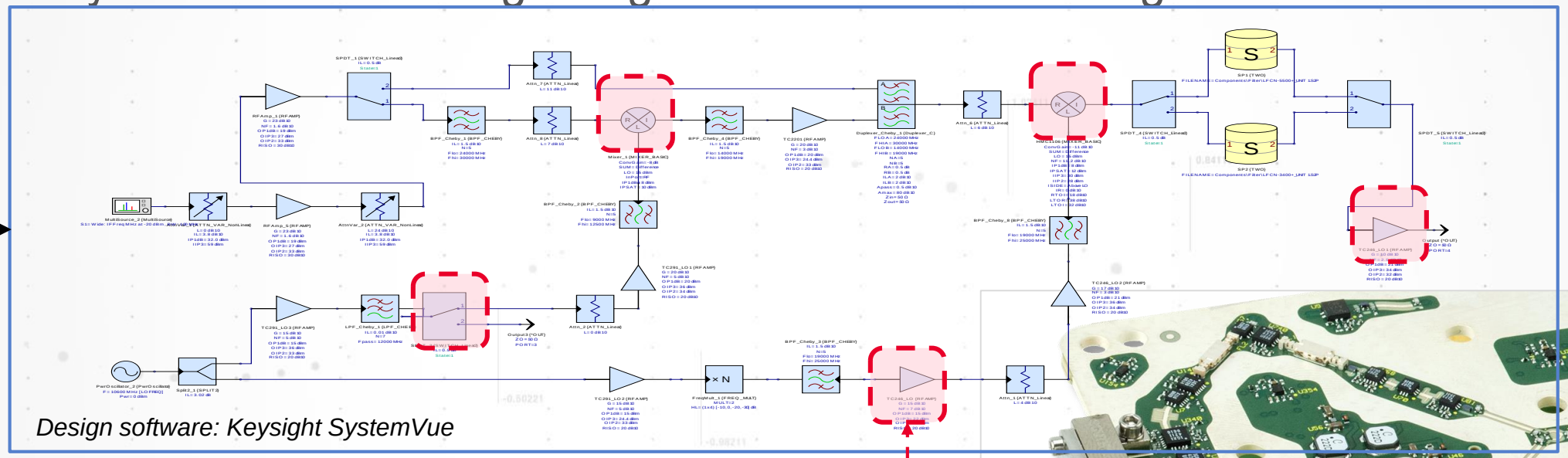
2. Architecting RF Transceivers

mmWave Design Flow

SystemVue

System level modeling using circuit level MMIC design data

Iteration



Design software: Keysight SystemVue

image: Keysight, 28GHz transceiver module

complete MMIC design flow, Keysight ADS

Front End Schematic

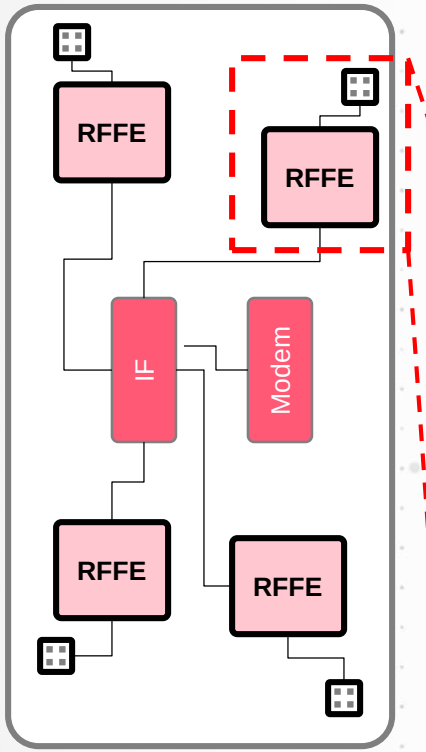
- Load Pull – power and PAE
- PA – Initial design with linear and non-linear simulation
- Optimization Cockpit
- Robust Statistical Design
- **X-Parameters**

Back End Layout

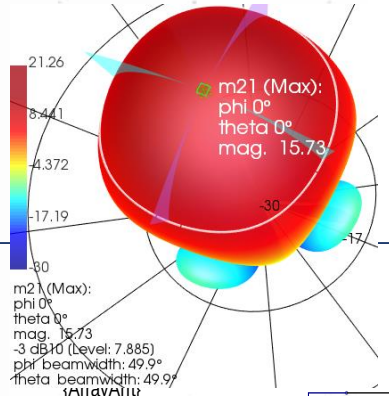
- Layout & 3D view Momentum
- DRC
- LVS
- Reticle Generation
- Package and Bond wire effects / 3D EM simulation

3. Phased Array and Beamforming

Antennas + Beamforming + Frequency Conversion

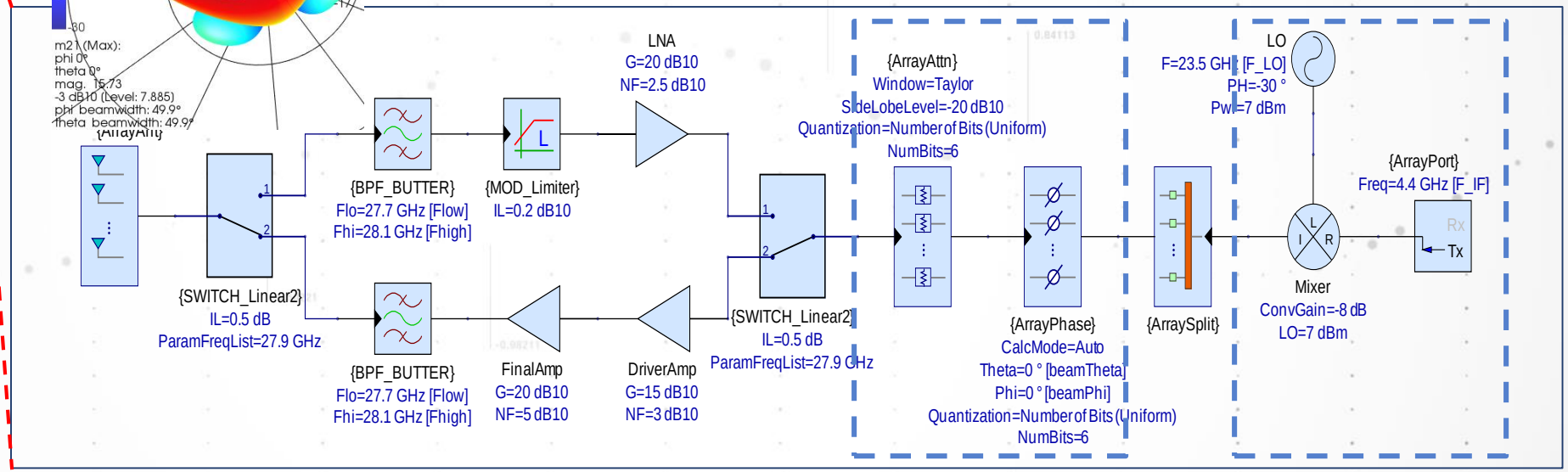


5G mmWave UE
Conceptual Block



<u># of Antennas and PAs determines maximum EIRP</u>

: Antenna element gain + Power summation gain + Beamforming gain



mmWave RFFE Functionality

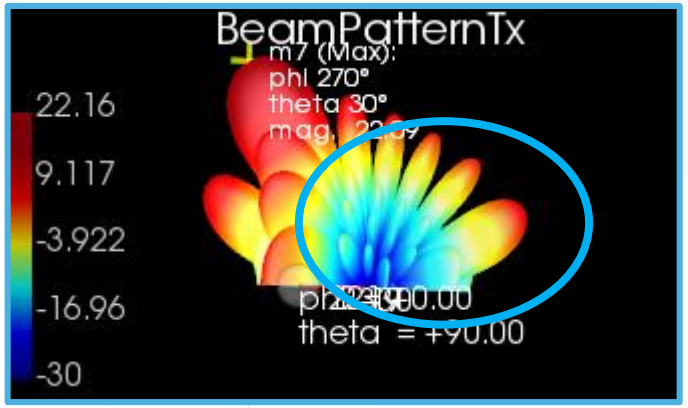
- Rx : T/R sw, VGA, PS, Combining, down-conversion
- Tx : T/R sw, PA, VGA, PS, Splitting, up-conversion

