Over the Air Test Solution for New 5G / mmWave Band Wireless ICs

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TestConX

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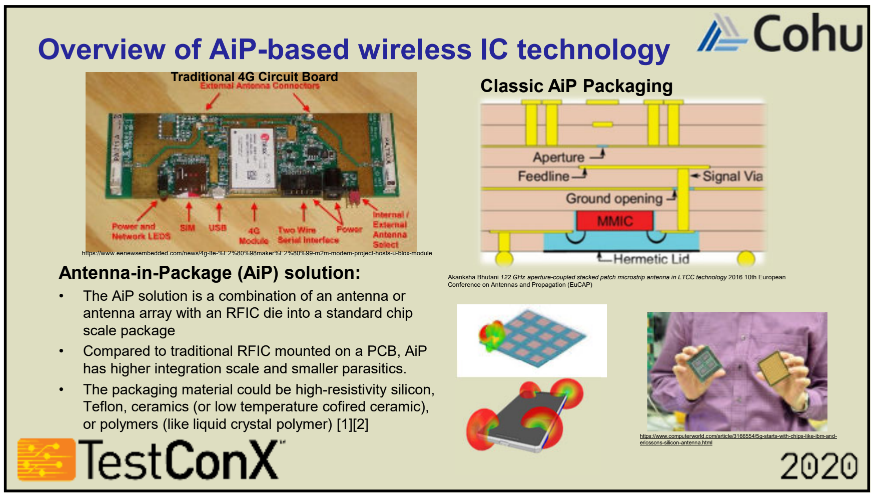
Overview of AiP-based wireless IC technology
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Traditional 4G Circuit Board
External Antenna Connectors
Power and Network LEDS
SIM
USB
4G Module
Two Wire Serial Interface
Power
Internal / External Antenna Select
Classic AiP Packaging
Aperture
Feedline
Signal Via
Ground opening
MMIC
Hermetic Lid
Antenna-in-Package (AiP) solution:
• The AiP solution is a combination of an antenna or antenna array with an RFIC die into a standard chip scale package
• Compared to traditional RFIC mounted on a PCB, AiP has higher integration scale and smaller parasitics.
• The packaging material could be high-resistivity silicon, Teflon, ceramics (or low temperature cofired ceramic), or polymers (like liquid crystal polymer) [1][2]
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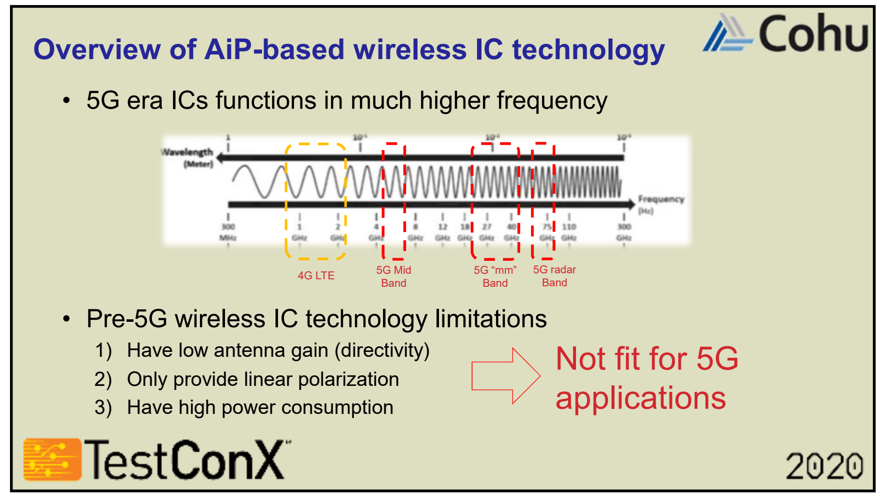
Overview of AiP-based wireless IC technology
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• 5G era ICs functions in much higher frequency
Wavelength (Meter)
Frequency (Hz)
4G LTE
5G Mid Band
5G "mm" Band
5G radar Band
• Pre-5G wireless IC technology limitations
1) Have low antenna gain (directivity)
2) Only provide linear polarization
3) Have high power consumption
Not fit for 5G applications
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5G & mmWave wireless ICs: New Standard

