KEYSIGHT WORLD 2019

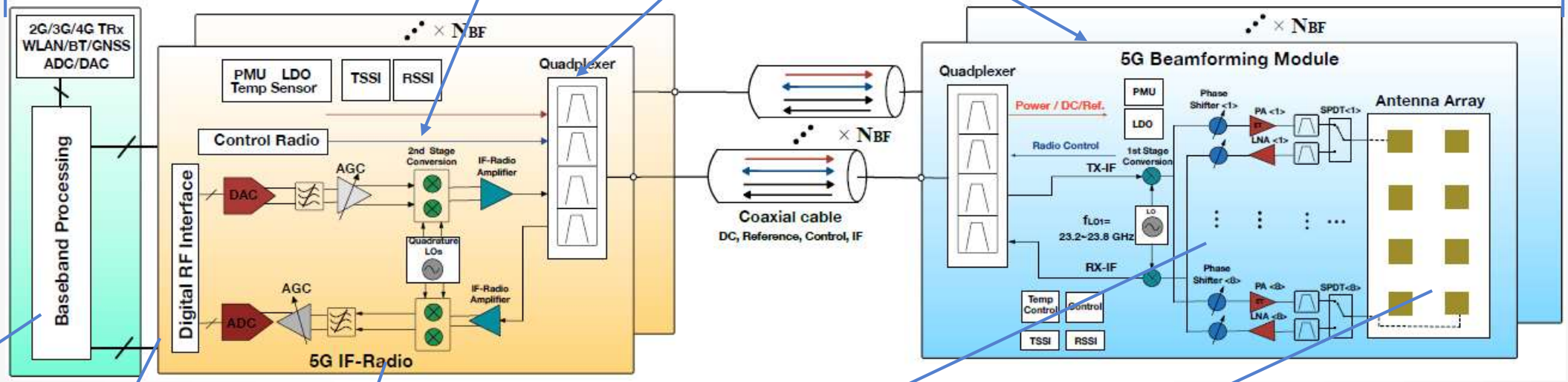
3GPP 5G NR System Design & Verification Solution

Application Engineer/ Keysight Technologies

WU Jiarui

5G Devices Design Challenge

- Architecture design
- Components, RF sub-system, Modules design



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

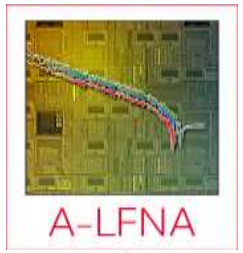
arXiv:1704.02540v1 [csIT] 8 Apr 2017

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

Keysight EEsof EDA Product Overview

SystemVue
– ESL

GoldenGate
– RF Mixed Signal

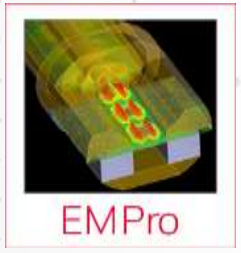


A-LFNA
– Advanced Low-Frequency Noise Analyzer

ADS
– MMIC, RF Board, SiP, HSD

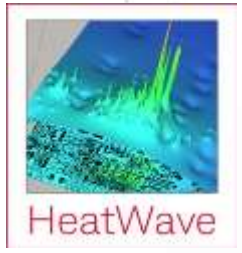
IC-CAP
– Device Modeling GaAs, GaN, Custom Models Measurement

WaferPro Express
– Wafer-level measurement and programming



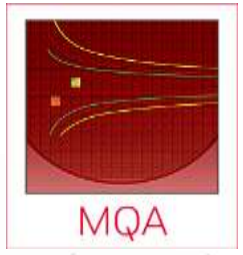
EMPro
– 3D EM

MBP
– Device Modeling Silicon



HeatWave
– IC electro-thermal analysis

Genesys
– RF Board



MQA
– Model Quality Assurance

What You Can Do for 5G?

Using SystemVue, ADS, GoldenGate & EMPro

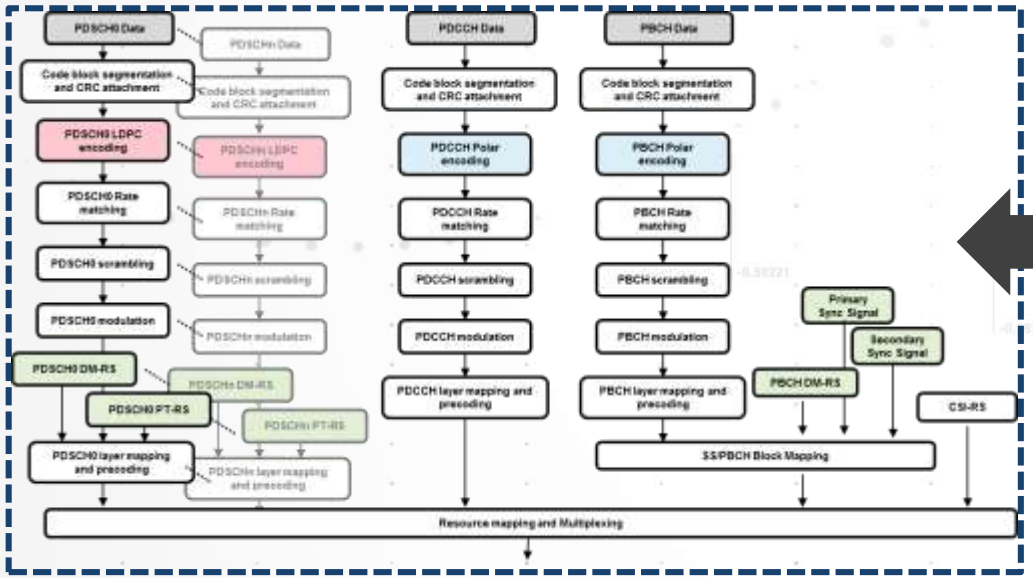
1. Standard Waveform Creation and Analysis
2. Link Level Performance
3. Architecting RF Transceivers
4. Over-The-Air(OTA) Simulation
5. Phased Array and Beamforming
6. Difficult System Engineering
7. Advanced End-To-End Link Performance
8. Multi-Radio Co-Existence

1. Standard Waveform Creation and Analysis

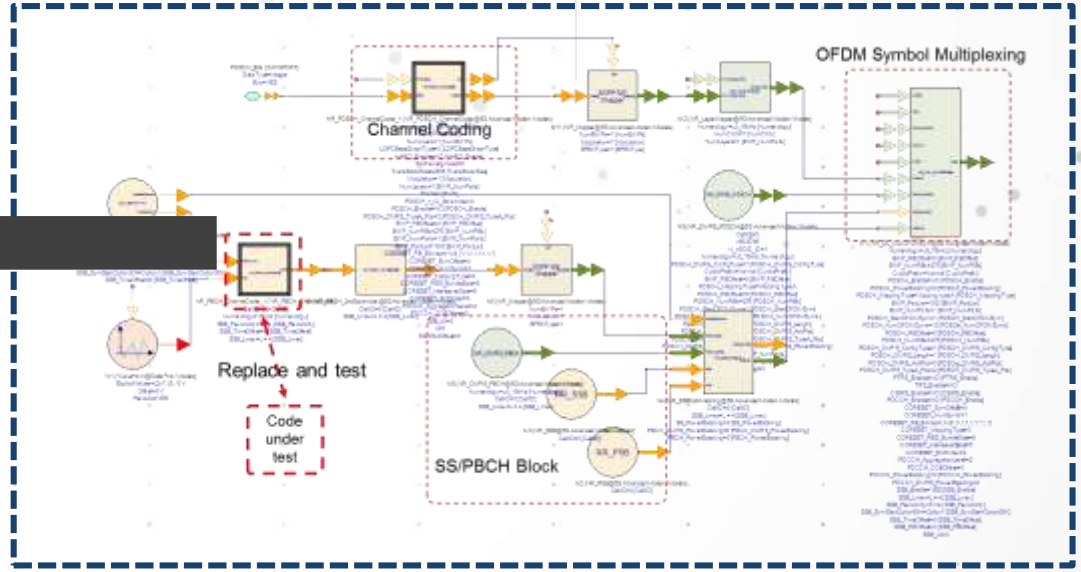
Baseband: Trusted Algorithm Reference IP

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



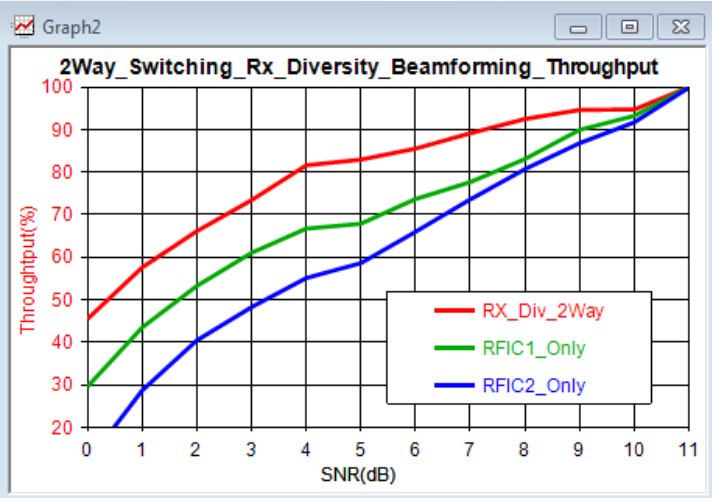
[NR Baseband Digital Signal Processing]

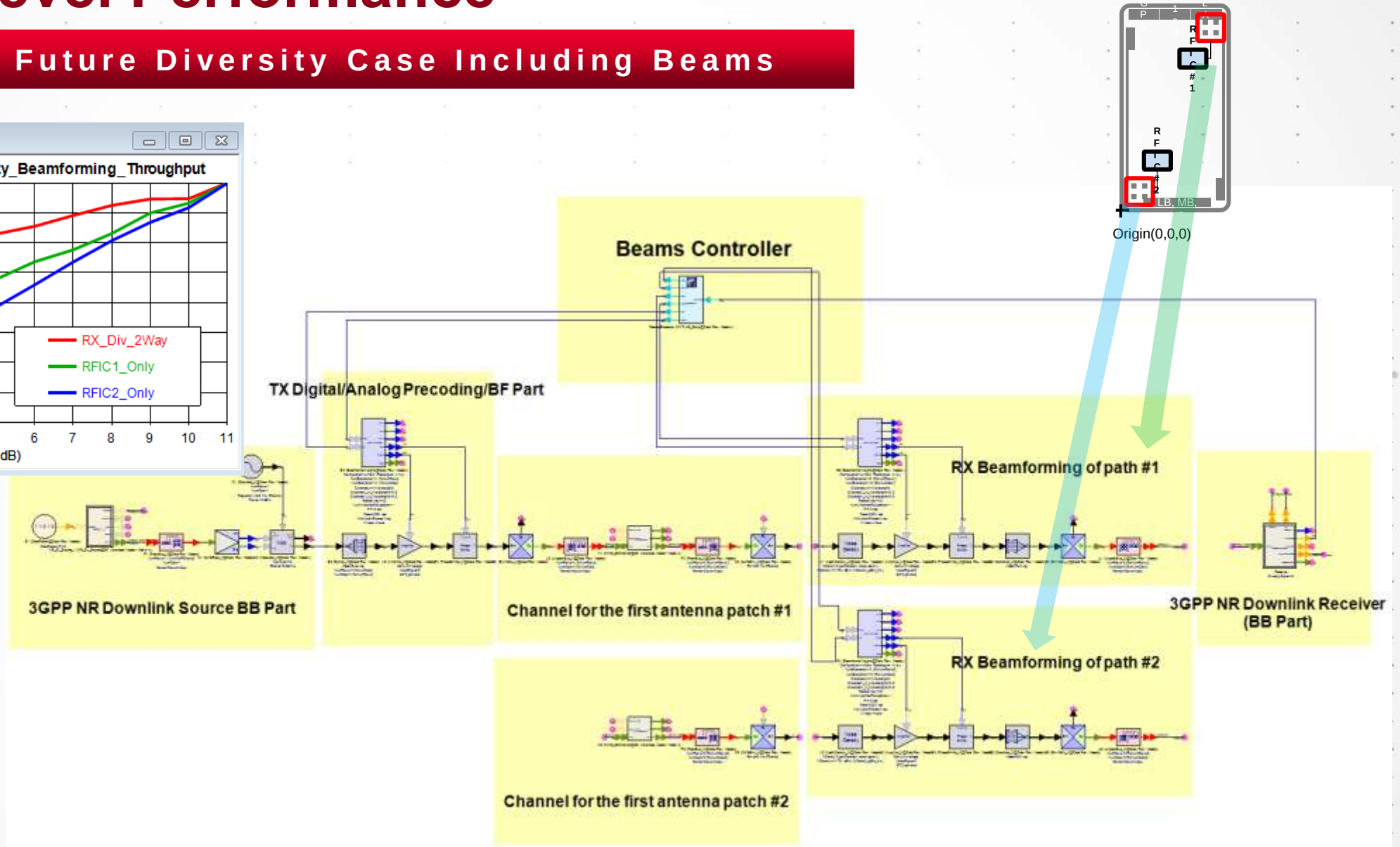


[Model Based Design for NR Baseband DSP]

