Design and Simulation of 5G 28-GHz Phased Array Transceiver Webcast
System / Circuit / EM Co-simulation with beam steering

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MMIC/Module Design Flow Specialist

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Introduction

• Why mm Wave Bands for 5G?
• Propagation issues at mm-wave for mobile communication
• Phased arrays and beam steering antennas

• 28GHz is one of the several candidate bands for the new 5G radio interface. Verizon has chosen 28 GHz for their pre-5G trial.
Agenda

• EM/Circuit Co-simulation / demo
• Transmit Chain components
  • Design and Simulation
  • Verification Test Bench (VTB) Simulation
• Analysis
• Transceiver Design Example
• Future work
  • EM/Circuit Co-simulation in ADS 2017
EM / Circuit Cosimulation

Antenna and other physical structures

Momentum Planar EM
Full 3D FEM Simulation
EM / Circuit Cosimulation

HB, S-Par, Envelope, Tran, DC, AC

Antenna and other physical structures

Momentum Planar EM
Full 3D FEM Simulation

Transceiver Components

Circuit level designs; X-parameter models, EM models, etc.
EM / Circuit Cosimulation

HB, S-Par, Envelope, Tran, DC, AC

Antenna and other physical structures

Momentum Planar EM
Full 3D FEM Simulation

Transceiver Components

Circuit level designs; X-parameter models, EM models, etc.

Complete EM / Circuit Simulation and Analysis

Captures the excitation from the T/R module and apply it to the Antenna(s)
The output from the circuit simulation drives/excites the Antenna ports

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28 GHz Transmit Chain with Patch Antenna System / Circuit / EM Co-simulation and beam steering
Transmit Chain with Patch Antenna
System / Circuit / EM Co-simulation and beam steering

Power Divider
Plextek RFI Buffer Amp
28 GHz BPF
Phase Shifter
Plextek RFI PA
4X4 Array .5 Lambda Patch Antenna

buffer_amp_Spar
buffer_amp_Spar
28G_BPF
cascade_phase_shifter
X16
state=3*state
28 GHz Power Divider

Designed with: TriQuint PHEMT process
Mm-Wave Small Signal Amps

28 GHz Buffer Amplifier

Plextek RFI

mm-Wave small signal Amp

Designed with: TriQuint PHEMT process
28 GHz Filter Response

28 GHz BPF

28 GHz Filter Response

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Page 11
Mm-Wave Power Amplifier

Designed with:
GCS InP_DHBT Process

Global Communications Semiconductors
X-Parameters

- Accurately captures all non-linearties
- Protects your IP
- Much faster simulation speed and trade-off analysis in hierarchical system design and verification.
- Accurate load pull modeling capability

Circuit Topology

X-parameter Model
X-Parameters

Overlaid Results

Model (Red) Vs. Circuit (Blue)

These values are with the available source power set to the value selected by the marker "Pindex."

<table>
<thead>
<tr>
<th>Maximum Power-Added Efficiency, %</th>
<th>Maximum Power Delivered, dBm</th>
<th>Transducer Power Gain</th>
<th>Compression</th>
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<tbody>
<tr>
<td>12.67</td>
<td>25.99</td>
<td>25.990</td>
<td>1.078</td>
</tr>
</tbody>
</table>

Move marker to specify available source power. The contour plots will be updated.
Mm-Wave Power Amplifier

Pin / Pout and Phase Response of PA

Circuit Sim – Red
X-Par model – Blue

Designed with:
GCS InP_DHBT Process

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Creating 16 X-Par models of Varied Pout and Phase
Using a Four Bit Phase Shifter (with 22.5 degree phase increments)

4 bit (16 States) Phase Shifter

22.5 deg

45 deg

90 deg

180 deg

Designed with: TriQuint PHEMT process
Calculating Phase Shifter Phase Error

When circuit 1 is “ON”, circuit 2 is “OFF”
When circuit 1 is “OFF”, circuit 2 is “ON”
SS_Gain = 32.75 dB
LS_Gain = 31.65 dB @ Pin = -3 dBm  (Pout = 28.65 dBm)
LS_Gain = 29.44 dB @ Pin =  1 dBm  (Pout = 30.44 dBm)
HB Analysis