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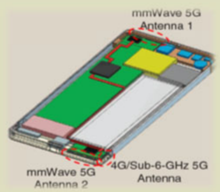
1. Needs much higher gain (directivity)

- Any wireless transmission loss subjects to same rule

Free Space Path Loss (FSPL):

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

- 4G application, single patch antenna Gain ~ 5 - 7 dB
- From 2.8 GHz to 28 GHz, FSPL increases 10 dB
- 5G wireless ICs typically have higher gain antenna



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5G & mmWave wireless ICs: New Standard

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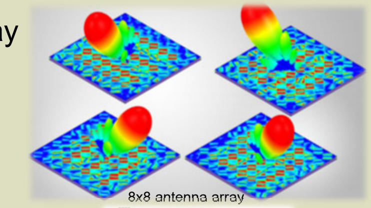
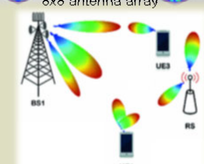
2. widely applying antenna array

- Electric phase shift control: steering radiation direction and forming a narrow beam
- High gain and directivity: typical array as small as four antennas can provide 15 - 20 dB gain
- Shorter communication distance: effective communication distance is hundreds of feet instead of several miles;





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5G & mmWave wireless ICs: New Standard

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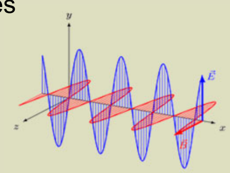
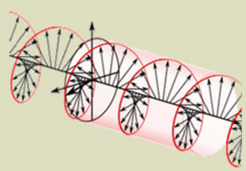
3. widely use antenna circular polarization

circular polarization advantages

- Wide tolerance on antenna alignment
- Resistive to signal magnitude degradation
- Less susceptible to Faraday Effect



electric and magnetic field in linear polarized EM wave
picture from Wikimedia



electric field vectors of a traveling circularly-polarized electromagnetic wave
picture from Wikipedia

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OTA test solutions for 5G / mmWave ICs

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New IC test requirement: Summary

- Contactor antenna needs wideband RF performance in high frequency
- Contactor antenna must radiate uniformly in whole antenna array
- Contactor antenna must be adaptable to linear / circular polarized radiation
- Contactor must provide low loss & ultra-wide band signal interface

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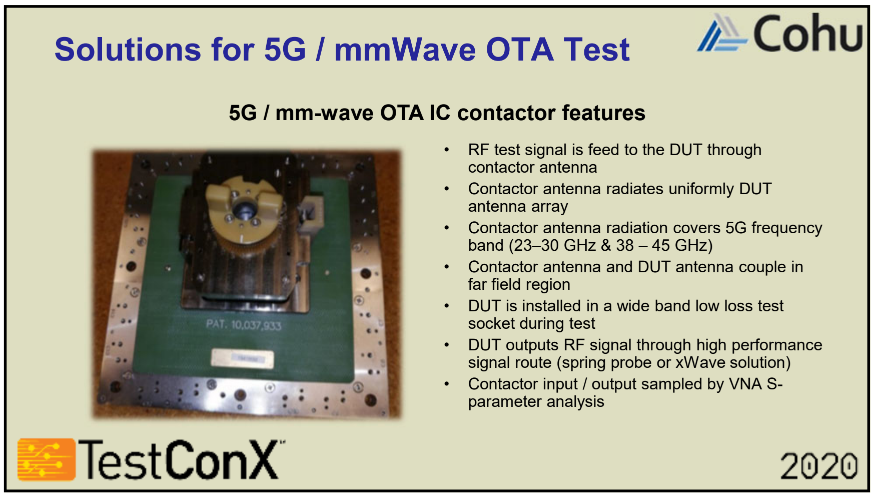