2. Link Level Performance

A Glance of Future Diversity Case Including Beams

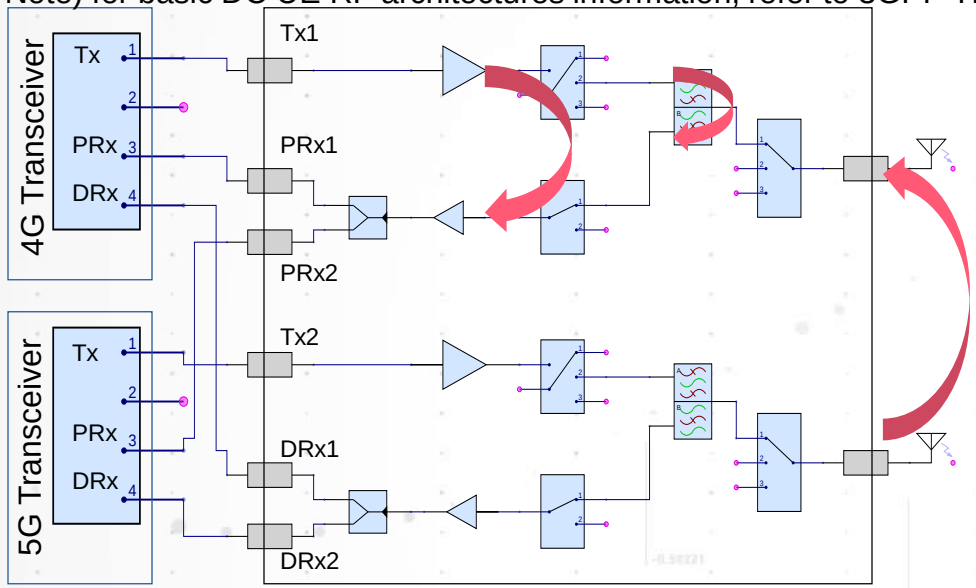




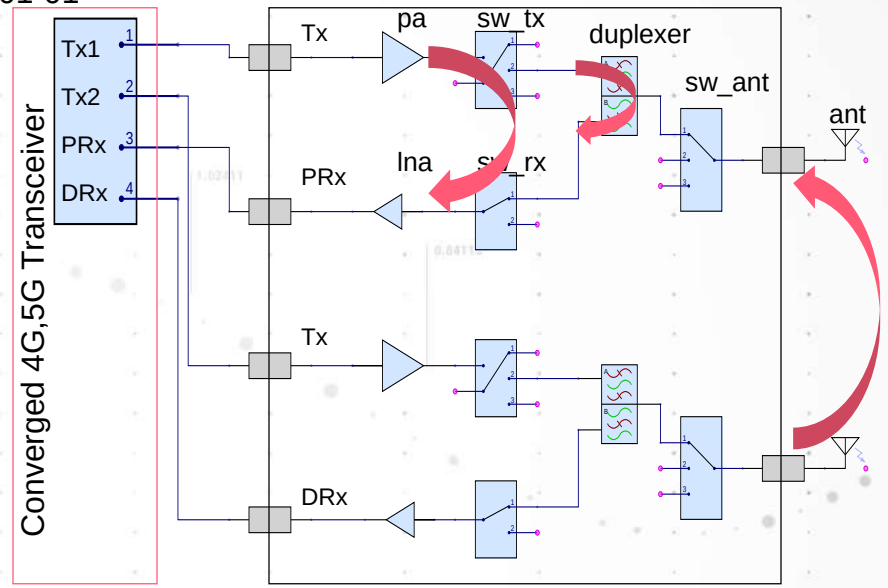
3. Architecting RF Transceivers

FR1 Dual Connectivity UE Architectures

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



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



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

Technical Issues:

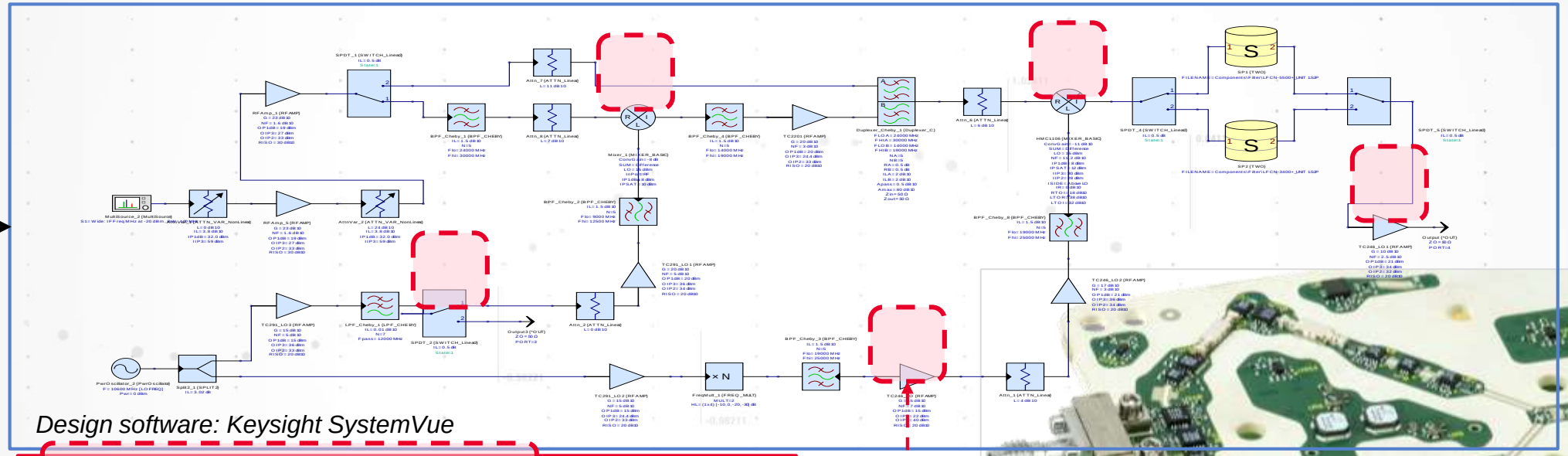
- Complex 4G, 5G Transceivers and Multi-band RFFE(RF Front End) Design
- Dual Connectivity Simultaneous UL Produces IMD onto Active Receiver (Rx)
- Noise measurements in Rx band to estimate the impact of Tx excess noise