Characterization of mmWave Components

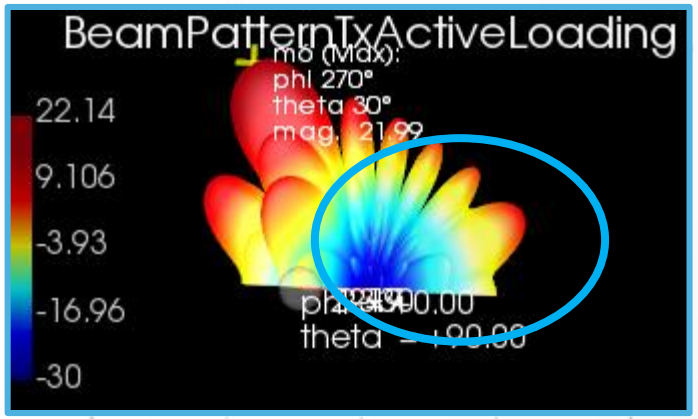
Array Antenna

Mutual Coupling

- Ideal coupling matrix: non-physical coupling based on the distance between the elements
- S-parameters: generated from electro magnetic 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



Ideal coupling matrix

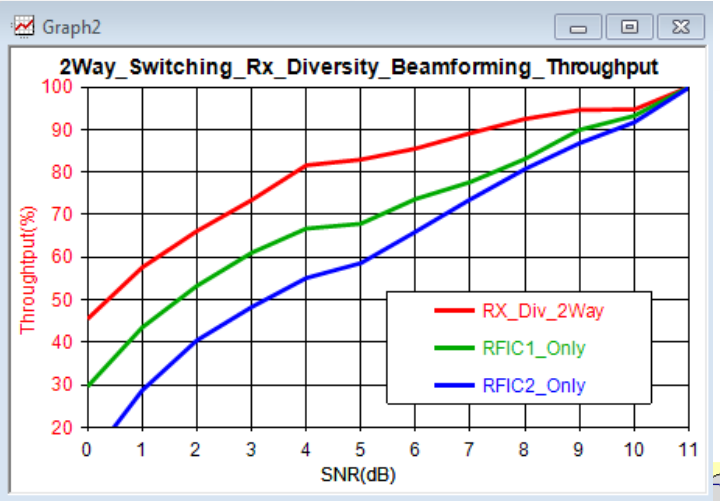


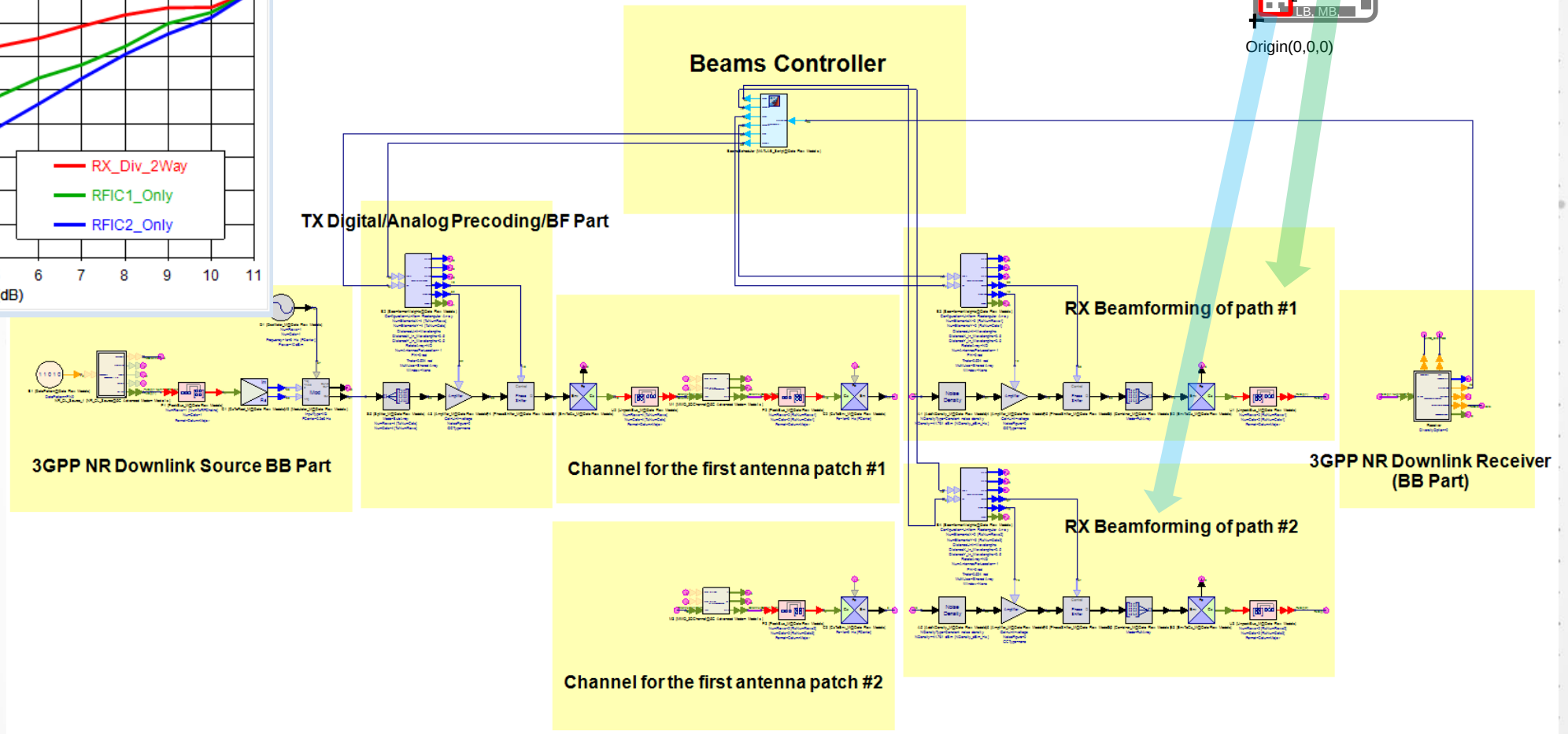
S-parameters

Increased null level from mutual coupling effect

4. Link Level Performance

A Glance of Future Diversity Case Including Beams





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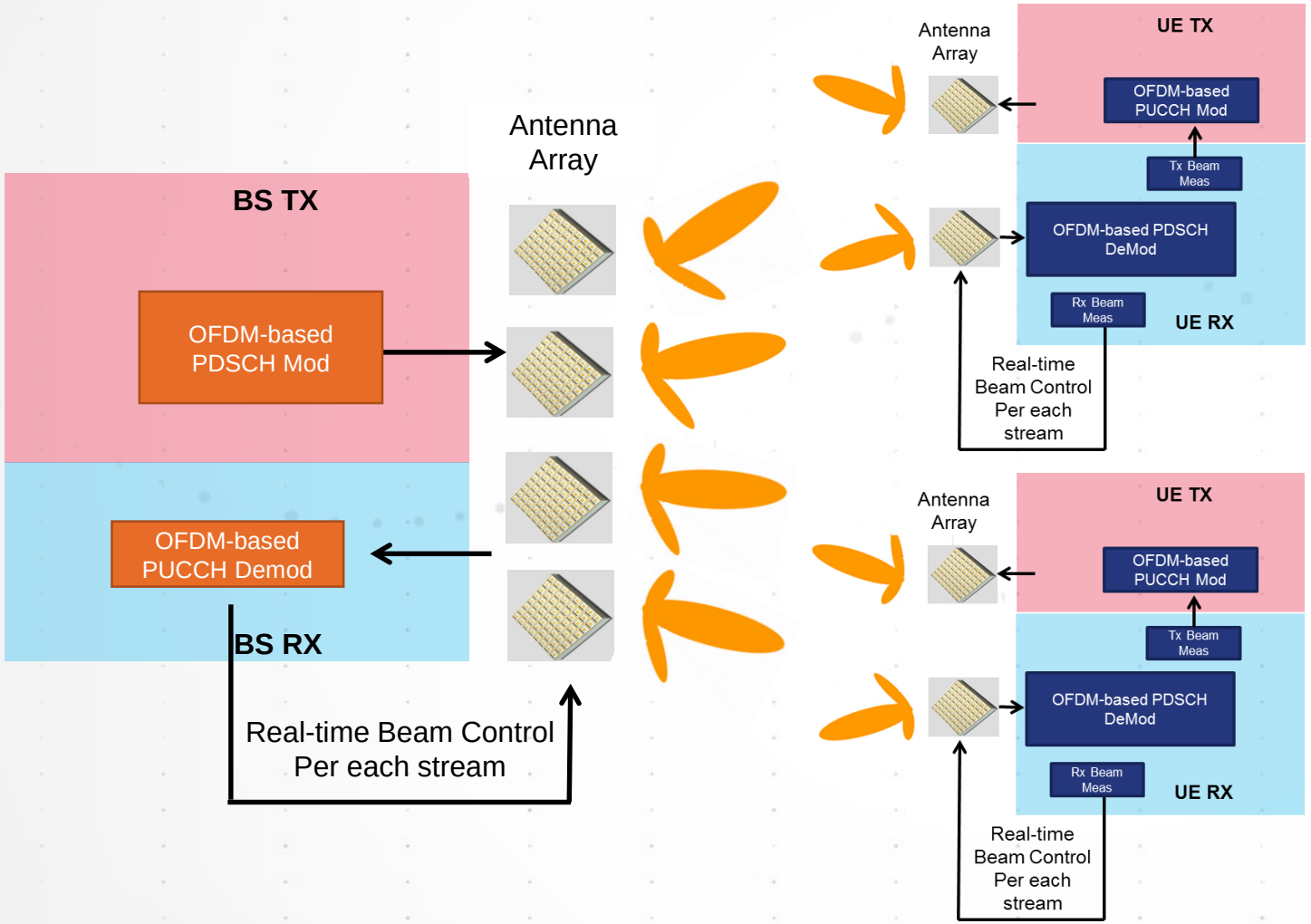
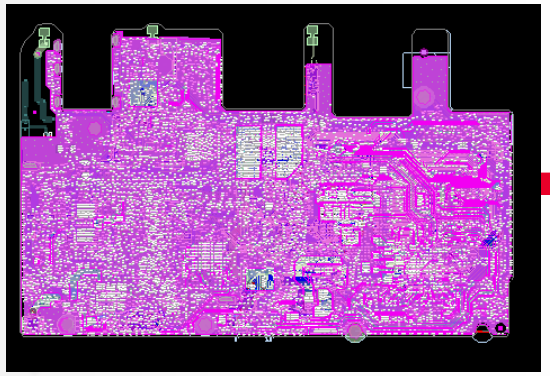
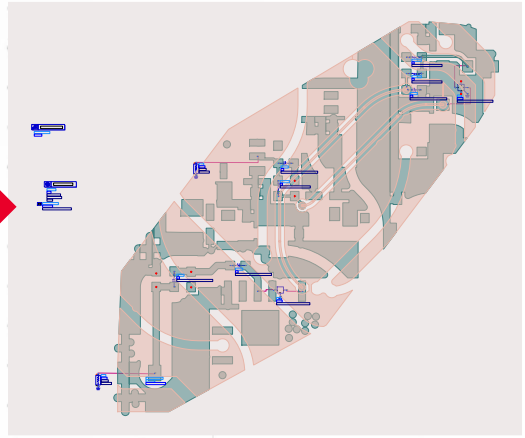
5. 5G OFDM Based Real time FPGA Prototype for Massive MIMO Verification