SS_Gain = 40 dB
LS_Gain = 38.8 dB @ Pin = -10 dBm (Pout = 28.8 dBm)
LS_Gain = 37.2 dB @ Pin = -7 dBm (Pout = 30.2 dBm)

Behavioral level designs

Gain = 40 dB
P -1dB = 28.8 dBm @ Pin -10 dBm
Patch Antenna Design

Adaptively Fitted Points
Discrete Frequency Points

Magnitude [dB]

$\text{m}_1$
$\text{freq}=26.51\text{GHz}$
$\text{db}(S_{11}\text{, fitted})=-10.338$

$\text{m}_2$
$\text{freq}=28.51\text{GHz}$
$\text{db}(S_{11}\text{, fitted})=-9.963$

$H=.794\text{ mm}$
$E_r=2.2$
$\text{TanD}=.0009$
Antenna Array configurations

Uniform Linear  Uniform Rect.  Triangular  Circular  3D/Conformal
Patch Antenna Design (4X4 array – ½ Lambda)

Momentum Planar EM Simulation

4X4 Patch Antenna Return Loss at its 16 Ports

freq, GHz

25.0 25.5 26.0 26.5 27.0 27.5 28.0 28.5 29.0 29.5 30.0

-40 -35 -30 -25 -20 -15 -10 -5 0

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The main beam always points in the direction of the increasing phase shift.
Well, if the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift now, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. **The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is 120° (60° left and 60° right).** With the sine theorem the necessary phase moving can be calculated.
Applying Phase Shift to Antenna Ports

http://www.radartutorial.eu/06.antennas/Phased%20Array%20Antenna.en.html

The phase shift $\Delta \phi$ between two successive elements is constant and is called phase-increment.

\[ x = d \cdot \sin \Theta_s \]

\[
\frac{360^\circ}{\Delta \phi} = \frac{\lambda}{x}
\]

$\Delta \phi =$ phase shift between two successive elements
$d =$ distance between the radiating elements
$\Theta_s =$ beam steering
Applying Phase Shift to Antenna Ports

Enter the numbers in the Red Equations

Wavelength Calculator

Center Frequency = freq1
Speed of light = c = 3e11 mm/sec
Wavelength (mm) = \( w = \frac{c}{freq1} \)

\[ w = \frac{3 \times 10^{11}}{freq1} \]

\[ w = 10.7 \]

Phase Shift Angle Calculator

Wavelength in mm = \( w \)
Distance between patches in mm = \( d \)
Desired Antenna Look-up Angle = angle

\[ d = \frac{6.36}{w} \]

Most common \( d = \frac{1}{2} \) Wavelength

\[ \text{Phase Shift} = 360^\circ \times \sin \left( \frac{3.14 \times \text{angle} \times 180}{180} \right) \]

\[ \text{Phase Shift} = 31.2 \]

Antenna Lookup Angle Calculator

\[ \text{Phase Shift} = 22.5 \]

\[ \text{Lookup Angle} = \sin \left( \frac{3.14 \times (\text{Phase Shift} \times w)}{(360^\circ \times d) \times 180} \right) \]

\[ \text{Lookup Angle} = 7.2 \]

<table>
<thead>
<tr>
<th>Phase Shift</th>
<th>Antenna look-up angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>61.5 degrees</td>
<td>20 degrees</td>
</tr>
<tr>
<td>31.2</td>
<td>10</td>
</tr>
<tr>
<td>22.5</td>
<td>7.2</td>
</tr>
</tbody>
</table>
Sweeping the Phase Shifter for Different Look-up Angles

PARAMETER SWEEP

ParamSweep
Sweep2
SweepVar="state"
Start=0
Stop=16
Step=1

VAR
VAR4
state=1

AC
AC1
Start=
Step=
Freq=28 GHz

Phase Shift | Antenna look-up angle
---|---
61.5 degrees | 20 degrees
31.2 | 10
22.5 | 7.2

28 GHz Transmit Chain with (4X4) 16 patch Antenna System / Circuit / EM Co-Simulation with Beam Steering
Momentum Visualization – Far Field Cut

Antenna incremental look-up angle = 7.2 degrees
Momentum Visualization – Far Field Cut