3. Architecting RF Transceivers

mmWave Design Flow

System level modeling using circuit level MMIC design data

Iteration



Design software: Keysight SystemVue

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**

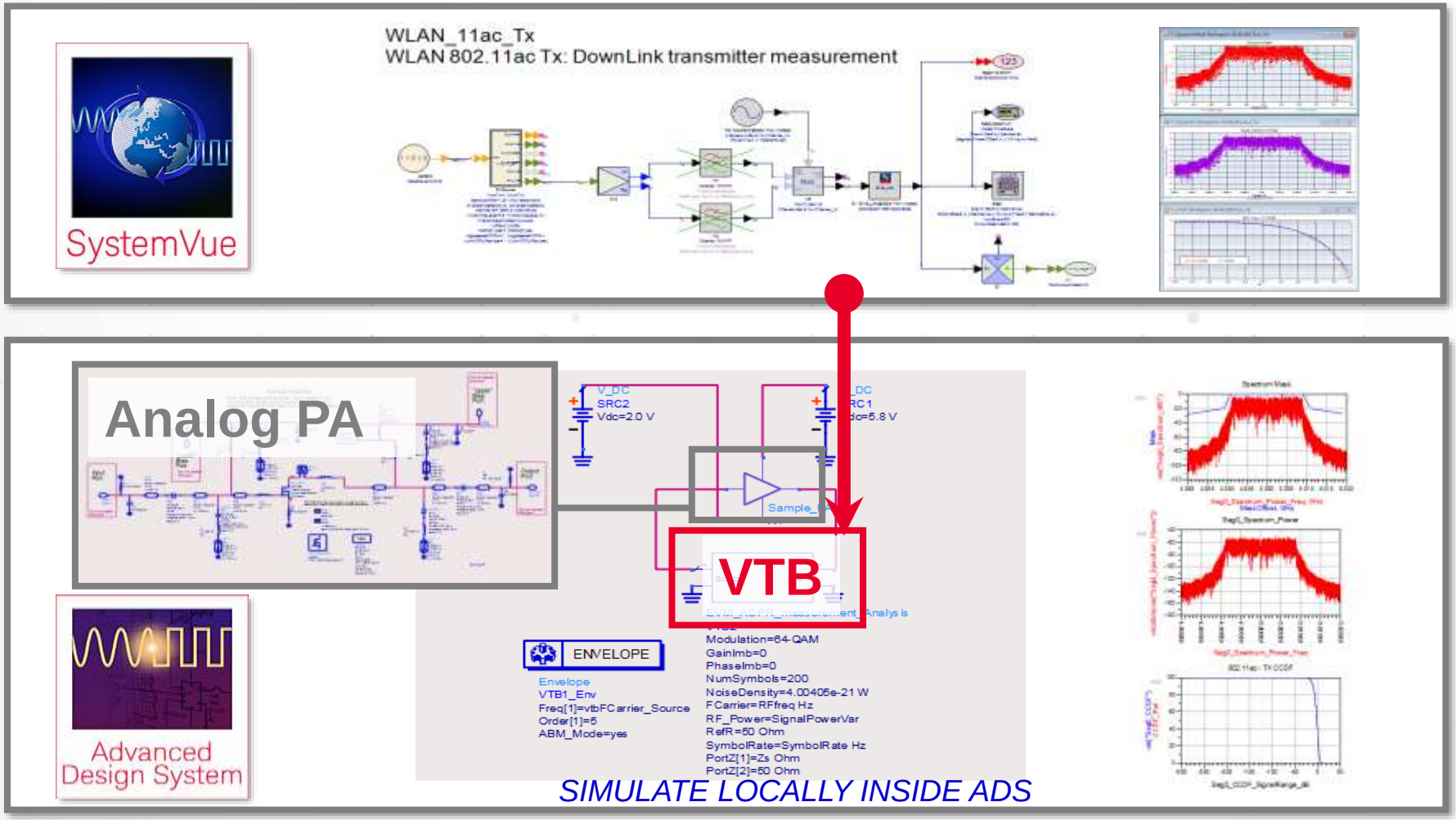
Back End Layout

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

image: Keysight, 28GHz transceiver module

Verification Method 1: Verification Test Bench

In ADS / GoldenGate

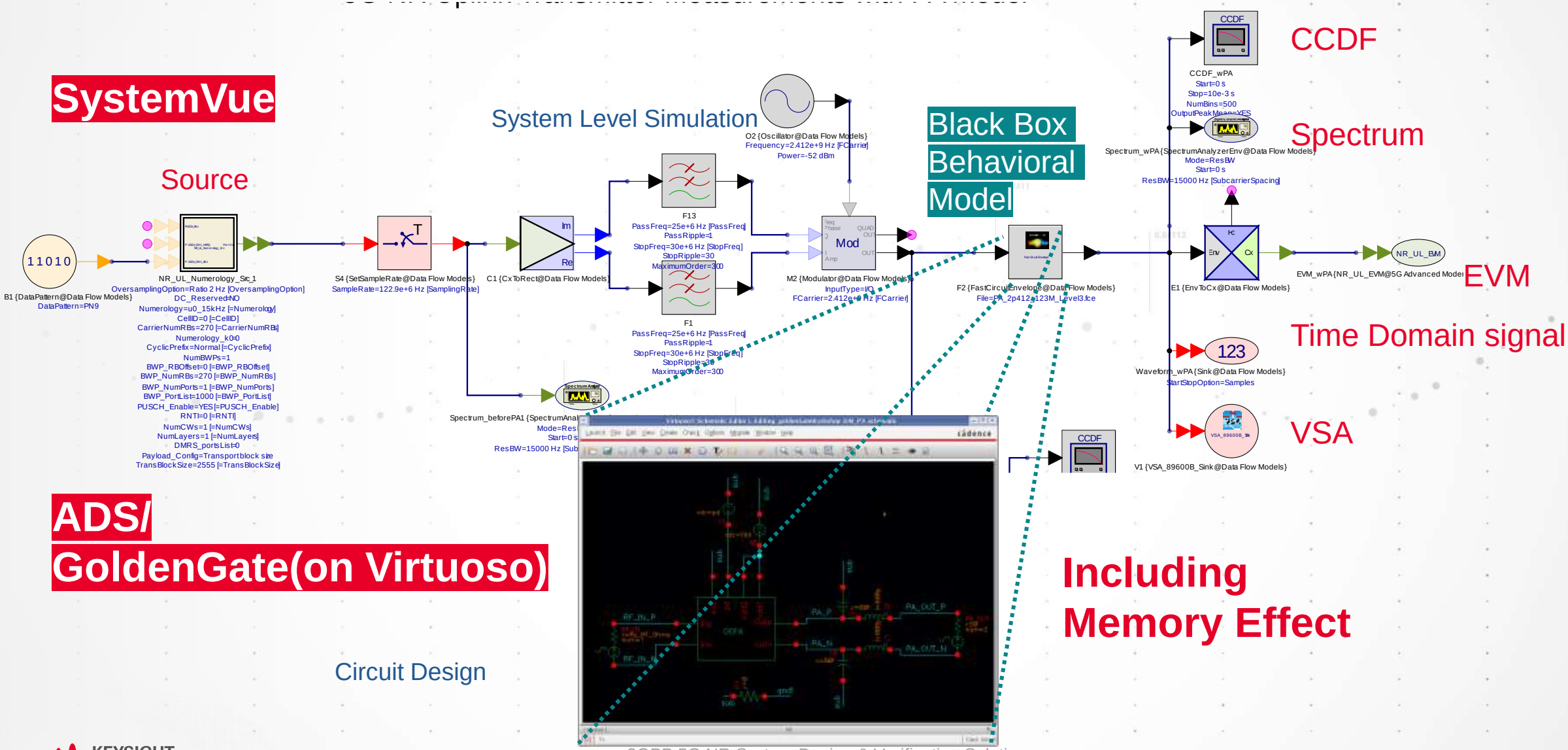


SIMULATE LOCALLY INSIDE ADS

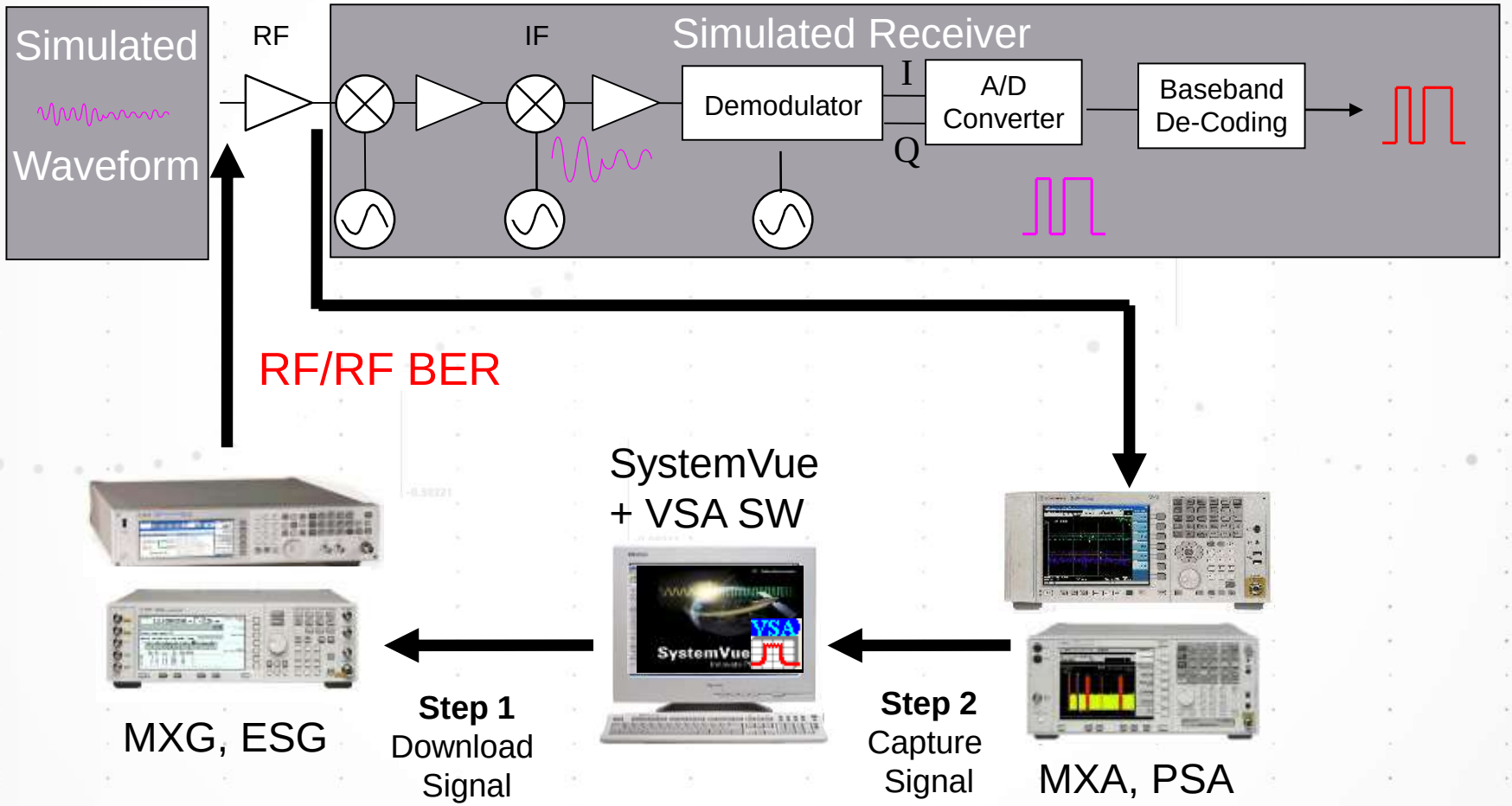
Verification Method 2: Fast-Circuit-Envelop Model

SystemVue

ADS/ GoldenGate(on Virtuoso)



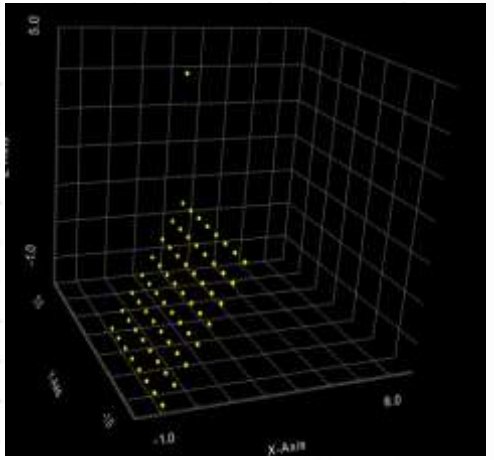
Early R&D Hardware Testing - *RF DUT*

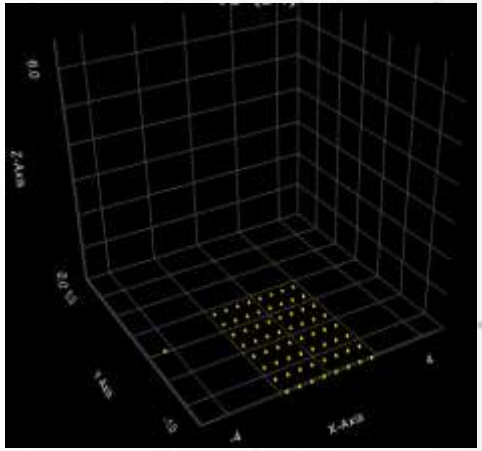


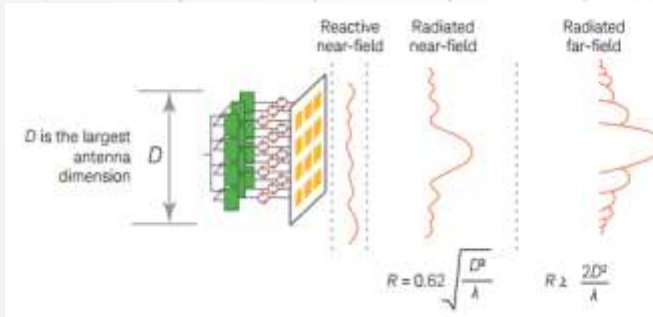
4. Over-The-Air(OTA) Simulation

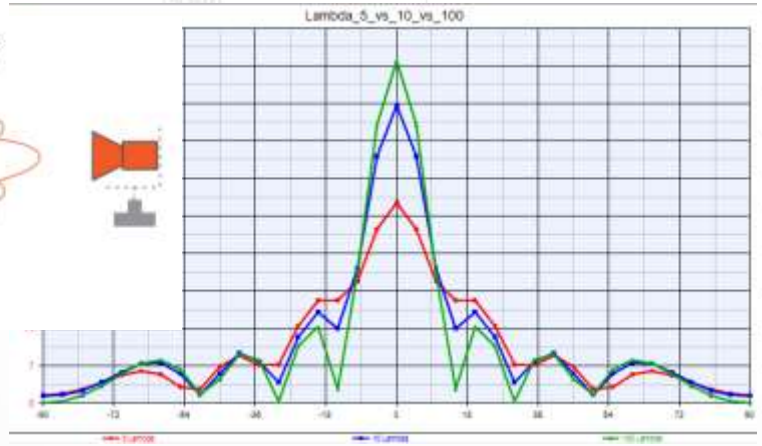
A Differentiator in Keysight OTA solution

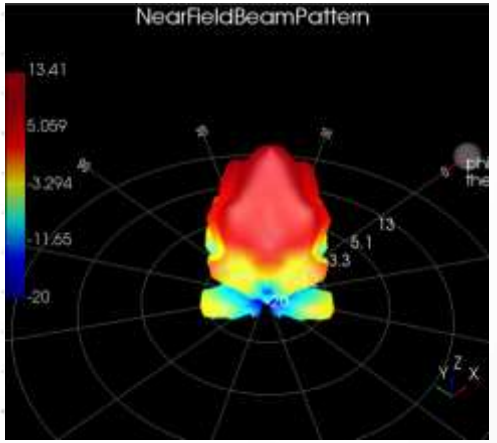
- OTA Tx & Rx
- Rotate array (with element patterns)
- Move probes (XYZ location & rotate probe pattern)
- Radiated near field and far field
- Dual-polarization & polarization mismatch
- Phase shift (narrowband) / time delay (wideband)