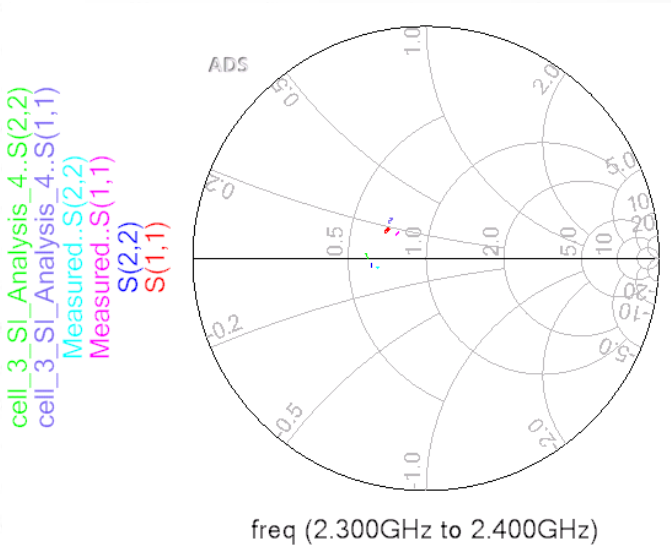


- Provide the HLS IP for real time Massive MIMO FPGA Prototype
- Support real time Massive MIMO adaptive beamforming
- Support real time beam tracking Support TDD mode
- Support up to 4 streams in BS(2 UEs, each UE has 2 streams)
- Support throughput test

6. High Band RF Matching







Layout Import *EM-Schematic Co-sim* *Accurate Match with Meas.*

Project output :

1) Reduce simulation time for RF team :

Previous : 1day /band ➡ Keysight ADS Flow : 1hour /band

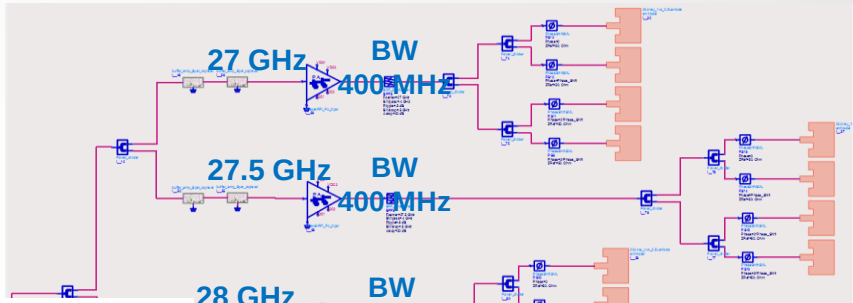
2~3weeks /board ➡ Keysight ADS Flow: <3 Day/board

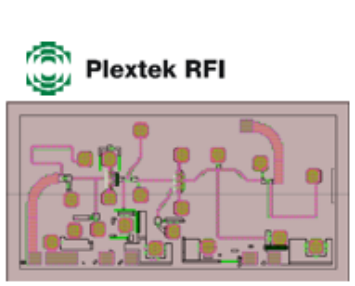
2) Great improved accuracy for high-band matching

Previous : Can't match meas. ➡ Keysight Flow : Accurate match with meas.