Antenna incremental look-up angle = 7.2 degrees

7.2 degrees
Momentum Visualization – Far Field Cut

21.6 degrees
Momentum Visualization – Far Field Cut

28.8 degrees
Momentum Visualization – Far Field Cut

36.0 degrees
Momentum Visualization – Far Field Cut

43.2 degrees
Momentum Visualization – Far Field Cut

50.4 degrees
The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is 120° (60° left and 60° right).
Momentum Visualization – Far Field Cut

- 50.4 degrees
Momentum Visualization – Far Field Cut

- 36.0 degrees
Momentum Visualization – Far Field Cut

- 28.8 degrees
Momentum Visualization – Far Field Cut

- 21.6 degrees
Momentum Visualization – Far Field Cut

- 14.4 degrees
Momentum Visualization – Far Field Cut

- 7.2 degrees
Momentum Visualization – Far Field Cut
Harmonic Balance - Sweep Pin for each state

Swept power for each phase state
For Multi Band Systems, select the channel frequency and sweep the phase.
EM Circuit Excitation for Multi Band Systems
Switched Beam Systems and Isolation
Four Channel Switched Beam System

SP4T_v4a_EM2 schematic

SPDT_Static
SWITCH1
State=0
Loss1=5 dB
VSWR1=1.1
Isolat=10 dB

PwrSplit2
PWR28
S21=0.707
S31=0.707

SPDT_Static
SWITCH4
State=1
Loss1=5 dB
VSWR1=1.1
Isolat=10 dB

Switch

28 GHz

Antenna 1
Antenna 2
Antenna 3
Antenna 4
SP4T Pin Diode Switch

32 - 38 dB isolation

< - 20 dB Return Loss
**Effect of Isolation with SP4T Pin Diode Switch**

*Good isolation; low leakage*

### Antenna 1 (ON)

<table>
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<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>28</td>
</tr>
<tr>
<td>Input power (Watts)</td>
<td>30.73 dBm</td>
</tr>
<tr>
<td>Radiated power (Watts)</td>
<td>30.14 dBm</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>12.4233</td>
</tr>
<tr>
<td>Gain (dBi)</td>
<td>11.8327</td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>87.2851</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>1.43544</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>0.719247</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>20, 95</td>
</tr>
<tr>
<td>E(\theta) max (mag, phase)</td>
<td>32.7705, 7.01924</td>
</tr>
<tr>
<td>E(\phi) max (mag, phase)</td>
<td>2.76503, -168.687</td>
</tr>
<tr>
<td>E(x) max (mag, phase)</td>
<td>0.215614, 80.0633</td>
</tr>
<tr>
<td>E(y) max (mag, phase)</td>
<td>30.9173, 7.05268</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>11.2082, -172.981</td>
</tr>
</tbody>
</table>

### Antenna 2 (OFF)

<table>
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<th>Value</th>
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<tbody>
<tr>
<td>Frequency (GHz)</td>
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</tr>
<tr>
<td>Input power (Watts)</td>
<td>-0.43 dBm</td>
</tr>
<tr>
<td>Radiated power (Watts)</td>
<td>-1.02 dBm</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>12.3942</td>
</tr>
<tr>
<td>Gain (dBi)</td>
<td>11.8038</td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>87.2898</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>0.00109234</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>0.724093</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>19, 89</td>
</tr>
<tr>
<td>E(\theta) max (mag, phase)</td>
<td>0.90677, 128.362</td>
</tr>
<tr>
<td>E(\phi) max (mag, phase)</td>
<td>0.0283236, 152.951</td>
</tr>
<tr>
<td>E(x) max (mag, phase)</td>
<td>0.0159763, -4.11212</td>
</tr>
<tr>
<td>E(y) max (mag, phase)</td>
<td>0.857687, 128.376</td>
</tr>
<tr>
<td>E(z) max (mag, phase)</td>
<td>0.295215, -51.6379</td>
</tr>
</tbody>
</table>