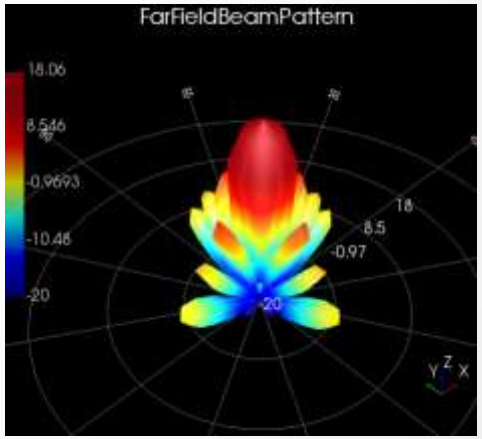




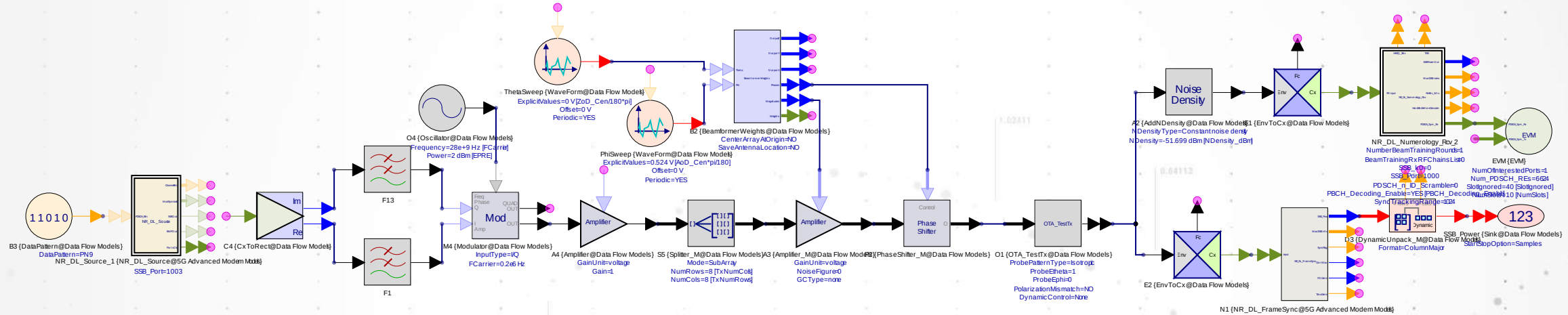


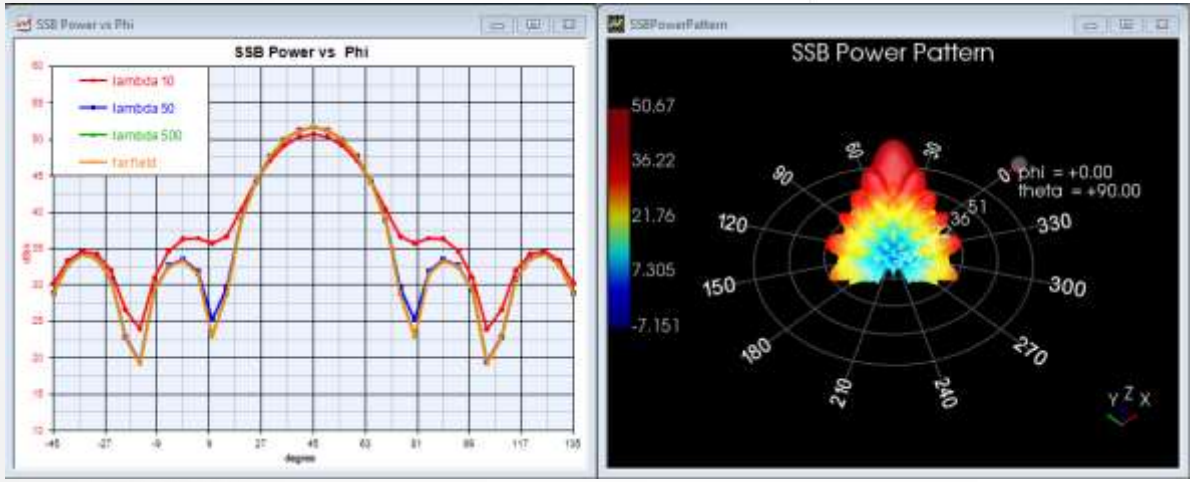


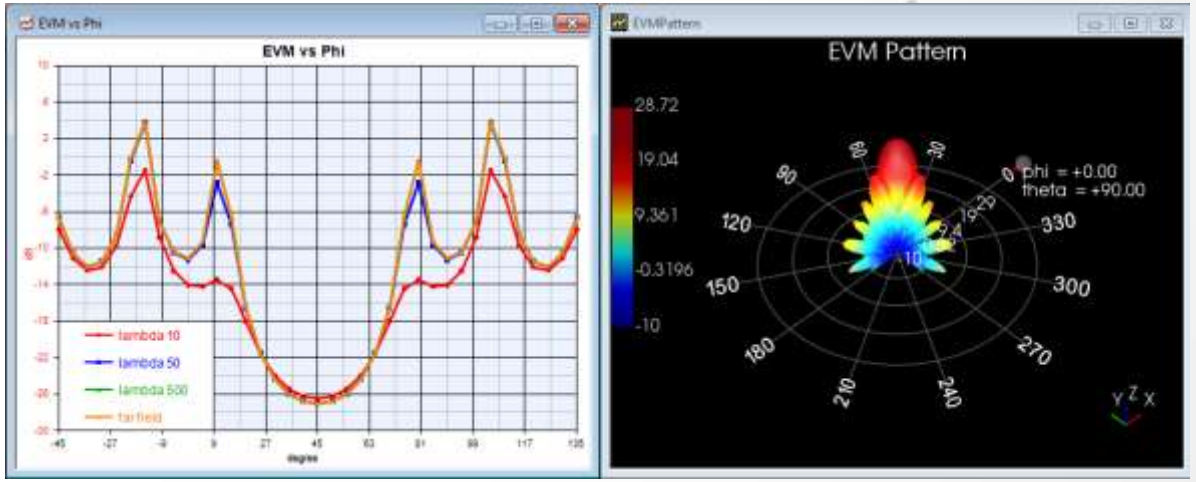




5G NR DL OTA Measurement Simulation

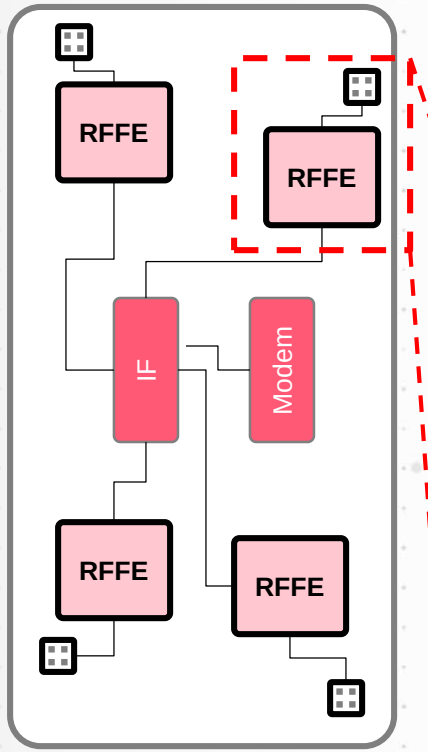




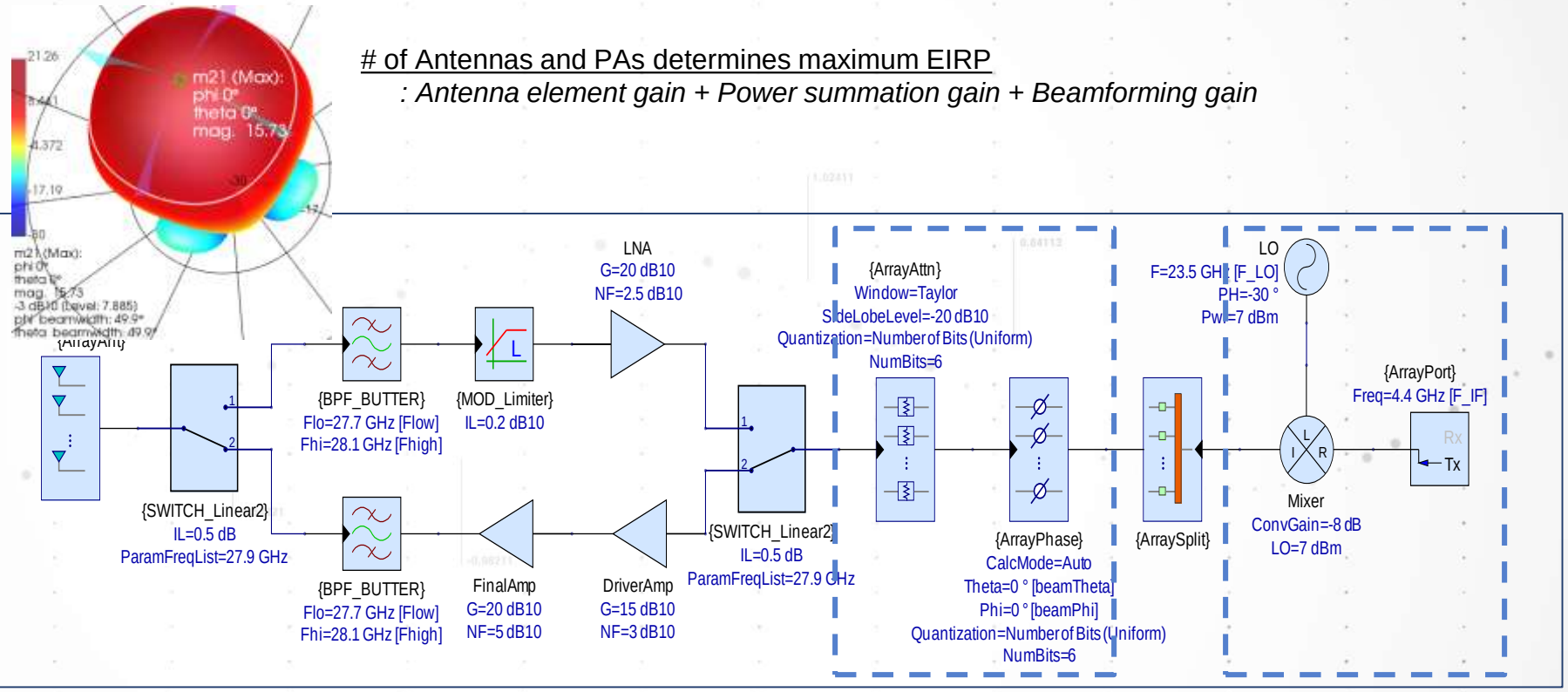


5. Phased Array and Beamforming

Antennas + Beamforming + Frequency Conversion



5G mmWave UE
Conceptual Block



# of Antennas and PAs determines maximum EIRP

: Antenna element gain + Power summation gain + Beamforming gain

mmWave RFFE Functionality

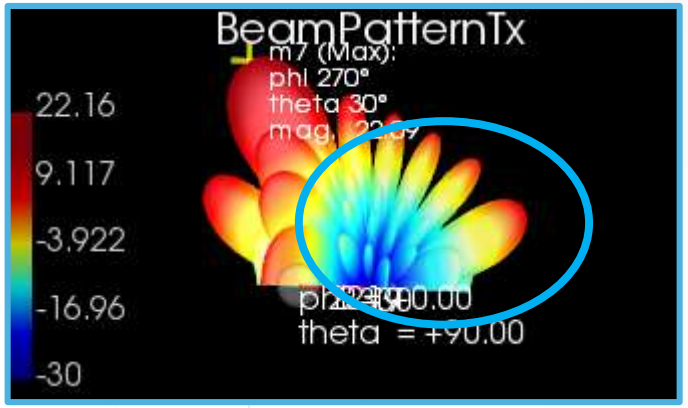
- Rx : T/R sw, VGA, PS, Combining, down-conversion
- Tx : T/R sw, PA, VGA, PS, Splitting, up-conversion