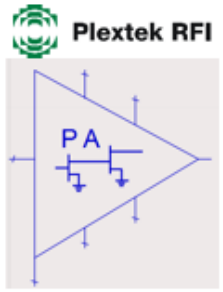
7. MM wave Transmitter Design

single pass sub-network



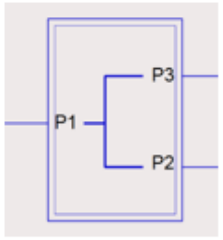


Plextek RFI Buffer Amp

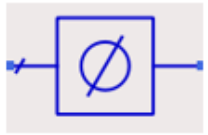


Plextek RFI PA

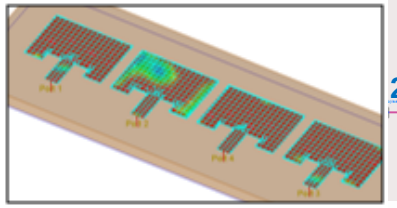
27 GHz BPF



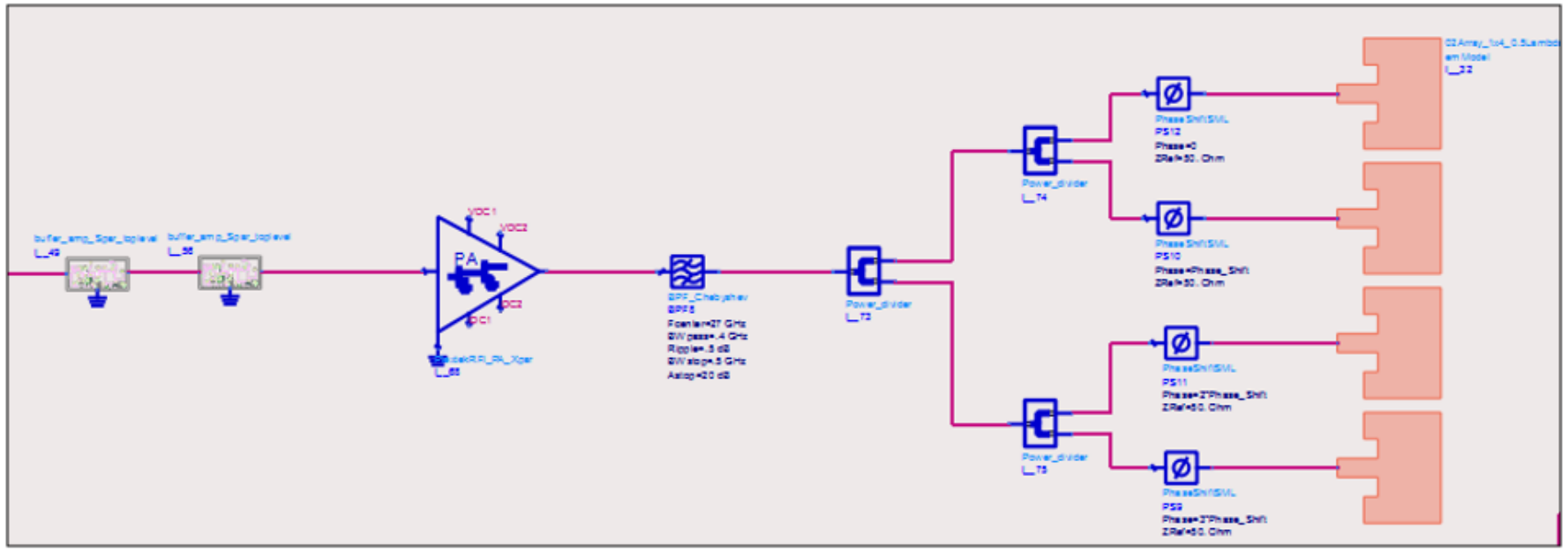
Power Divider

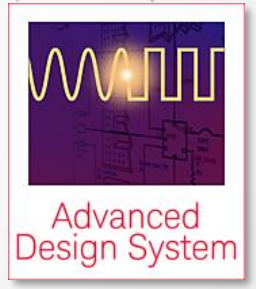


Phase Shifter



1X4 Array .5 Lambda Patch Antenna





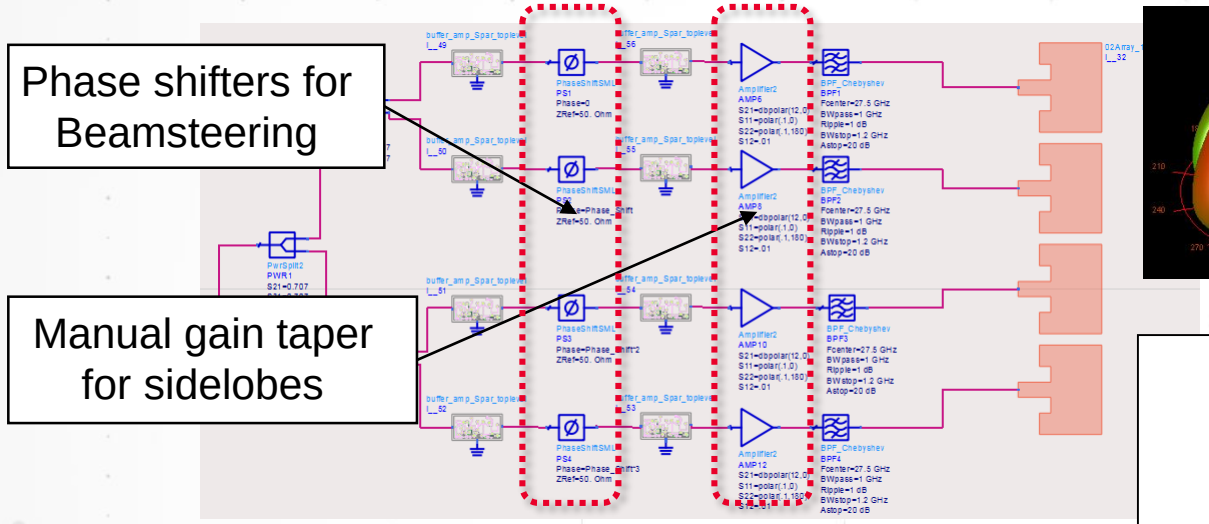
7. EM Co-Sim: 1x4 Transmitter Array in ADS/Momentum

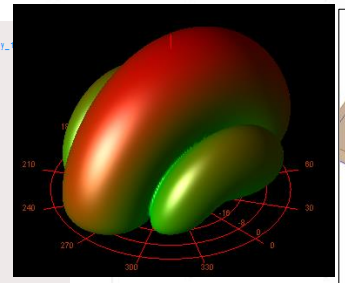
System / Circuit / EM Co-simulation and beam steering