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Modeling the Switch in ADS

SPDT_Static
SWITCH1
State=0
Loss1=.5 dB
VSWR1=1.1
Isolat=35 dB

PwrSplit2
PWR28
S21=0.707
S31=0.707

SPDT_Static
SWITCH4
State=1
Loss1=.5 dB
VSWR1=1.1
Isolat=35 dB

>30 dB isolation
Using a Switch with 35 dB Isolation

**Good isolation; low leakage**

### Antenna 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Frequency (GHz)</td>
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<tr>
<td>Input power (Watts)</td>
<td>0.978996</td>
</tr>
<tr>
<td>Radiated power (Watts)</td>
<td>0.85567</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>12.4312</td>
</tr>
<tr>
<td>Gain (dBi)</td>
<td>11.8464</td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>87.4028</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>1.19182</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>0.71795</td>
</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>20 93</td>
</tr>
<tr>
<td>E(theta) max (mag,phase)</td>
<td>29.9341 -41.8171</td>
</tr>
<tr>
<td>E(phi) max (mag,phase)</td>
<td>1.39354 139.278</td>
</tr>
<tr>
<td>E(x) max (mag,phase)</td>
<td>0.085041 119.957</td>
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<tr>
<td>E(y) max (mag,phase)</td>
<td>28.1632 -41.8143</td>
</tr>
<tr>
<td>E(z) max (mag,phase)</td>
<td>10.2381 138.183</td>
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</tbody>
</table>

### Antenna 2

**Good isolation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Frequency (GHz)</td>
<td>28</td>
</tr>
<tr>
<td>Input power (Watts)</td>
<td>0.000566996</td>
</tr>
<tr>
<td>Radiated power (Watts)</td>
<td>0.00049404</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>12.3942</td>
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<tr>
<td>Gain (dBi)</td>
<td>11.8038</td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>87.2898</td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>0.000683482</td>
</tr>
<tr>
<td>Effective angle (Steradians)</td>
<td>0.724092</td>
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<td>Angle of U Max (theta, phi)</td>
<td>19 89</td>
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<tr>
<td>E(theta) max (mag,phase)</td>
<td>0.717269 -41.8854</td>
</tr>
<tr>
<td>E(phi) max (mag,phase)</td>
<td>0.0224044 -17.2967</td>
</tr>
<tr>
<td>E(x) max (mag,phase)</td>
<td>0.0126375 -174.36</td>
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<td>E(y) max (mag,phase)</td>
<td>0.678443 -41.8717</td>
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<tr>
<td>E(z) max (mag,phase)</td>
<td>0.23352 138.115</td>
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</tbody>
</table>
Using a Switch with 20 dB Isolation

**Bad isolation; high leakage**

### Antenna 1

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<tr>
<th>Parameter</th>
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<th>Value 2</th>
</tr>
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<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>Input power (Watts)</td>
<td>29.91 dBm</td>
<td>0.978711</td>
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<td>Radiated power (Watts)</td>
<td>29.32 dBm</td>
<td>0.855422</td>
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<tr>
<td>Directivity (dBi)</td>
<td>12.4312</td>
<td></td>
</tr>
<tr>
<td>Gain (dBi)</td>
<td>11.8465</td>
<td></td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>87.403</td>
<td></td>
</tr>
<tr>
<td>Maximum intensity (Watts/Steradian)</td>
<td>1.19149</td>
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<tr>
<td>Effective angle (Steradians)</td>
<td>0.717943</td>
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</tr>
<tr>
<td>Angle of U Max (theta, phi)</td>
<td>20</td>
<td>93</td>
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<tr>
<td>E(theta) max (mag, phase)</td>
<td>29.9299</td>
<td>-41.8515</td>
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<tr>
<td>E(phi) max (mag, phase)</td>
<td>1.39343</td>
<td>139.242</td>
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<td>0.084937</td>
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<tr>
<td>E(y) max (mag, phase)</td>
<td>28.1593</td>
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<tr>
<td>E(z) max (mag, phase)</td>
<td>10.2366</td>
<td>138.148</td>
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### Antenna 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
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<tbody>
<tr>
<td>Frequency (GHz)</td>
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<tr>
<td>Input power (Watts)</td>
<td>12.54 dBm</td>
<td>0.0179474</td>
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<tr>
<td>Radiated power (Watts)</td>
<td>11.95 dBm</td>
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<td>Directivity (dBi)</td>
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<td>Gain (dBi)</td>
<td>11.8043</td>
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<td>Radiation efficiency (%)</td>
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<td>Maximum intensity (Watts/Steradian)</td>
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<td>Effective angle (Steradians)</td>
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<td>Angle of U Max (theta, phi)</td>
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<td>1.31393</td>
<td>138.145</td>
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</tbody>
</table>
Using a Switch with 10 dB Isolation