Characterization of mmWave Components

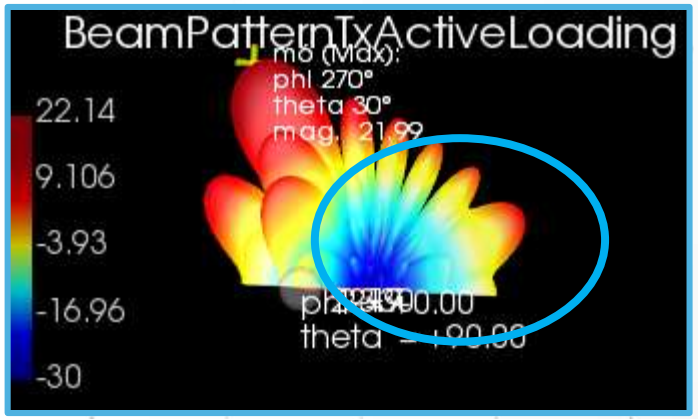
Array Antenna

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

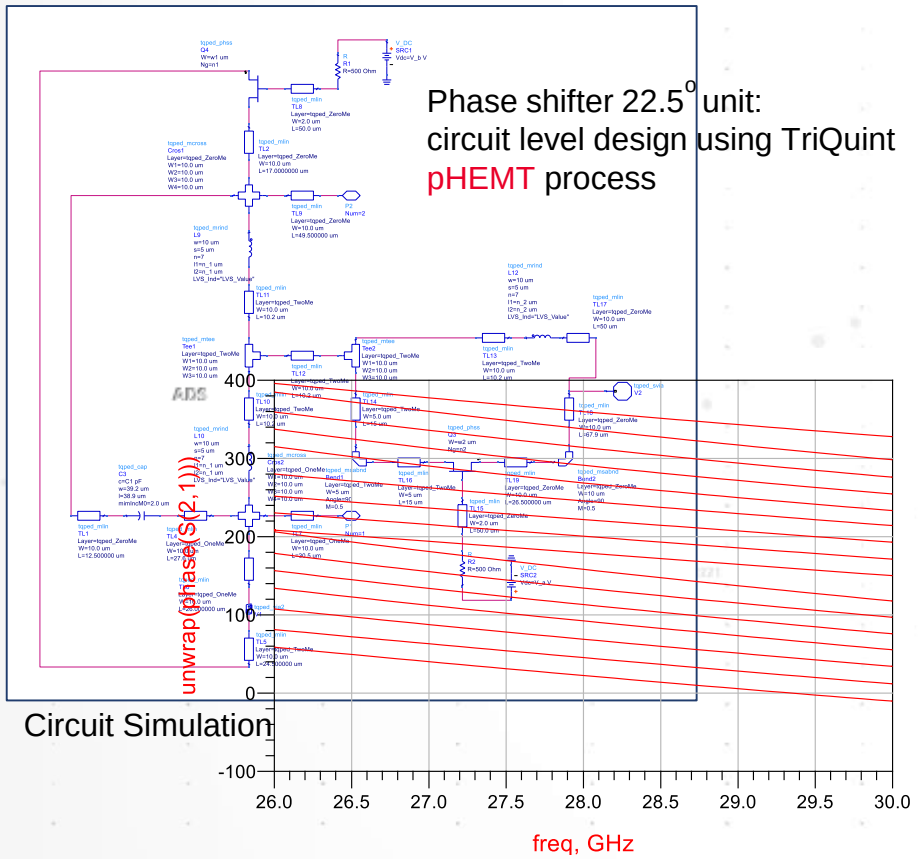


S-parameters

Increased null level from mutual coupling effect

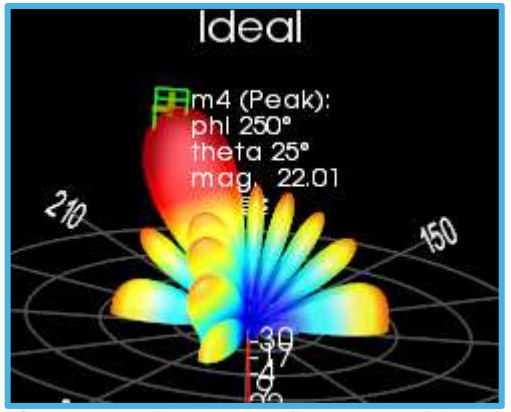
Characterization of mmWave Components

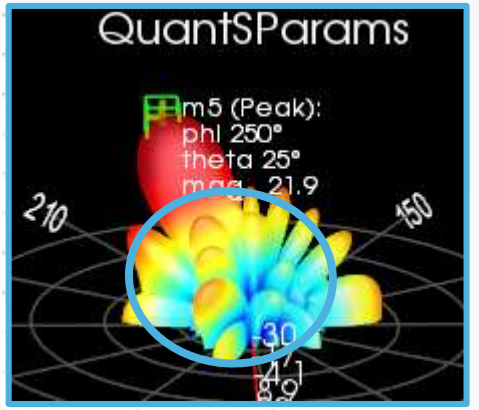
Phase Shifter / Digital Attenuator

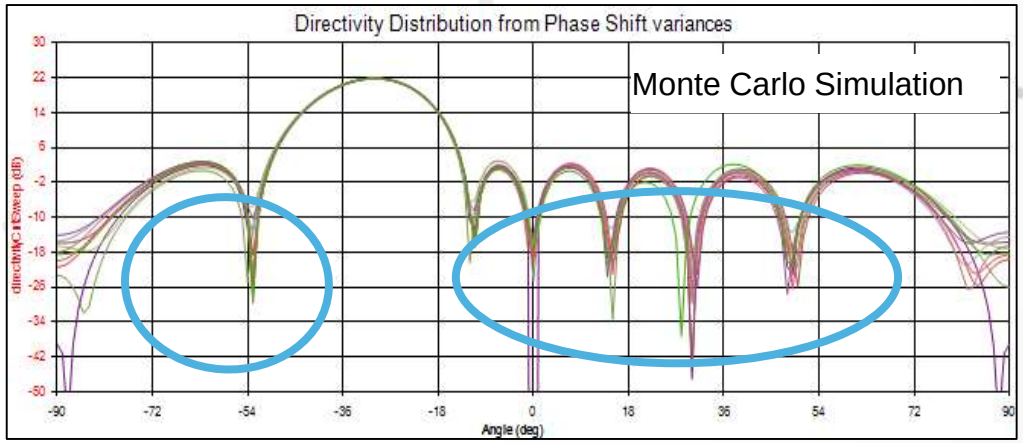


Circuit Simulation

Phase shifter 22.5^{o} unit:
circuit level design using TriQuint pHEMT process





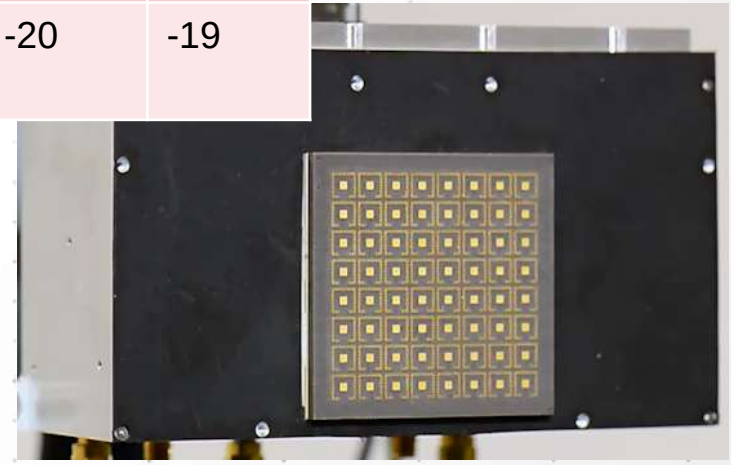


[component level characterization to system level beam quality analysis]

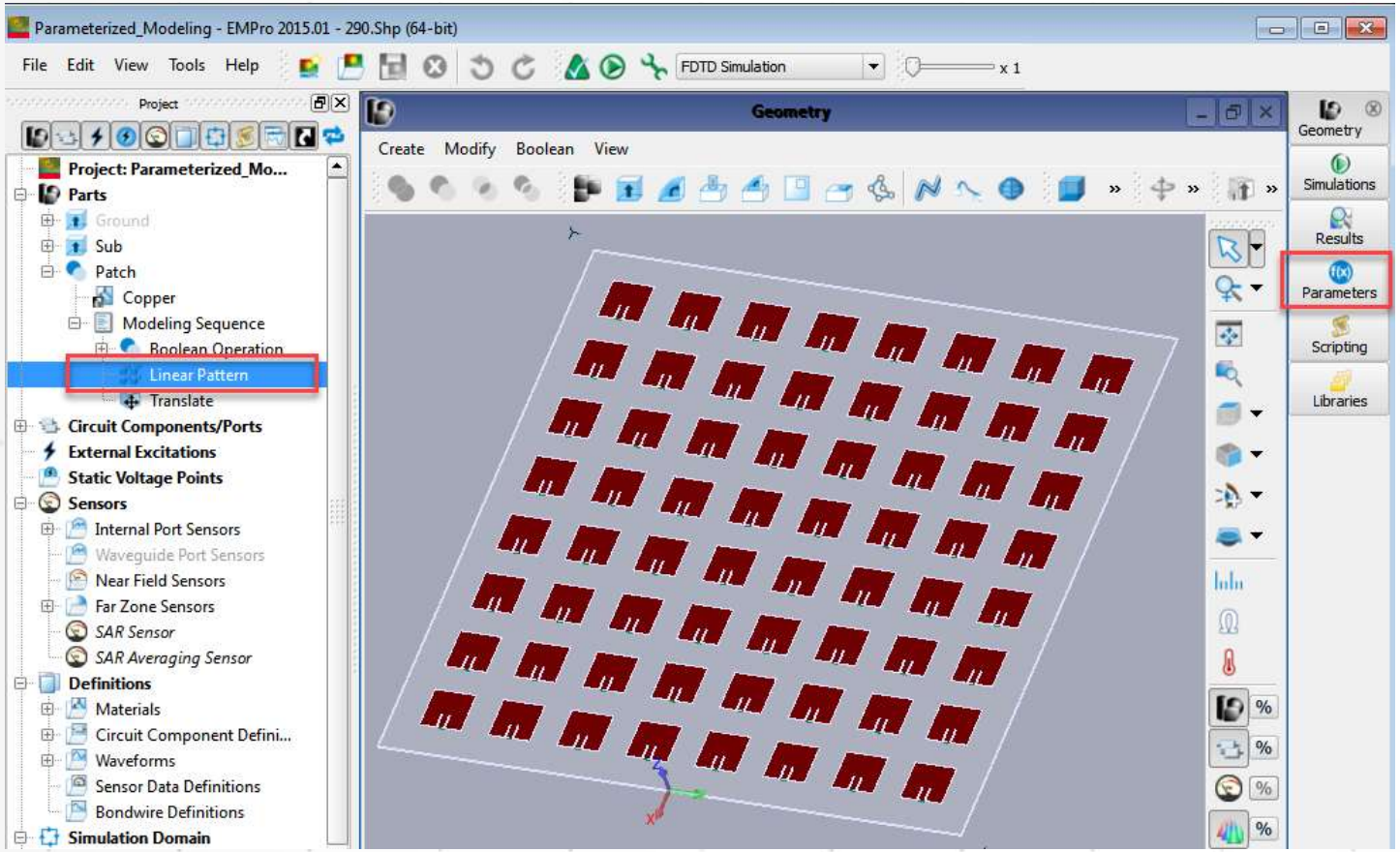
Simulation vs Measurement Results

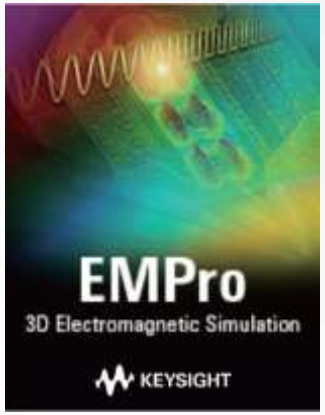
8x8 28GHz URA rf Beamformer RF-IF converter

Beam Direction	3dB Beamwidth (deg)		First Null Left (deg)		First Null Right (deg)		First Sidelobe Left (dB)		First Sidelobe Right (dB)	
	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
0 degree	12.2	12.0	-15	-15	15	14	-20	-19	-20	-18
30 degree	14.5	14.0	14	13	50	50	-20	-21	-20	-20
-30 degree	14.5	14.5	-50	-50	-14	-13	-20	-22	-20	-19