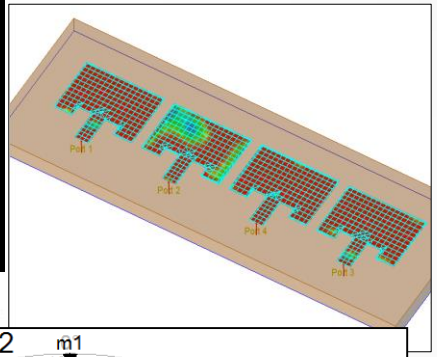
Advanced Design System

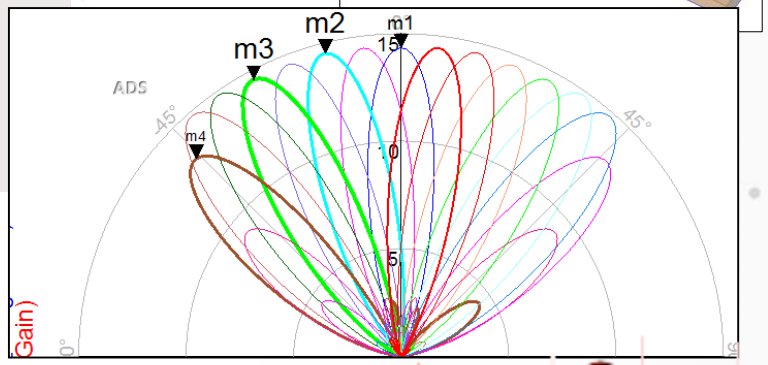
Phase shifters for Beamsteering

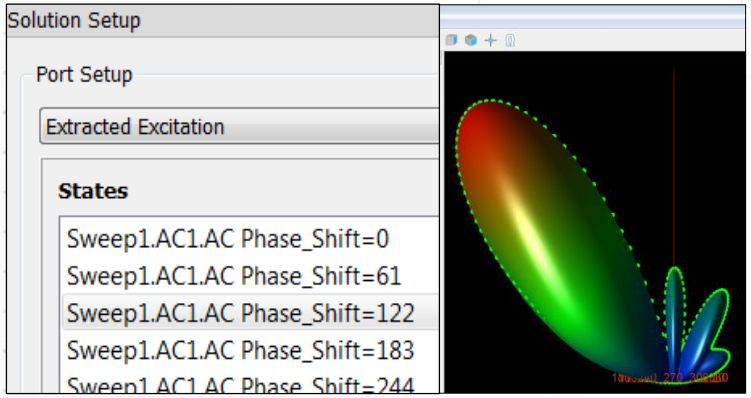
Manual gain taper for sidelobes

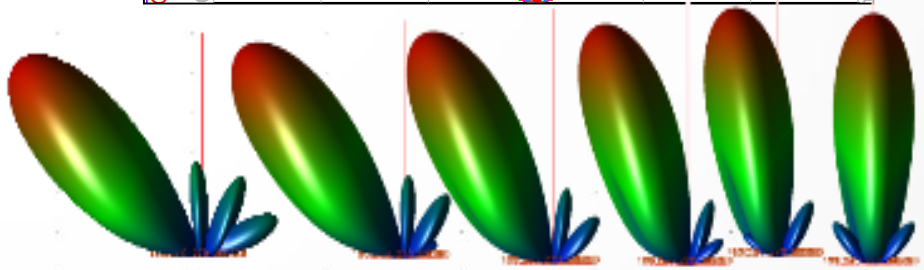




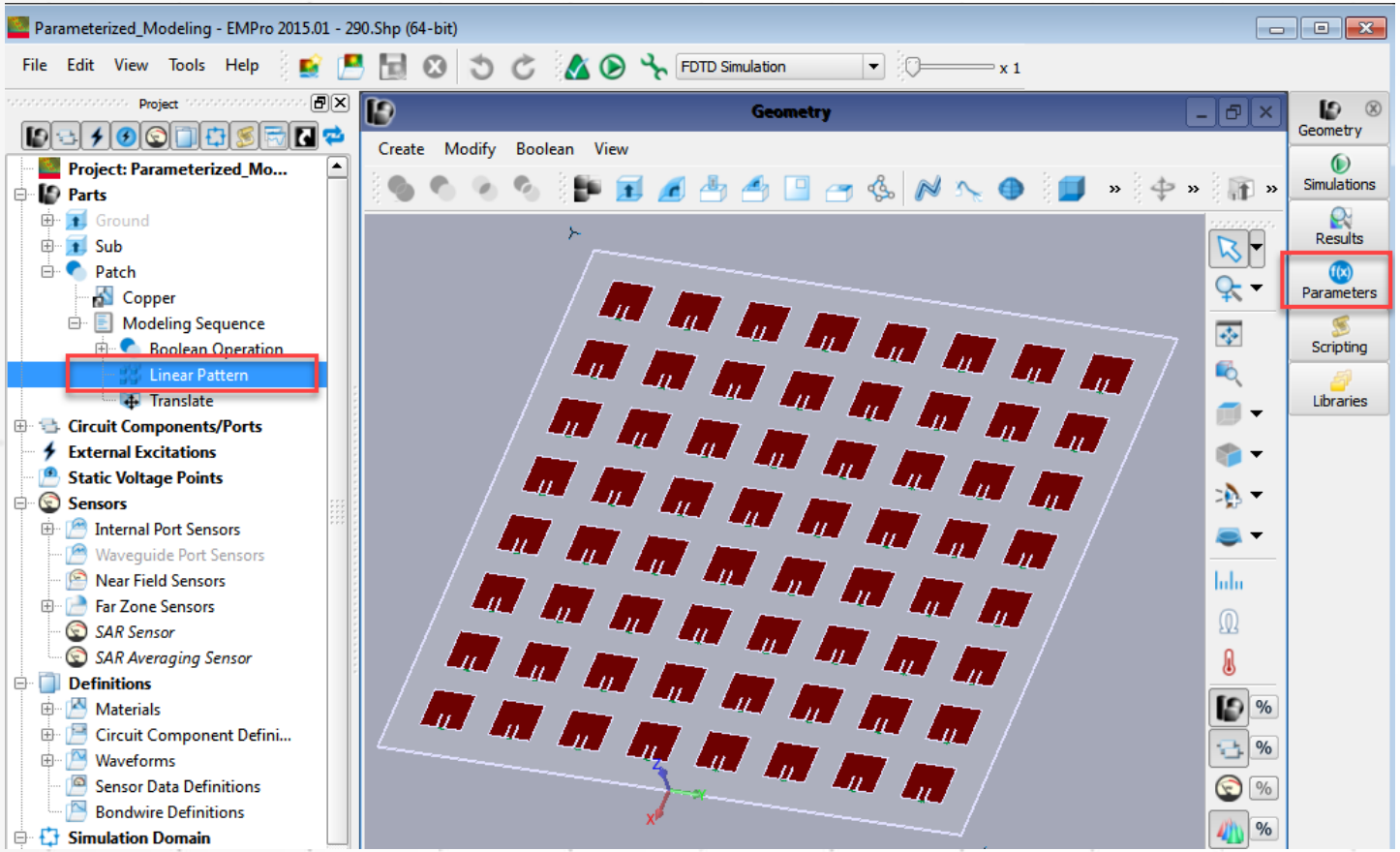




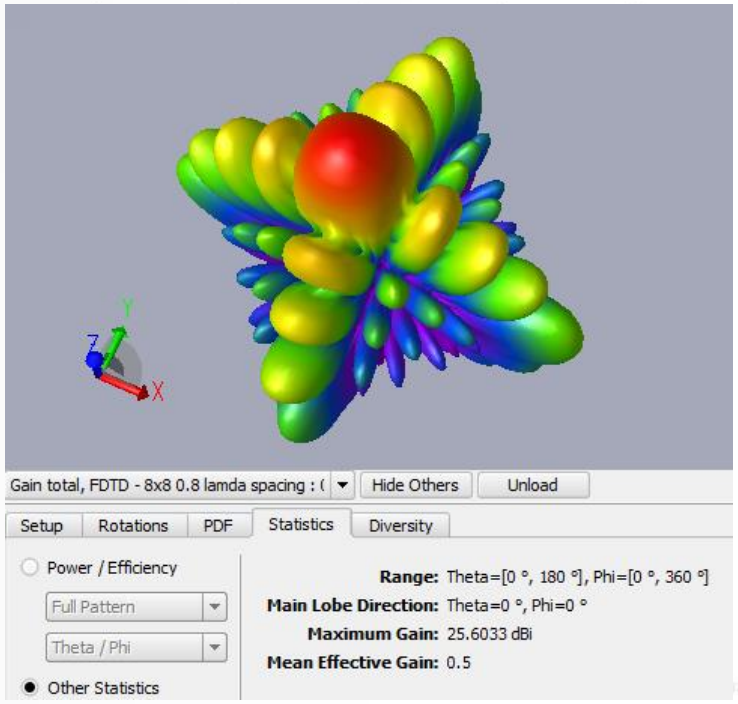




8. Phased Array Antenna Design -- EMPro

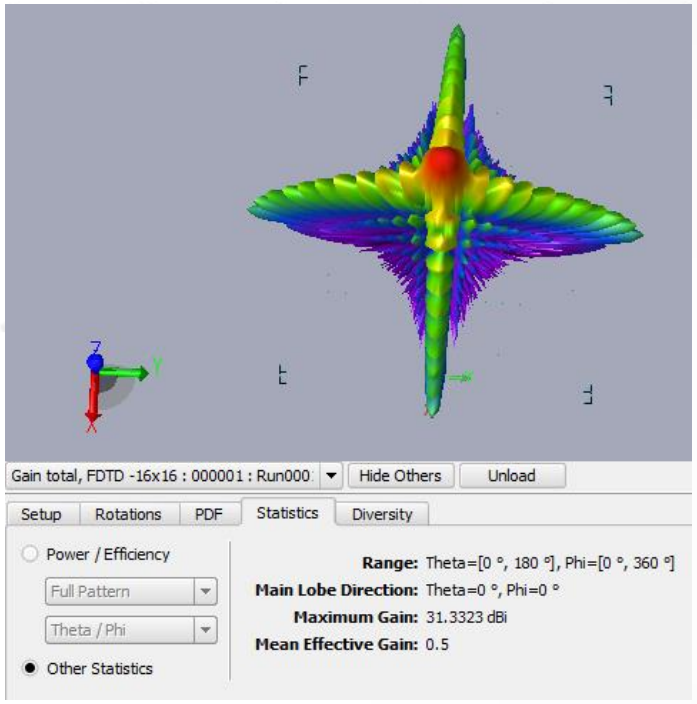


8. EMPro – 3D EM Simulation(FDTD)



8*8 (0.8 lamda spacing)