Solutions for 5G / mmWave OTA Test
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5G / mm-wave OTA IC contactor features
PAT. 10,037,933
• RF test signal is feed to the DUT through contactor antenna
• Contactor antenna radiates uniformly DUT antenna array
• Contactor antenna radiation covers 5G frequency band (23–30 GHz & 38 – 45 GHz)
• Contactor antenna and DUT antenna couple in far field region
• DUT is installed in a wide band low loss test socket during test
• DUT outputs RF signal through high performance signal route (spring probe or xWave solution)
• Contactor input / output sampled by VNA S-parameter analysis
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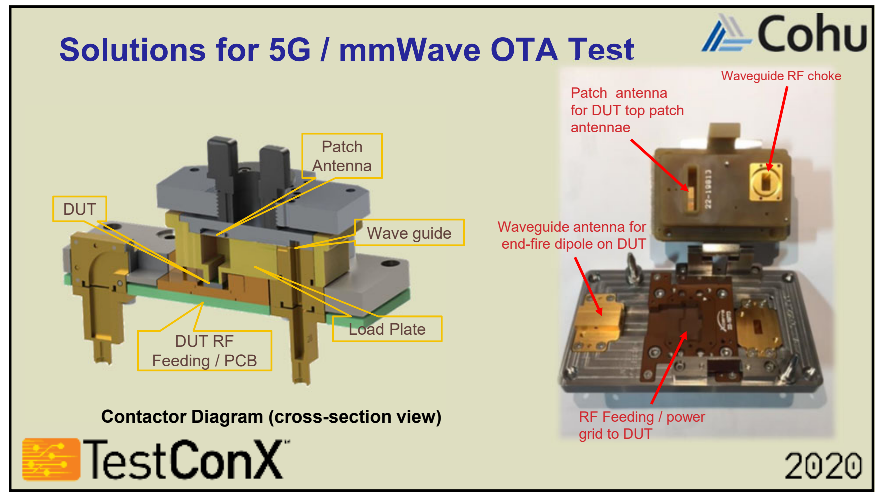

Solutions for 5G / mmWave OTA Test
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Patch Antenna
DUT
Wave guide
Load Plate
DUT RF Feeding / PCB
Contactor Diagram (cross-section view)
Waveguide RF choke
Patch antenna for DUT top patch antennae
Waveguide antenna for end-fire dipole on DUT
RF Feeding / power grid to DUT
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Solutions for 5G / mmWave OTA Test

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- Contactor antenna design guideline

Antenna Gain is given by:

$$Gain(\text{dB}) = 10 \cdot \log\left(\frac{4\pi S}{\lambda^2} \cdot \eta_A\right)$$

η_A is the antenna efficiency, S is antenna aperture size

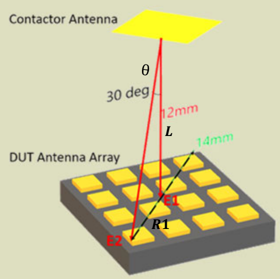
➡ **Bigger aperture provides bigger gain**

-3dB Beam width θ is estimated:

$Gain_{E1}$ - $Gain_{E2}$ = 3dB; $\theta = 2 \cdot \tan\frac{R1}{L}$

In practice, we find:

➡ **Bigger aperture gives narrower beam**



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Solutions for 5G / mmWave OTA Test

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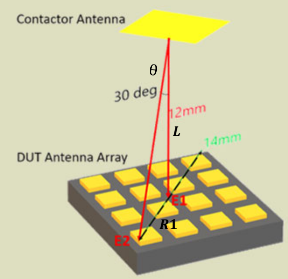
- Contactor antenna design guideline