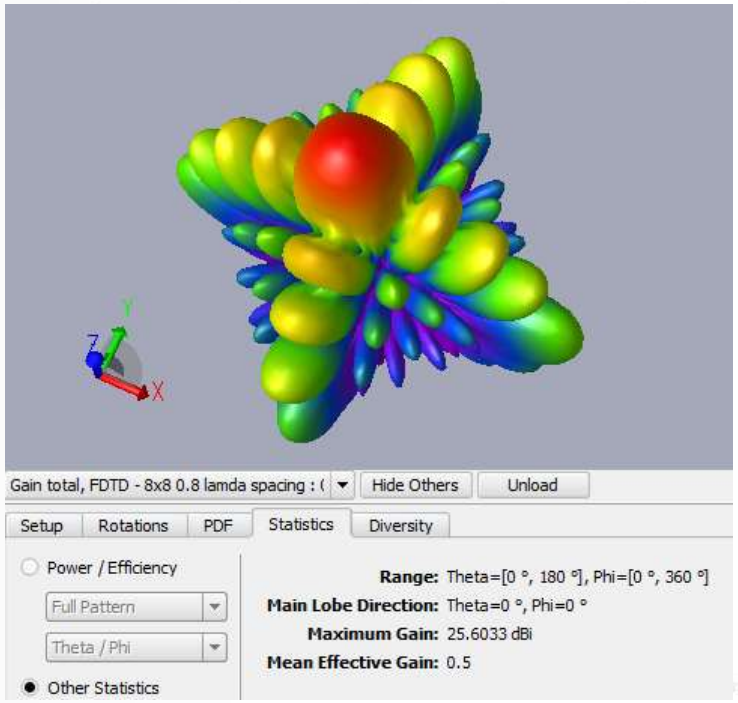


Phased Array Antenna Design -- EMPro



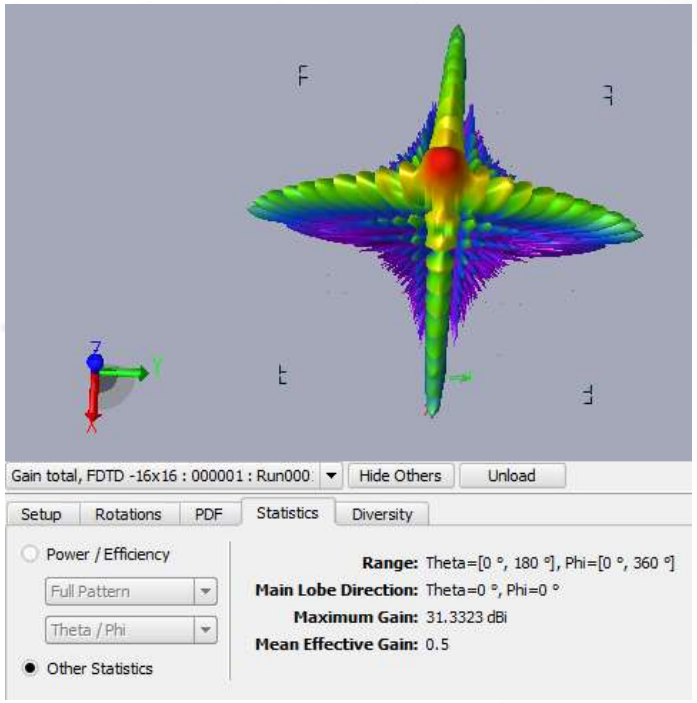


EMPro – 3D EM Simulation(FDTD)



8*8 (0.8 lamda spacing)

4 K80 GPU
4min，40s

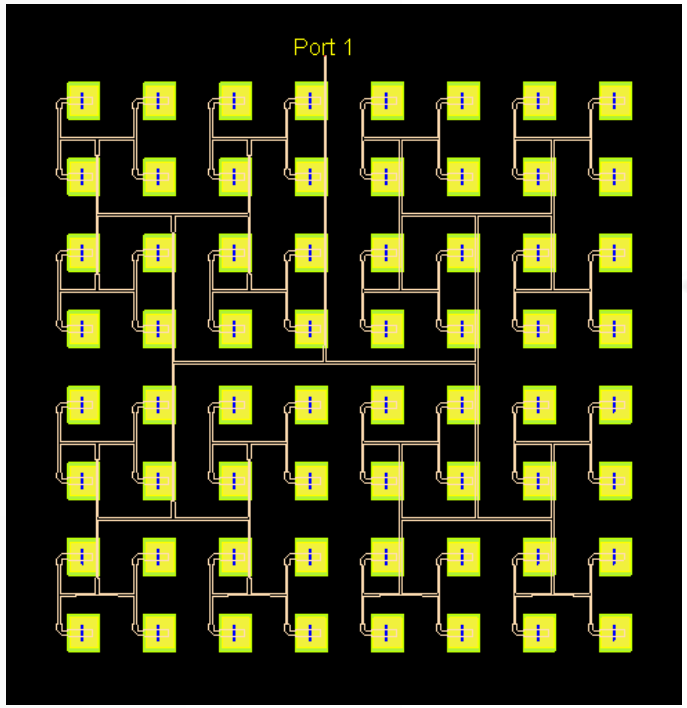


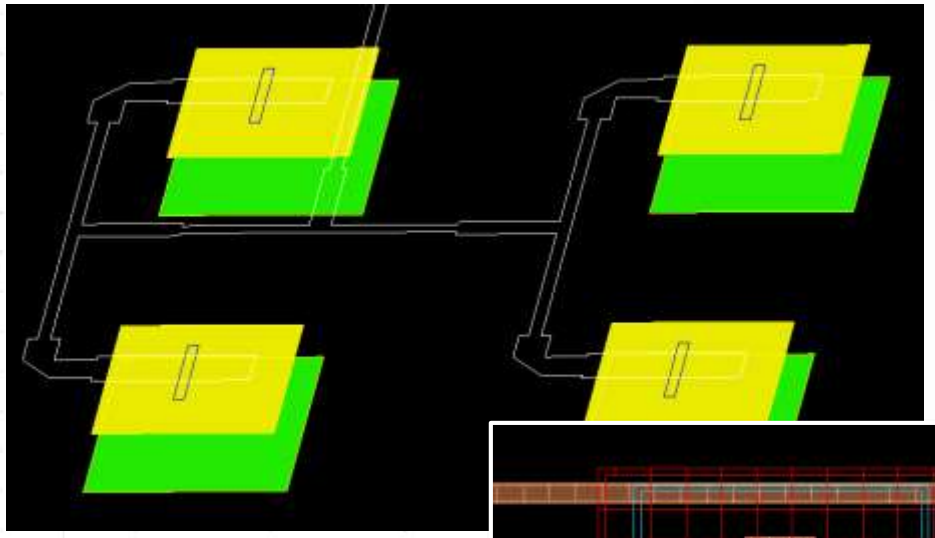
16*16

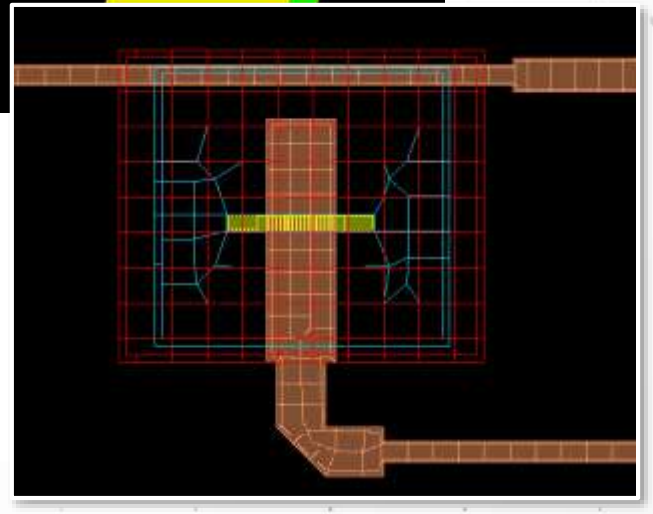
4 K80 GPU
27min，46s

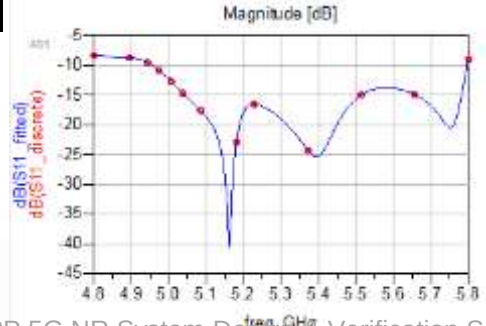
Planar Antenna: ADS Momentum 8x8 patch array