4 K80 GPU
4min，40s

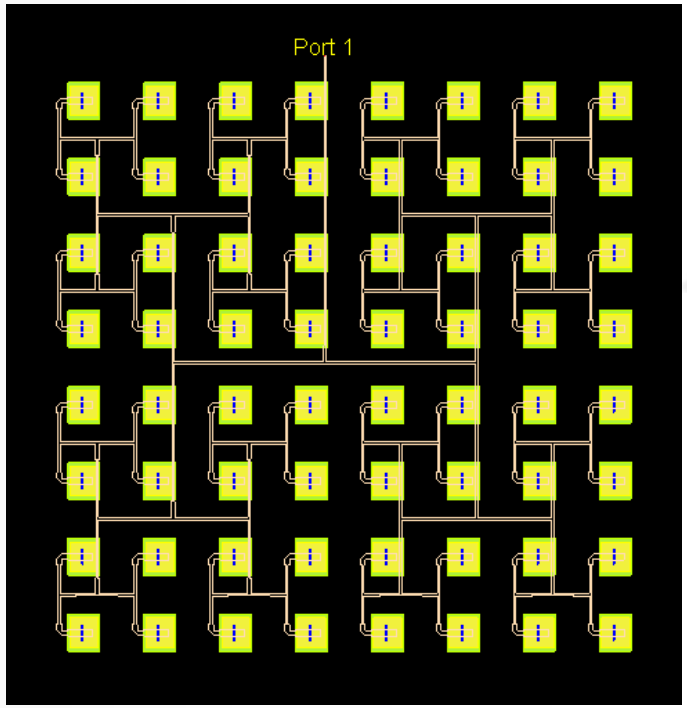


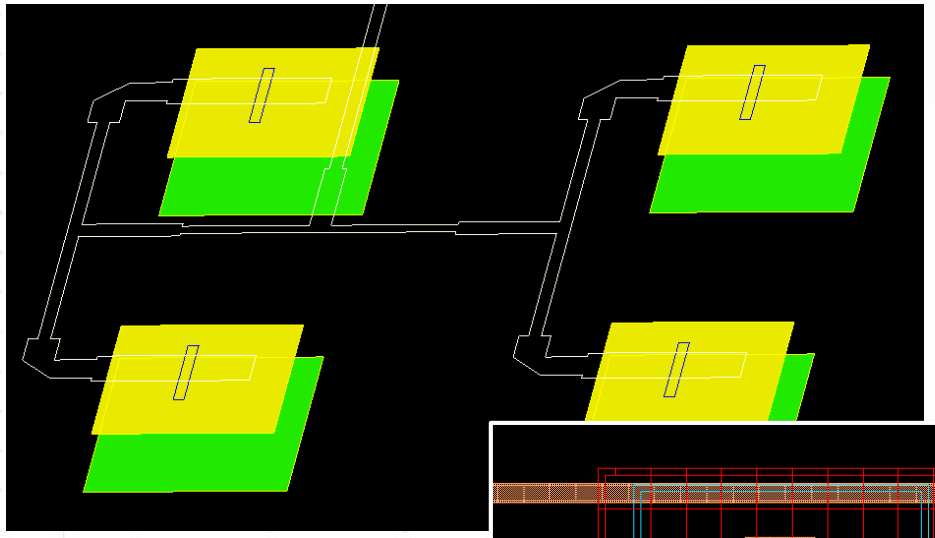
16*16

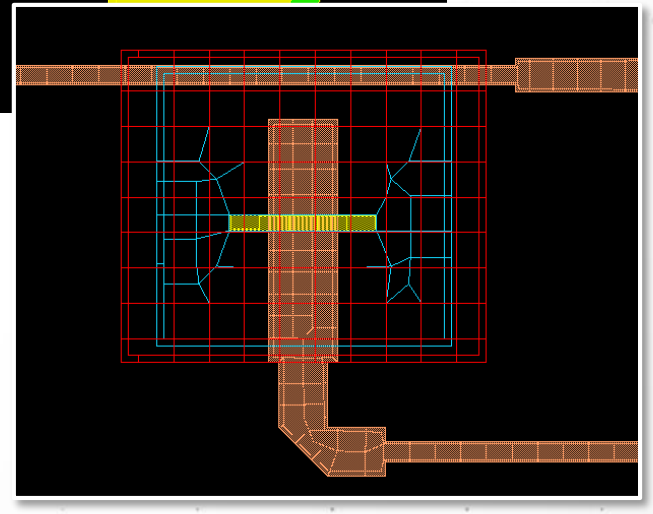
4 K80 GPU
27min，46s

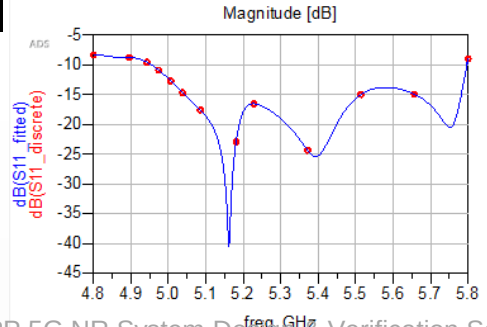
8. Planar Antenna: ADS Momentum 8x8 patch array

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









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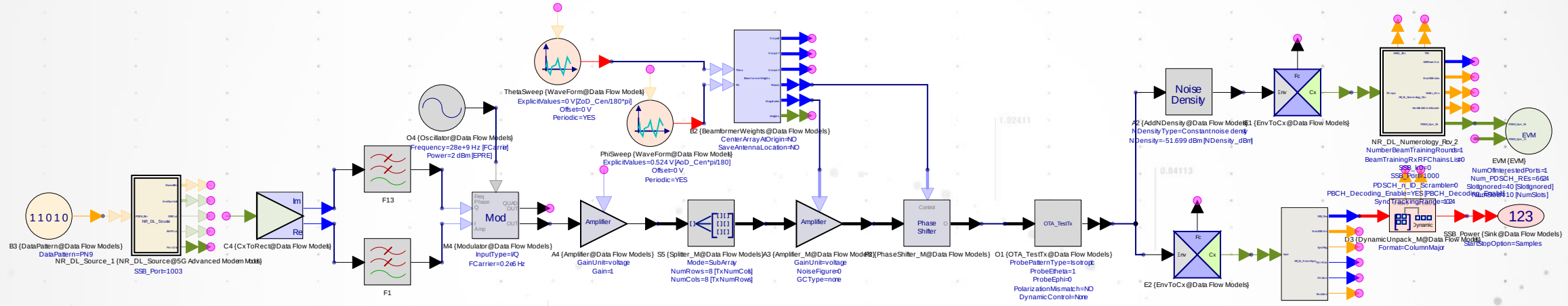
5G NR Base Station Conformance Test Summary-FR 1 & 2

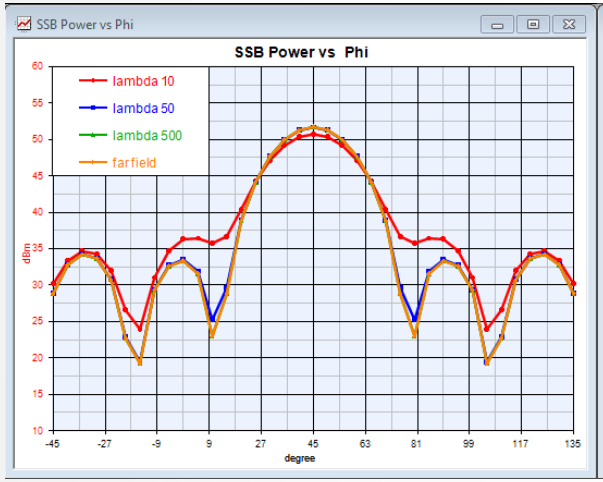
Conducted & radiated conformance tests

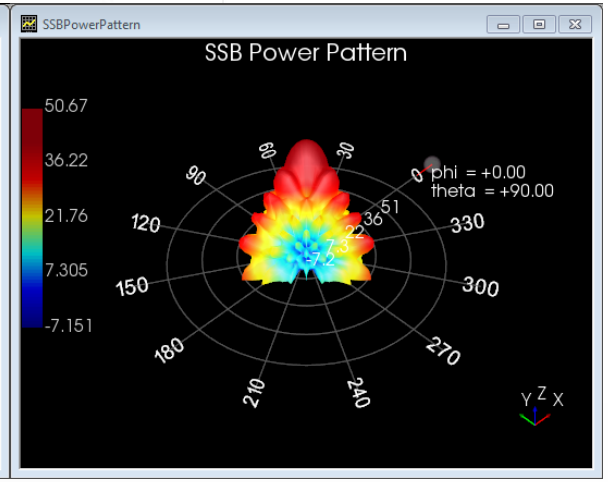
Transmitter Characteristics (chp 6)	Receiver Characteristics (chp 7)	Performance Requirements (chp 8)

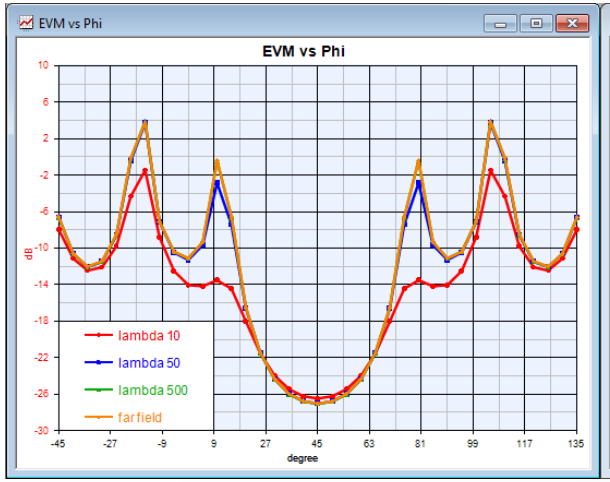
• **Transmit Power** (TRP, EIRP)
• **Output Power Dynamics** (RE Power Control DR / Total Power DR / ...)
• **Transmit On/Off Power** (TX Off Power / TX Transient Period)
• **Signal Quality** (Freq Error / EVM / Time Alignment Error /...)
• **Unwanted Emissions** (Occupied BW / ALCR / Spurious /...)
• **Intermodulation** (Interference...)
	• **Reference Sensitivity Level**
	• **Dynamic Range**
	• **In-Band Selectivity & Blocking Characteristics** (Adjacent Channel Selectivity (ACS))
	• **Out-of-Band Blocking**
	• **Spurious Emissions**
	• **Intermodulation**
	• **In-channel Selectivity**
		• **Performance Requirements for PUSCH**
		  • Multipath fading propagation for given SNR
		• **Performance Requirements for PUCCH**
		  • ACK missed detection
		  • NACK to ACK detection
		  • UCI BLER performance (format 2)
		• **Performance Requirements for PRACH**
		  • False alarm probability and missed detection

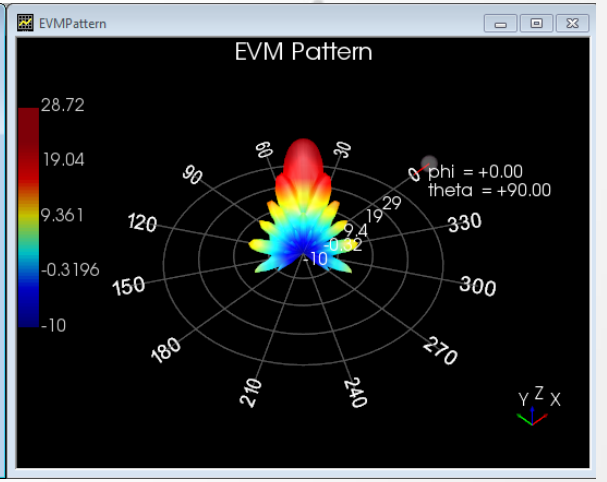
9. Verification: 5G NR DL OTA Measurement Simulation