- For example, contactor antenna with -3 dB beam width 60°
- DUT antenna array diameter: 14mm diagonal
- Antenna coupling distance L:
  L = 7/ tan(30°) ≈ 12mm



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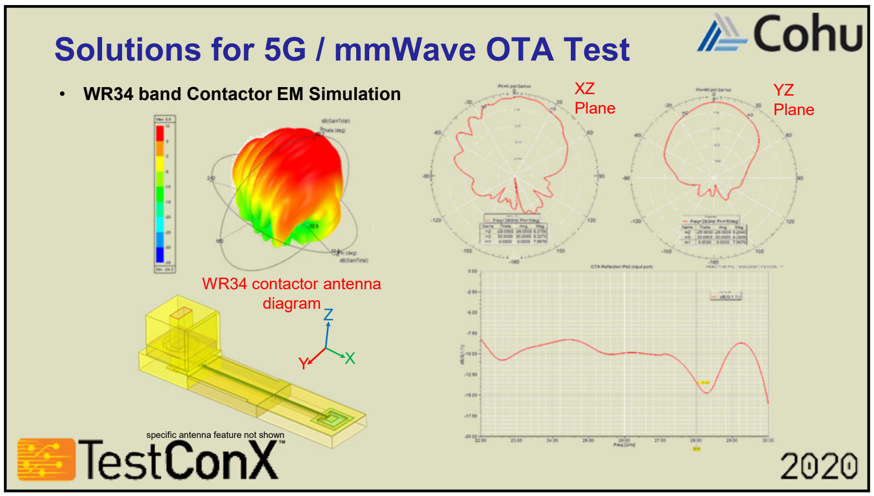
Solutions for 5G / mmWave OTA Test
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• WR34 band Contactor EM Simulation
XZ Plane
YZ Plane
WR34 contactor antenna diagram
Z
Y
X
specific antenna feature not shown
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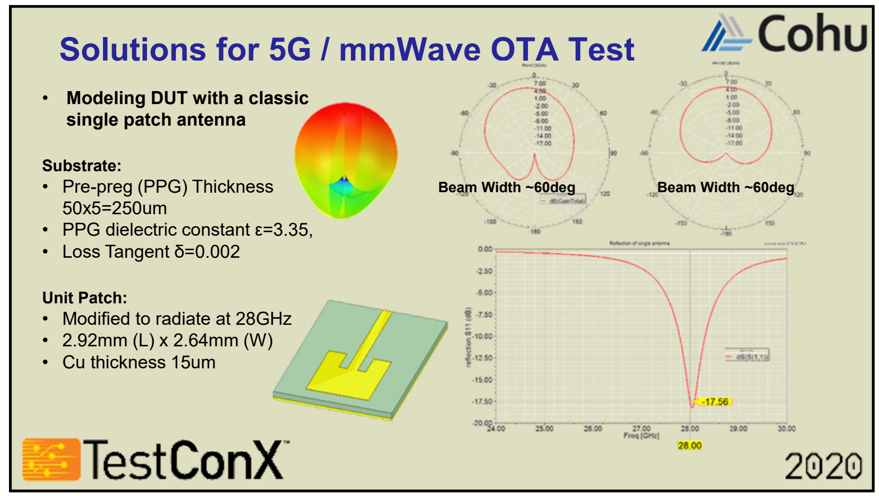
Solutions for 5G / mmWave OTA Test
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• Modeling DUT with a classic single patch antenna
Substrate:
• Pre-preg (PPG) Thickness 50x5=250um
• PPG dielectric constant ε=3.35,
• Loss Tangent δ=0.002
Unit Patch:
• Modified to radiate at 28GHz
• 2.92mm (L) x 2.64mm (W)
• Cu thickness 15um
Beam Width ~60deg
Beam Width ~60deg
-17.56
28.00
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Solutions for 5G / mmWave OTA Test