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



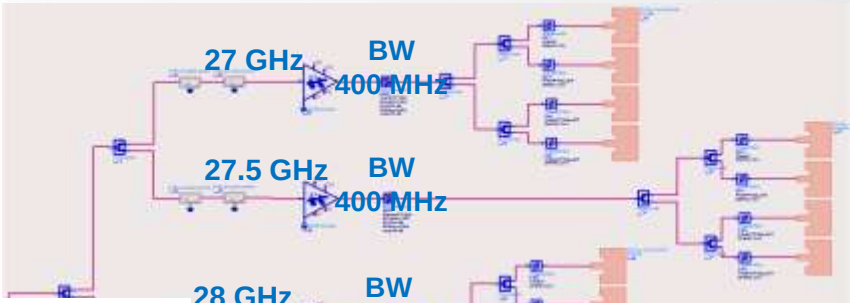


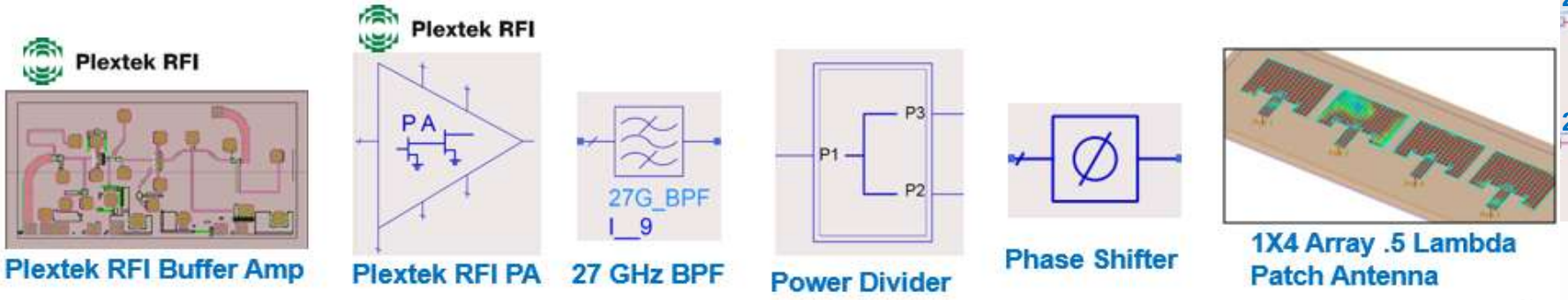


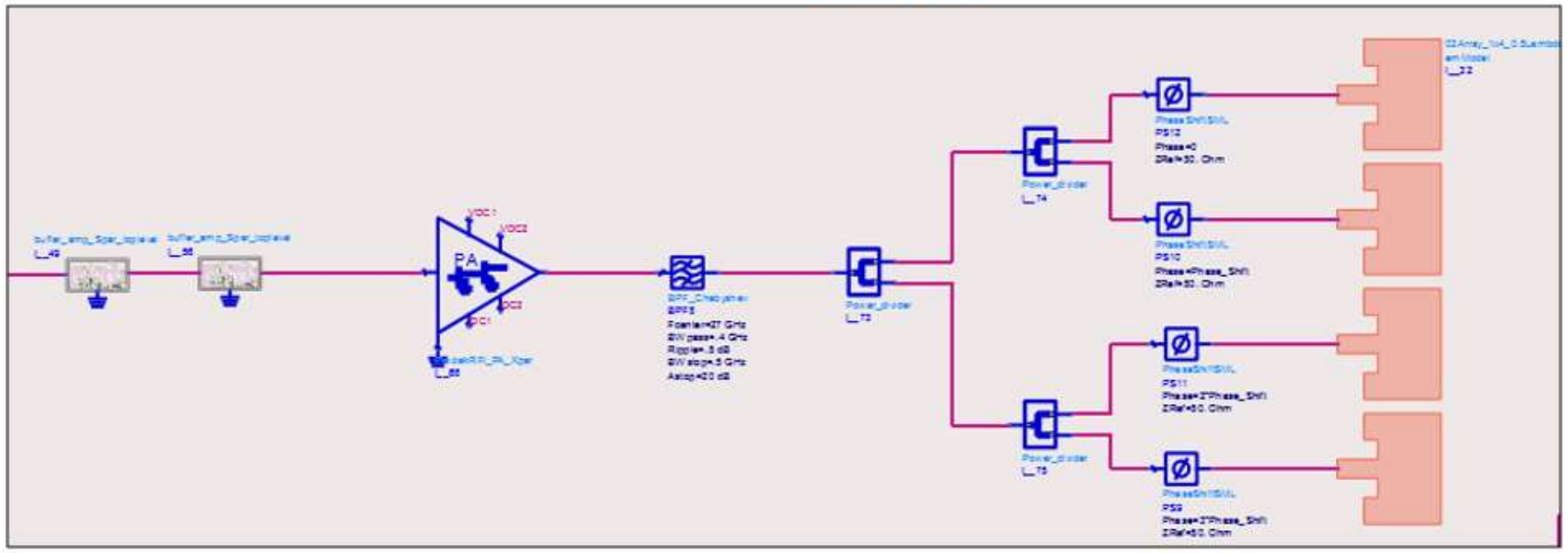


Transmitter

single pass sub-network

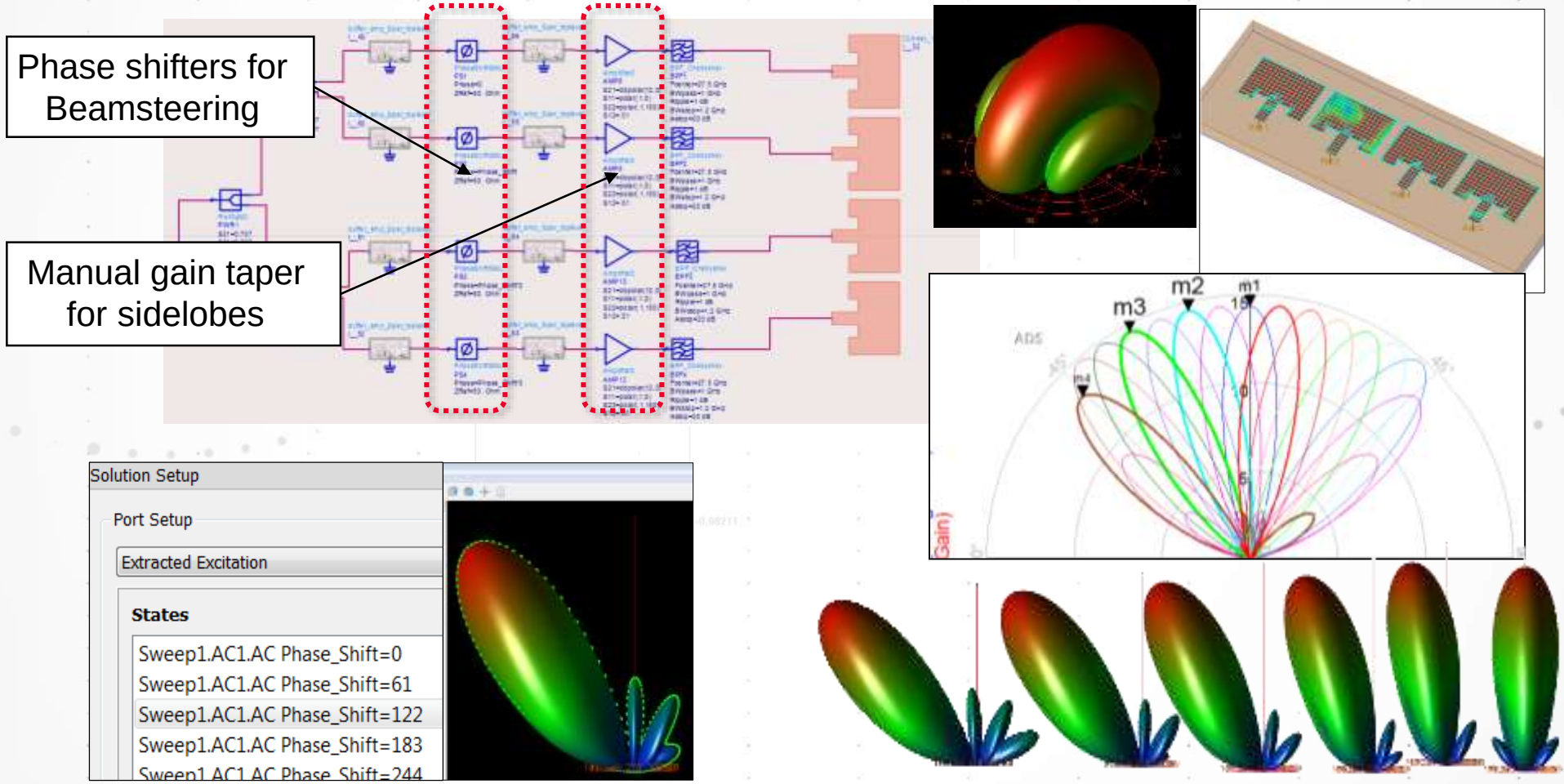






EM Co-Sim: 1x4 Transmitter Array in ADS/Momentum

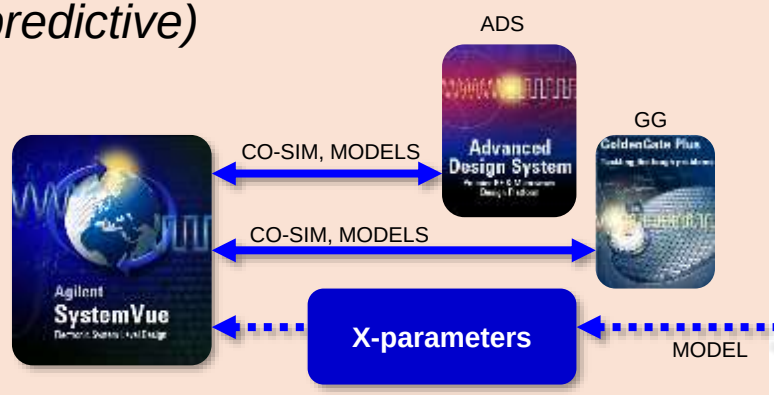
System / Circuit / EM Co-simulation and beam steering



6. Difficult System Level Engineering

SIMULATION-BASED DPD

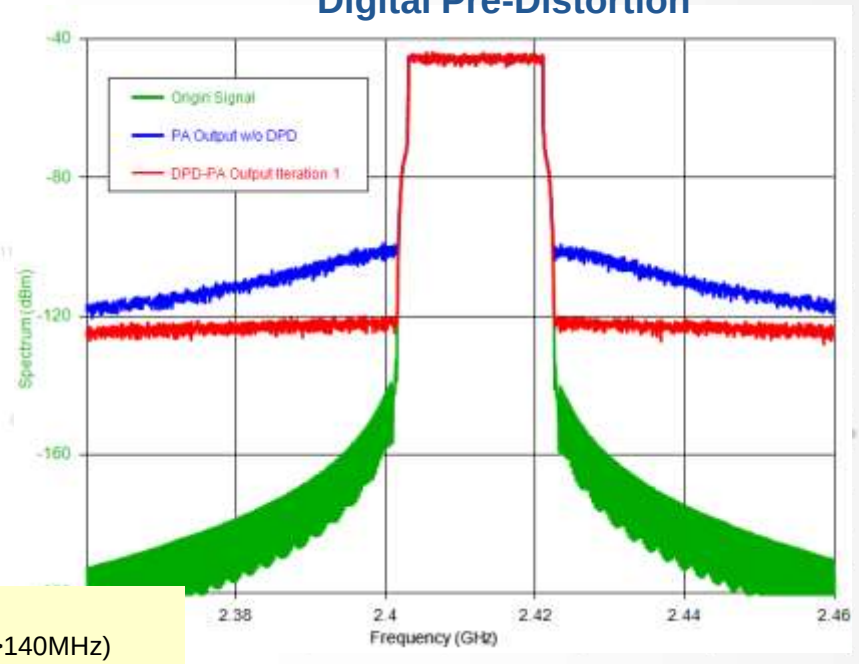
(predictive)



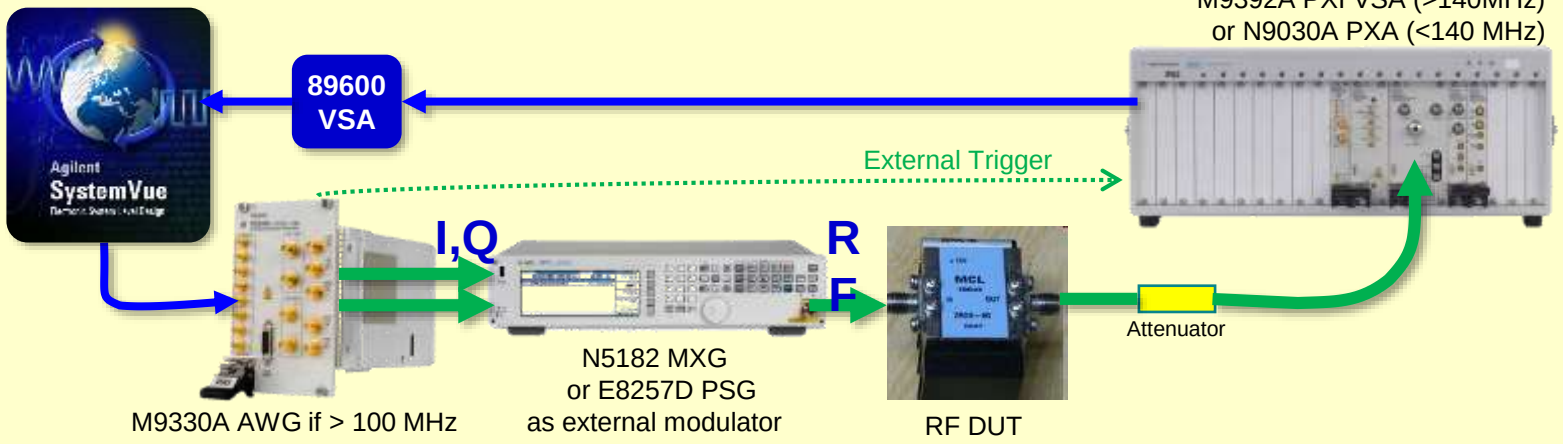
PA Model Extraction (Memory and Non-linear effect)

N5241,2 PNA-X RF DUT

Digital Pre-Distortion

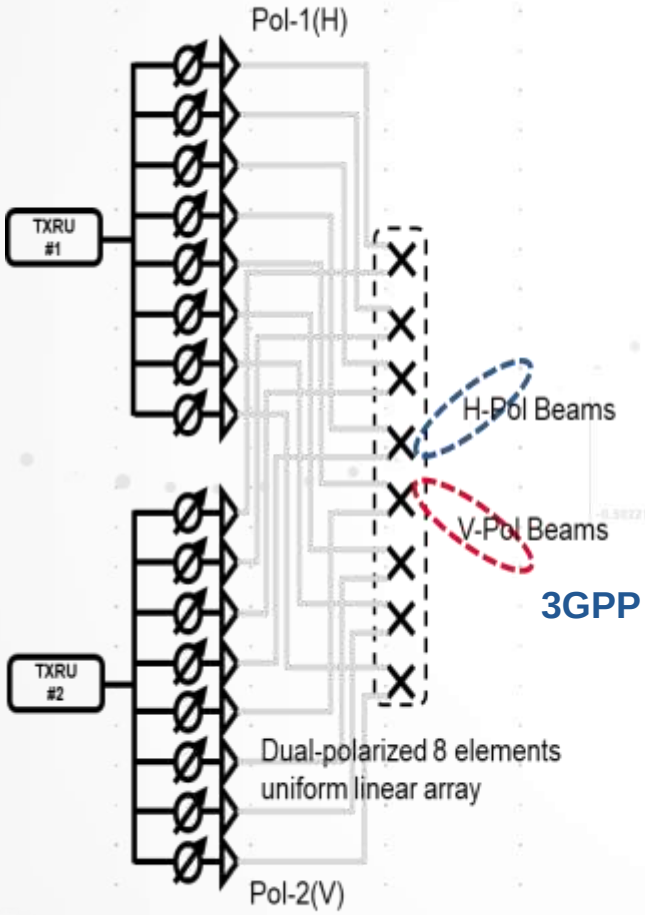


MEASUREMENT-BASED DPD



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]
- XPRindB: cross polarization ratio

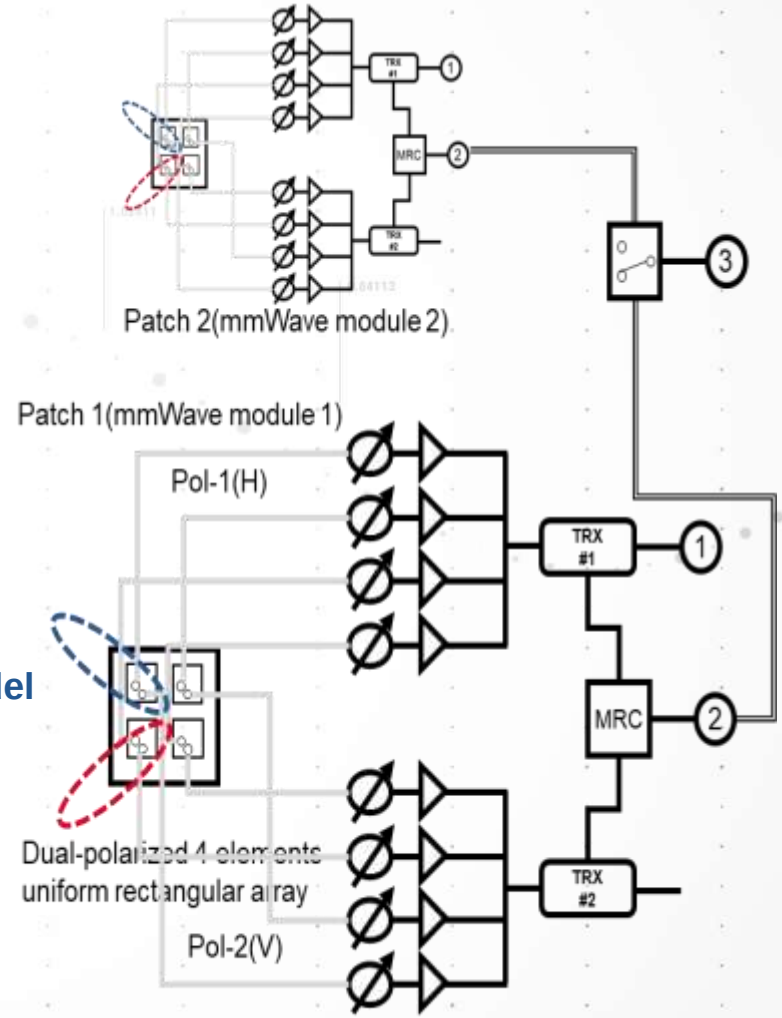
Antenna pattern files
- Complex vector components: Mag(Etheta, Ephi), Ang(Etheta, Ephi)
- PhaseCenter_Yes: antenna position information from pattern files
- PhaseCenter_No: antenna position information from user definition