Very bad isolation; very high leakage

Antenna 1

29.89 dBm
29.31 dBm

Antenna 2

22.54 dBm
21.95 dBm

Very bad isolation

Good isolation is important to have in components
5G Verification Test benches (VTB) in ADS

VTB is a regular component in the ADS simulation environment, which is linked to the Verification Test Bench (VTB) in SystemVue.

VTBs enable circuit designers to make use of sources and measurement setups from SystemVue and verify the performance of a circuit using real world complex modulated signals conforming to advanced wireless standards such as 2G/3G/4G/5G.
5G FBMC Transmit Analysis VTB

Note: OFDM is the technology that has been selected by 3GPP rather than FBMC. ADS 2017 plans to include this update. The VTB flow is the same.
5G FBMC Transmit Analysis VTB

Pin = -50 dBm
SS Gain = 49 dB

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<th>CCDF_AftDUT_MeanPower_dBm_Index</th>
<th>Gain dB</th>
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<td>49.013</td>
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<th>EVM_BefDUT__EVM_dB</th>
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<tbody>
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<table>
<thead>
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<th>EVM_AftDUT__EVM_dB</th>
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<td>-65.377</td>
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<table>
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<table>
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</tbody>
</table>

<table>
<thead>
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<th>CCDF_BefDUT_PeakPower_dBm</th>
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<tbody>
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<table>
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</table>
5G FBMC Transmit Analysis VTB

Pin = -25 dBm  SS Gain = 49 dB
LS Gain = 47.8 dB; 1.2 dB compressed

<table>
<thead>
<tr>
<th>CCDF_AftDUT_MeanPower_dBm_Index</th>
<th>Gain_dB</th>
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Analysis

1. Effect of the Feed Network and Line Lengths
2. Effect of Varying PA’s AM / PM Response
3. Effect of Coupling and Cross talk
4. Effect of PA Dynamic Impedance with Antenna
Analysis

1. Effect of the Feed Network and Line Lengths

2. Effect of Varying PA’s AM / PM Response

3. Effect of Coupling and Cross talk

4. Effect of PA Dynamic Impedance with Antenna
Effect of Feeding Network and Line Lengths

- Quad: Low chip to antenna loss, symmetric design → no calibration required
- Quad: Low-cost PCB design possible (only 4 layers in certain designs)
- Quad: Uniform heat over phased-array, resilient to failures, mix/match technology (SiGe/GaAs, CMOS)
- 4x4 or 4x8: Lower cost (less chips), but more loss, more complex PCB, single-point failures, all CMOS
- Both will be used: One in base-stations/UE, and the other in mobile

Gabriel M. Rebeiz, RFIC Symposium Plenary Talk, June 2017

Slide is taken from Dr. Gabriel Rebeiz’s
RFIC Symposium Plenary talk, June 2017
System with identical PA’s and **No Interconnect Lines**

*No added phase*
System with identical PA’s and **No Interconnect Lines**

*No added phase*

**Phase Shift = 0 deg**

- **Side lobe**: 14.33 dB down
- **Null**: 34.9 dB down
Adding Short Interconnects from PA’s to Antenna
Adding Interconnects from PA’s to Antenna

Phase Shift = 0 deg

Side lobe  8.93  dB down  (14.33 with no lines)
Null    18.75  dB down  (34.9 with no lines)
Adding Longer Interconnects from PA’s to Antenna

Phase Shift = 0 deg

Side lobe 10.63 dB down (14.33 with no lines)
Null 24.73 dB down (34.9 with no lines)
Analysis

1. Effect of the Feed Network and Line Lengths

2. Effect of Varying PA’s AM / PM Response

3. Effect of Coupling and Cross talk

4. Effect of PA Dynamic Impedance with Antenna
Case 1 – Using Identical PA’s

Lobe is 14.56 dB down
Null is 36.26 dB down

Lobe is 11.04 dB down
Null is at 35.89 dB down
X-Parameters of Various PA’s with Varied Amplitude and Phase