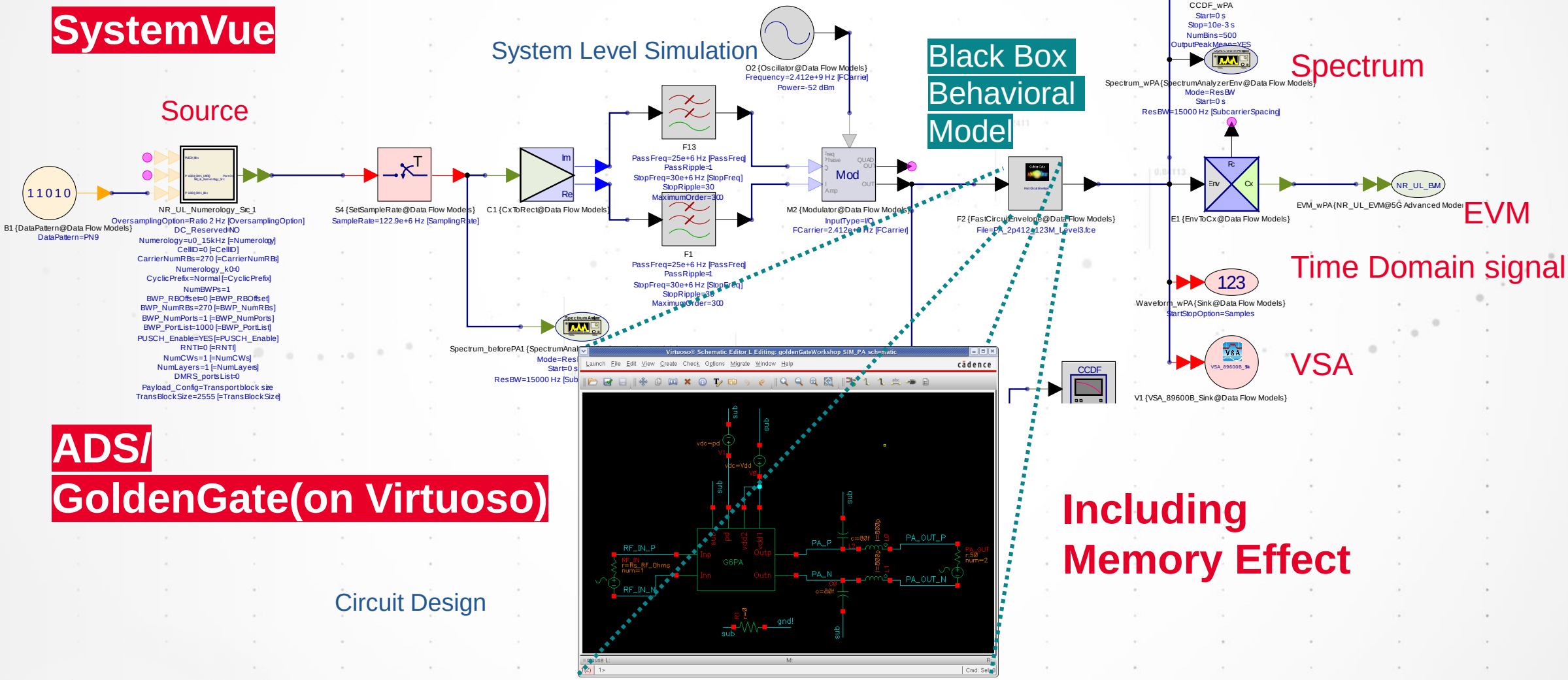






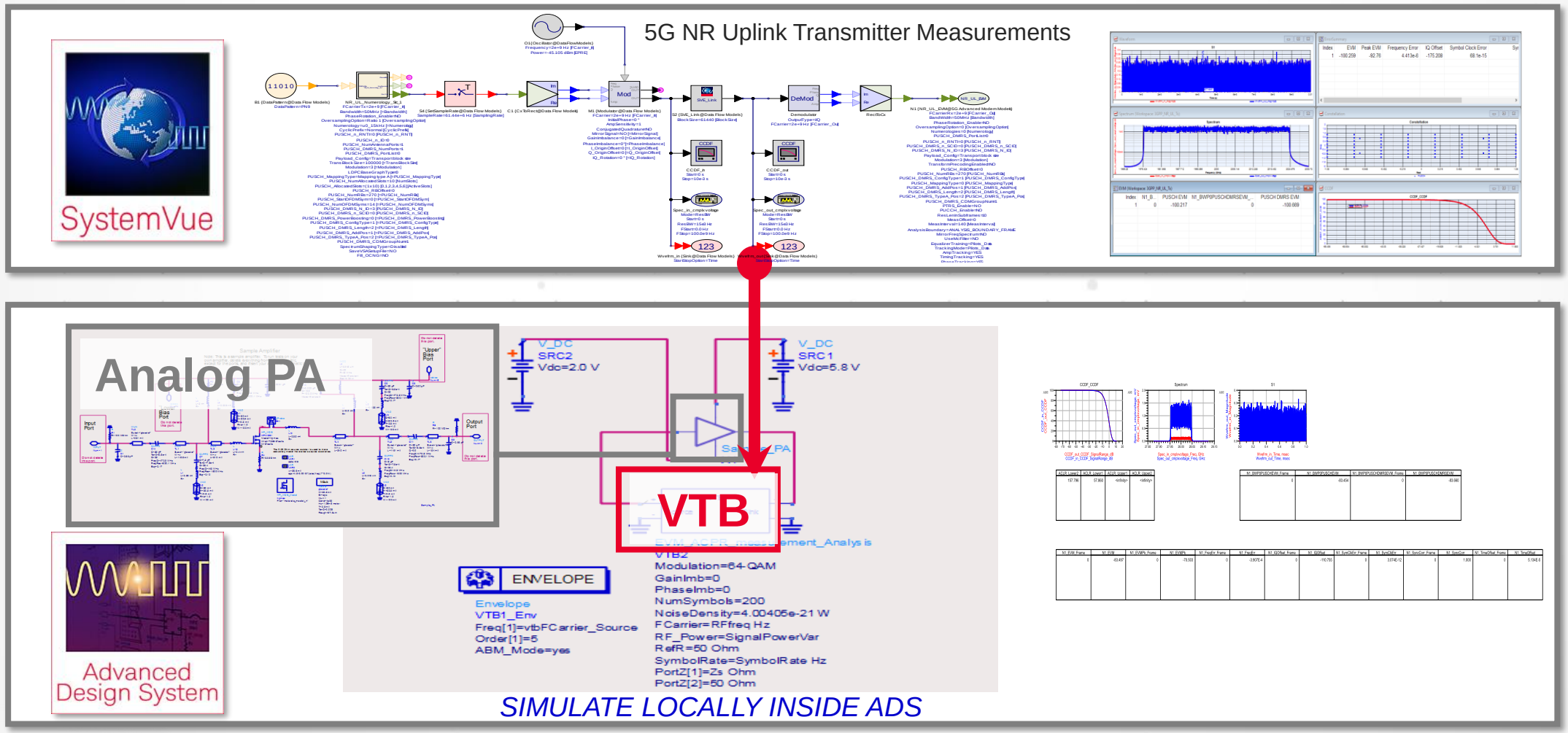


9. Verification : Fast-Circuit-Envelop Model



9. Verification : Verification Test Bench

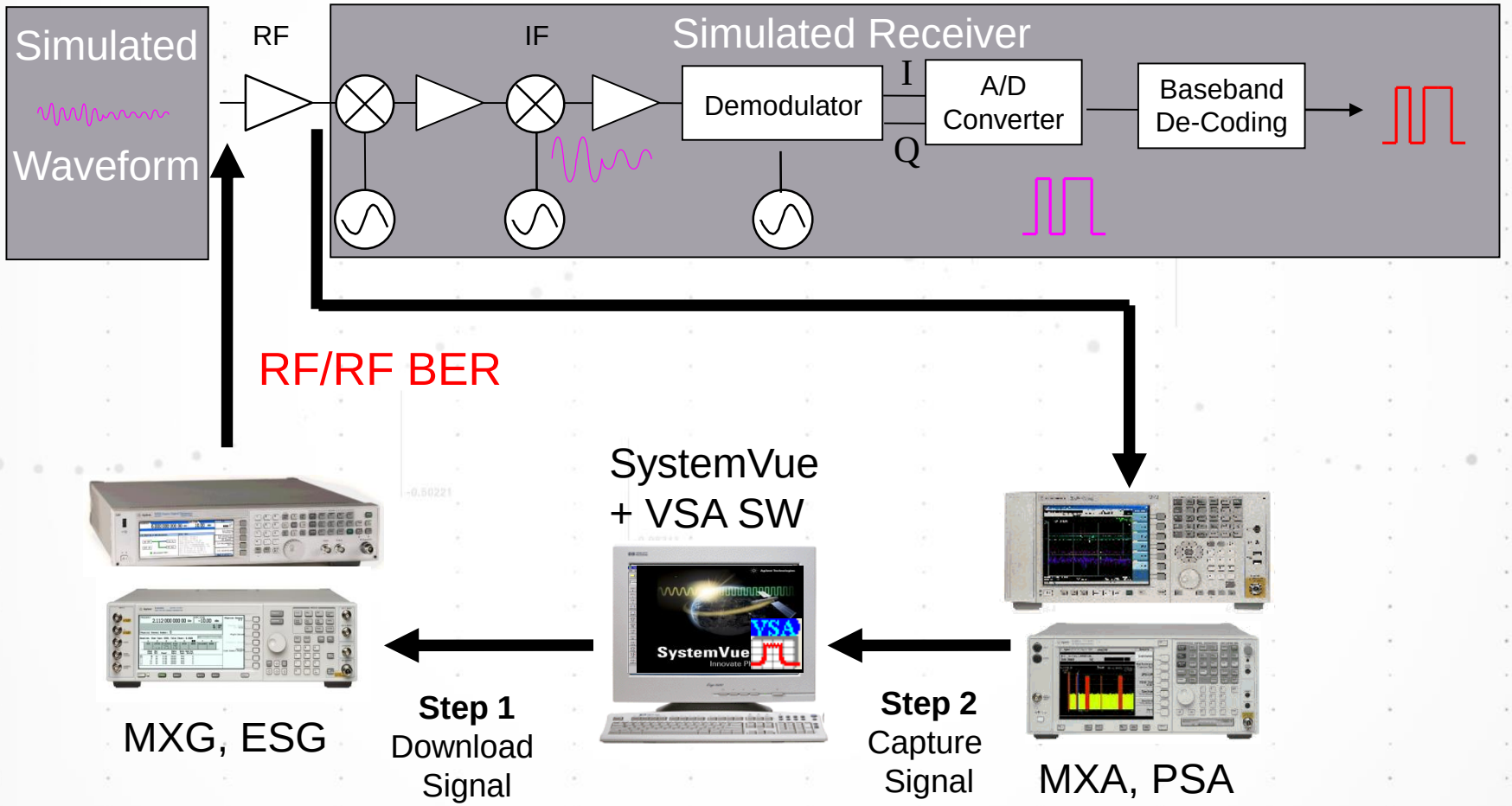
In ADS / GoldenGate



Agenda

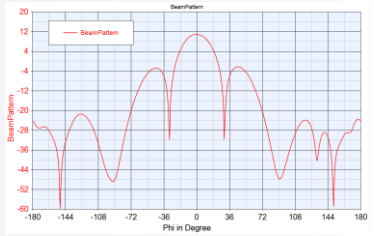
- Design Challenges for 5G Physical Layer Design Overview
- System Architecture Design
- Baseband RF Antenna Design
- Baseband RF Antenna Simulation Verification
- Early emulation system for hardware test

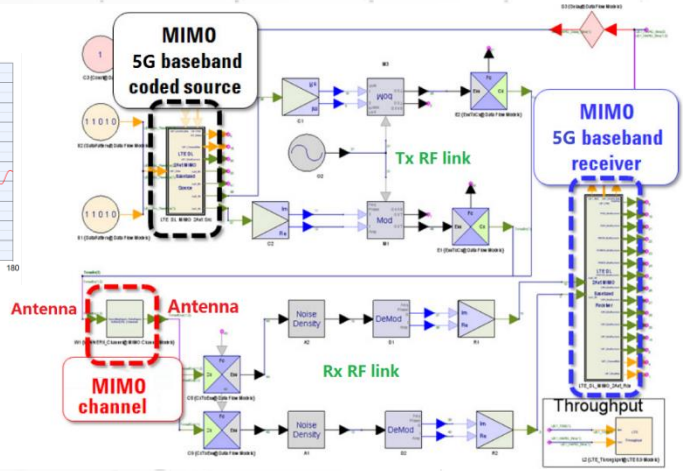
Early R&D Hardware Testing - *RF DUT*

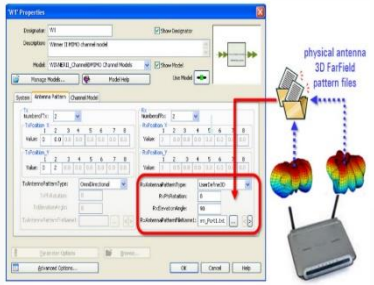


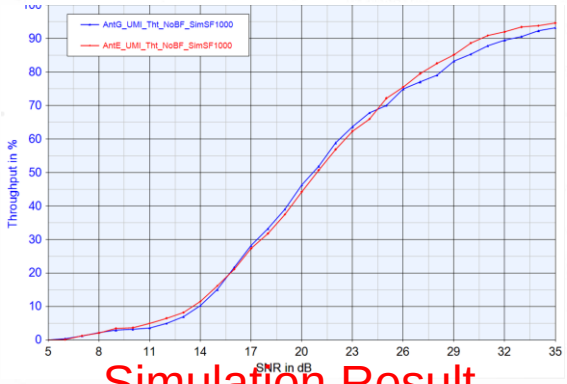
Keysight Phase Array Antenna Test

- Throughput/Beam Pattern Simulation in SystemVue to get Antenna Performance baseline



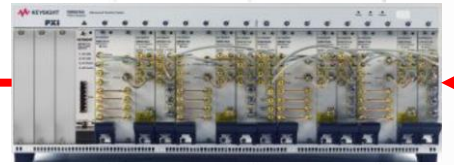


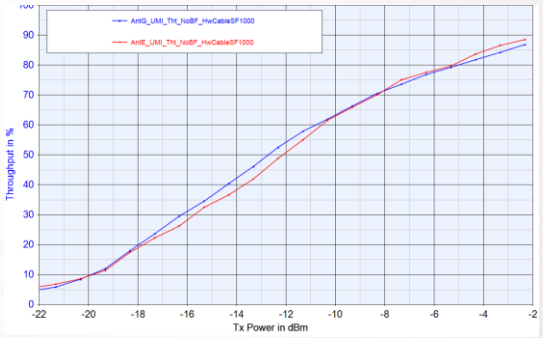




Simulation Result

- Massive MIMO Throughput/Beam Pattern OTA Test with Keysight Instruments & SystemVue





Test Result