3GPP mmW wireless channel model

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

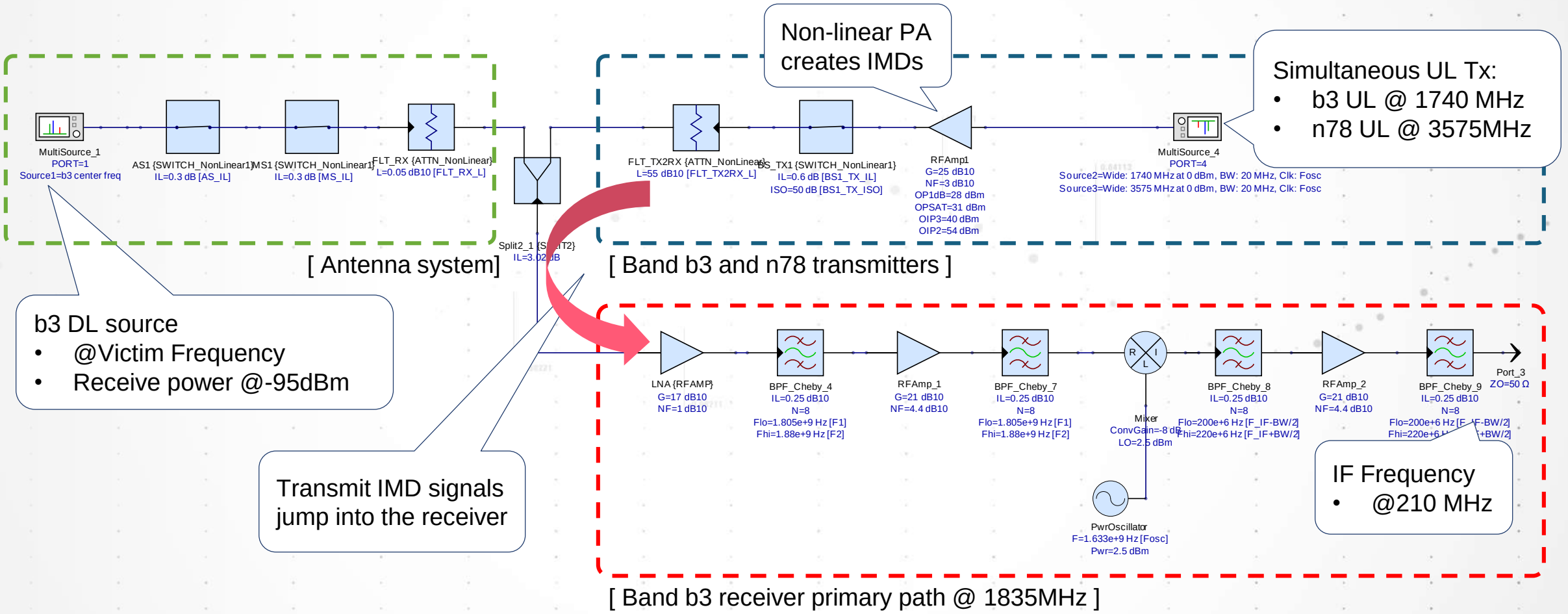
Scenario #2
- Number of stream (PDSCH_DMRS) : 1
- Diversity combining : Maximal Ratio Combining
- # of mmWave module: 1

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

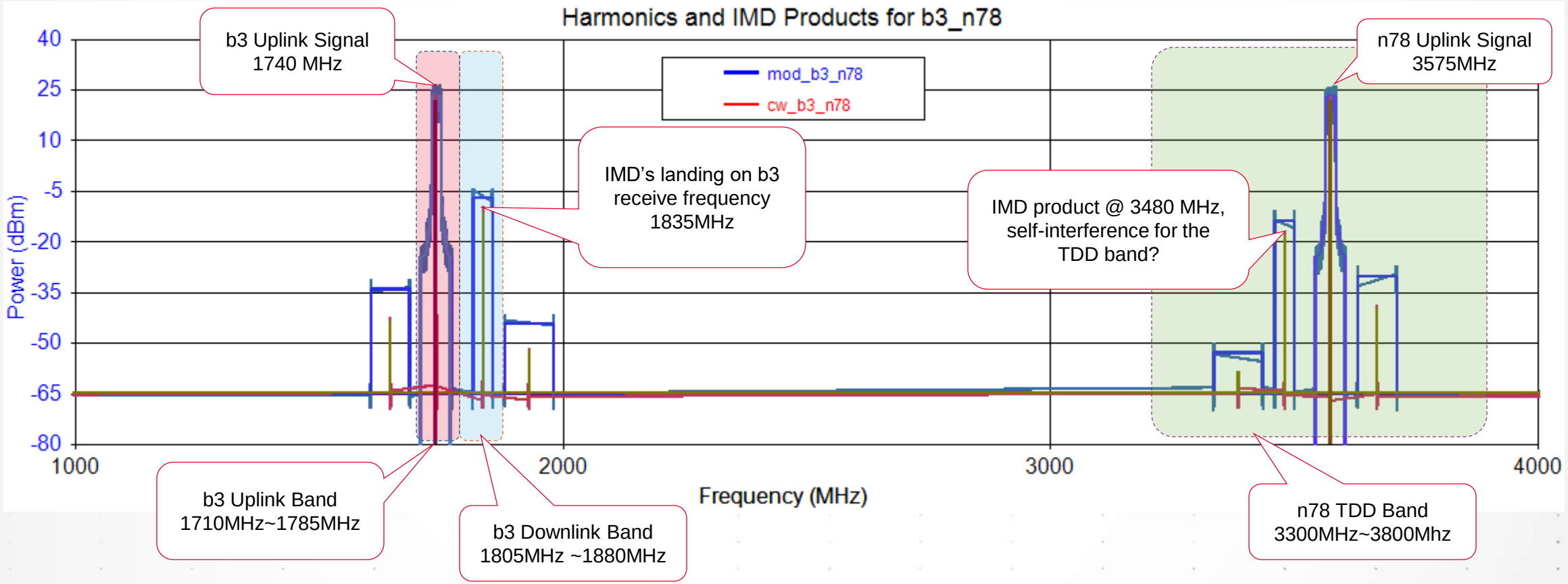


8. Multi-Radio Co-Existence

FR1 Transceiver Modeling in Frequency Domain



Transmitter Intermodulations



Customer Example

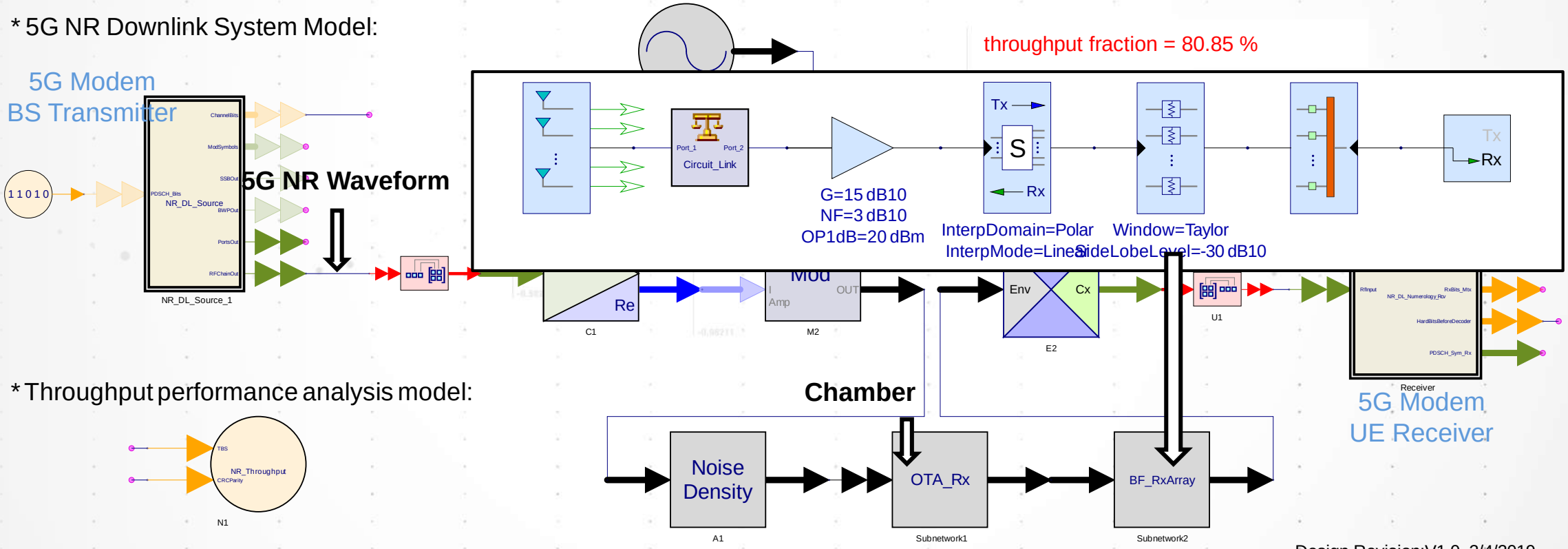
5G NR UE FR2 Radiated Receiver Characteristics

* Channel configuration information:

3GPP TS 38.521, Annex A DL Refereence Measurement Channel

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

* 5G NR Downlink System Model:



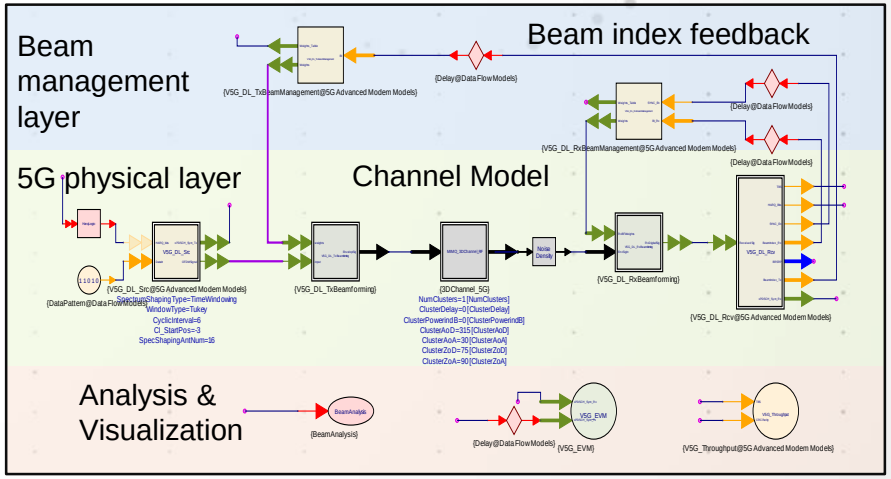
* Throughput performance analysis model:

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

Summary

- What You Can Do for 5G using SystemVue?
  - Standard Waveform Creation and Analysis
  - Link Level Performance
  - Over-The-Air(OTA) Simulation
  - Architecting RF Transceivers
  - Phased Array and Beamforming
  - Difficult System Engineering
  - Advanced End-To-End Link Performance
  - Multi-Radio Co-Existence

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

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