Graph showing dBm values against RFpwr for different parameters.
Case 2 – Using Different PA’s

Phase=0

Lobe is 12.813 dB down
Null is at 24.76 dB down

Phase= 62

Lobe is 10.96 dB down
Null is at 24.28 dB down

Compared with the case of identical PA’s
Lobe is 14.56 dB down
Null is 36.26 dB down
Summary: Response Using Identical PA’s Vs Different PA’s

With Identical PA’s

Lobe is 14.56 dB down
Null is 36.26 dB down

With Different PA’s

Lobe is 12.81 dB down
Null is 24.76 dB down
Important to Design Circuits with Small Variability

Wide variation

Smaller variation

Phase

Pout

Phase

Pout
Analysis

1. Effect of the Feed Network and Line Lengths

2. Effect of Varying PA’s AM / PM Response

3. Effect of Coupling and Cross talk

4. Effect of PA Dynamic Impedance with Antenna
Coupling / Crosstalk between:

• Adjacent Channels
• PA’s
• Antenna elements
• Feed Lines and Antenna elements
Response with No Coupling
Response with No Coupling @ 0deg

Lobe is 14.53 dB down
Null is 35.94 dB down

m1
Theta=-0.000
10*log10(mag(Directivity))=17.491

m2
Theta=42.000
10*log10(mag(Directivity))=2.962

m3
Theta=29.000
10*log10(mag(Directivity))=-18.451
Response with Coupling
Response with Coupling 0deg

Lobe is 11.73 dB down
Null is 19.29 dB down

Compared with the case of no coupling
Lobe is 14.53 dB down
Null is 35.94 dB down
Analysis

1. Effect of the Feed Network and Line Lengths
2. Effect of Varying PA’s AM / PM Response
3. Effect of Coupling and Cross talk
4. Effect of PA Loading and Change in Impedance
Effect of scan angle

As scan angle increases:

- Effective cross-section area “A” of the array decreases
  - Less power to main lobe (lower peak gain)
  - Less directivity (wider beam)

- PA loading & impedance changes
  - Affects the final beam shape
  - In extreme cases can create blind spots

- More energy goes to side lobes (“grating lobes”)

Watch out for unexpected interference (pilot tones, jamming) and false echoes (clutter) coming from unwanted directions
Effect of PA Dynamic Impedance with Antenna

ACTIVE INPUT IMPEDANCE

As we have seen in the previous section, coupling between the elements in the array has a significant effect on the element’s impedance. To understand what is happening a diagram will be helpful, figure 6-1 shows the array configuration, the various element excitation signals and the coupling paths.

\[ Z = \frac{V}{I} \]
\[ Z_i = \frac{(V_1 + V_2 + V_3 + V_4 + V_5 + V_6)}{I_1} \]

The importance of active input impedance should not be underestimated. Its effects can be dramatic because it directly impacts the amplitude and phase excitations of the array elements and these are the very parameters you are using to control the array!

From:
An Introduction to Phased Array Design
A Technical Note by N. Tucker
15/04/2011
Effect of PA Dynamic Impedance with Antenna

Phased Array system Architecture exploration

[Diagram showing source, splitter, digital attenuator, digital phase shifter, amplifier, and antenna array with parameters and settings.]
Effect of PA Dynamic Impedance with Antenna

Mild blind angles are observed here due to the active reflection coefficients and accurate models for amplifiers, Phase shifters and attenuators.

The simulation can further be enhanced if employed load pulled X-parameters.
5G 28-GHz Phased Array Transceiver
0.18um SiGe BiCMOS technology
Full Phased Array Transceiver