Accelerate 5G Design with ADS SystemVue Empro

5G Library

Reference transmitter

1011010010
10010110…

System architecture study

SystemVue

Baseband Verification library as golden reference

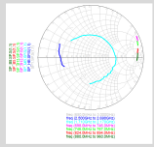
Spectrasys analysis for RF architecture design

Phase Array for antenna array

Baseband RF Antenna Design

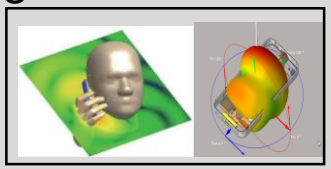
HDL

SystemVue



RF Circuit Design
RF Matching
RF+Em cosim

ADS



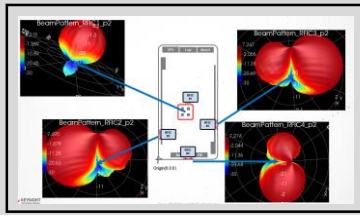
Empro

Baseband RF Antenna validation

Advanced Design System

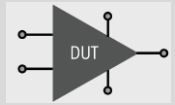
GoldenGate

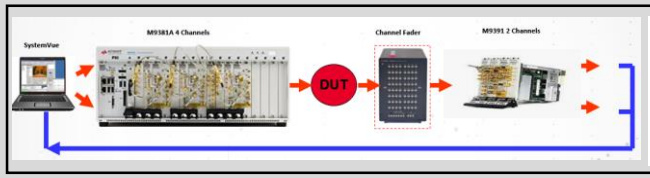
SystemVue



Conformance test template
5G Fading Channel Model
SystemVue ADS Cosim
ADS VTB
OTA for antenna verification

DUT validation with test equipment





5G Antenna OTA Test

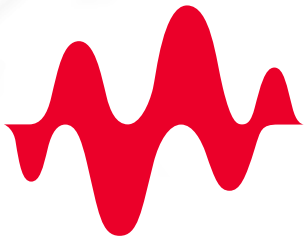
5G NR Prototype Verification

5G Library

Reference receiver

1011010010
10010110…

BER
EVM



KEYSIGHT
TECHNOLOGIES

Thank you