Transmit

Receive

LOS Link
10 Km
SiGe BiCMOS Doherty Power Amplifier

Doherty PA

PA Output Power and Phase

Small Signal S-Parameters
Transceiver Transmit Chain

Amps

Phase Shifters

PA’s

Filters

Transmit Patch Antenna

LOS Link 10 Km
Transceiver Receive Chain

LOS Link
10 Km

2 Receive Antennas
Dipole & Patch

LNA's

Phase Shifters

Amps
## Transceiver

<table>
<thead>
<tr>
<th>Pin</th>
<th>PA_in</th>
<th>PA_out</th>
<th>P_Antenna</th>
<th>LNA_in</th>
<th>LNA_out</th>
<th>P_received</th>
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<tr>
<td>-10.3 dBm</td>
<td>-4.65 dBm</td>
<td>20.4 dBm</td>
<td>16.8 dBm</td>
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<td>-34.7 dBm</td>
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<table>
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<tr>
<th>state</th>
<th>dBm(V_in)[1]</th>
<th>dBm(PA_in[1];1)</th>
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<th>dBm(T1[1];1)</th>
<th>dBm(R1a[1];1)</th>
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<td>-31.780</td>
<td>19.045</td>
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</table>

- **P_Antenna:** 16.8 dBm
- **Antenna gain:** 14 dB
- **LNA_in:** -77 dBm

→ 108 dB Loss in the LOS Link
Receiver Noise Figure

Gain = 60 dB
S11 = -35 dB
S22 = -27 dB
NF = 3.5 dB
Transmit Chain Verification Test Bench (VTB) for EVM
## Transmit Chain EVM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>EVM_BefDUT_EVM dB</td>
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<tr>
<td>EVM_AftDUT_EVM dB</td>
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<td>CCDF_BefDUT_PeakPower_dBm</td>
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<td>CCDF_AftDUT_PeakPower_dBm</td>
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<tr>
<td>Gain dB</td>
<td>57.952</td>
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![Graphs showing CCDF, Waveform, and Spectrum analysis for Transmit Chain EVM](image)
Receive Chain Verification Test Bench (VTB) for BER

5G_FBMC_Rx_AWGN_Analysis

VTB1
FCarrier_In=28e+09 Hz   PortZ[1]=50 Ohm
FCarrier_Out=28e+09 Hz   PortZ[2]=50 Ohm
SignalPower=.01 W
BaseSampleRate=1e+07 Hz
OversampleRatio=Ratio 2
SNR=20
IdleInterval=0 sec
ModType=16-QAM
NumFrames=10
MirrorSignal=NO
GainImbalance=0
PhaselImbalance=0
I_OriginOffset=0
Q_OriginOffset=0
IQ_Rotation=0
Receive Chain Verification Test Bench (VTB) for BER

<table>
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<th>SNR</th>
<th>B2_BER</th>
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<tbody>
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<td>20.000</td>
<td>0.001</td>
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</table>
Transceiver – Transmit Antenna
Transceiver – Receive Antenna 1

Gain, Directivity

$10 \times \log_{10}(\text{mag(Directivity)})$
$10 \times \log_{10}(\text{mag(Gain)})$
Transceiver – Receive Antenna 2

Gain, Directivity

$10 \log_{10}(\text{mag(Directivity)})$

$10 \log_{10}(\text{mag(Gain)})$

Theta (-180.000 to 180.000)

dB(Gain)

Theta

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Future Work

EM Excitation in ADS 2016

EM Excitation in ADS 2017
Includes Circuit Envelope

Allows bringing in modulated 5G sources from system view to perform full 5G analysis
Acknowledgement

I extend my sincere gratitude to the following people who have helped me put this project material together:

- Anil Panday
- Plextek RFI
- Rupam Anand

Special Thanks to the following people who have provided me with feedback and support

- Carmina Stremlau
- How-Siang Yap
- Murthy Upmaka
- Bhumit Rojivadia (Intern)
- Sangkyo Shin
Conclusion

This webcast has demonstrated the importance of:

• EM/Circuit Co-simulation in 5G design and simulation
• Verification Test Bench (VTB) Simulation

• Analysis
  ➢ Effect of the Feed Network and Line Lengths
  ➢ Effect of Varying PA’s AM / PM Response
  ➢ Effect of Coupling and Crosstalk
  ➢ Effect of PA Dynamic Impedance with Antenna

• Transceiver Design Example
  ➢ Using Tower Jazz .18um SiGe BiCMOS technology
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I will supply the ADS workspace and slides
Keysight EEsod EDA
“How to” Video

- “How To” Video Series
- Application Focused
  (10 min each)
- Free workspace

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