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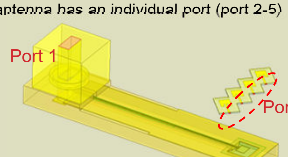
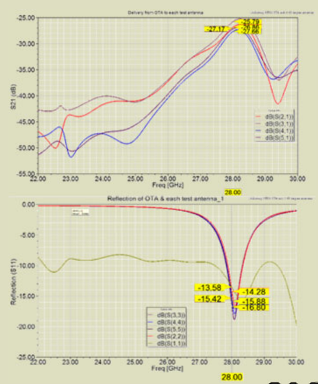
- **Radiation Uniformity & Beam Width Evaluation**

Conditions:

- Four identical 28GHz patch antennas forming an array
- 5.4 mm away from each other over a 20 mm range
- Each antenna has an individual port (port 2-5)





Result:

- Contactor and DUT antennas have trivial reflection
- Energy delivery ratio S21 > -28 dB at 20 mm distance
- Difference on each antenna's S21 < 2dB

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Solutions for 5G / mmWave OTA Test

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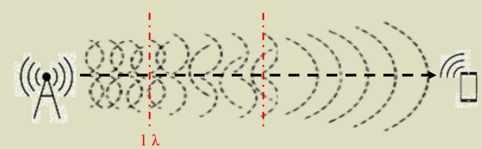
- **Determinate Contactor Antenna & DUT Distance**

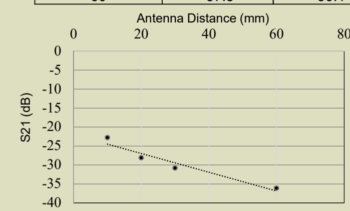


At 28 GHz, λ = 10.7 mm,
according to Friis' Equation (Far Field)

$$\frac{P_r}{P_t} = D_t D_r \left(\frac{\lambda}{4\pi d}\right)$$

EM simulation result using HFSS

Antenna Distance (mm)	S21 Calculation (dB)	S21 Simulation (dB)
10	-22.0	-22.8
20	-28.0	-28.1
30	-31.5	-30.8
60	-37.5	-36.1



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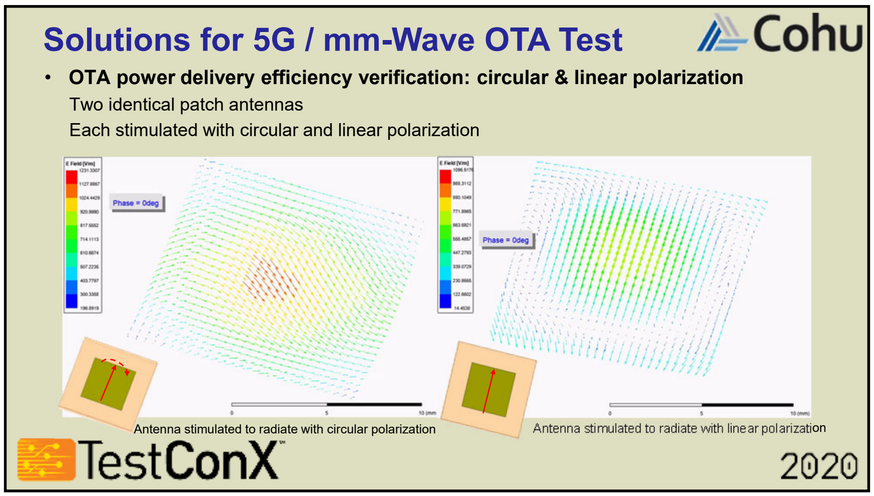

Solutions for 5G / mm-Wave OTA Test
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OTA power delivery efficiency verification: circular & linear polarization
Two identical patch antennas
Each stimulated with circular and linear polarization
Phase = 0deg
Phase = 0deg
Antenna stimulated to radiate with circular polarization
Antenna stimulated to radiate with linear polarization
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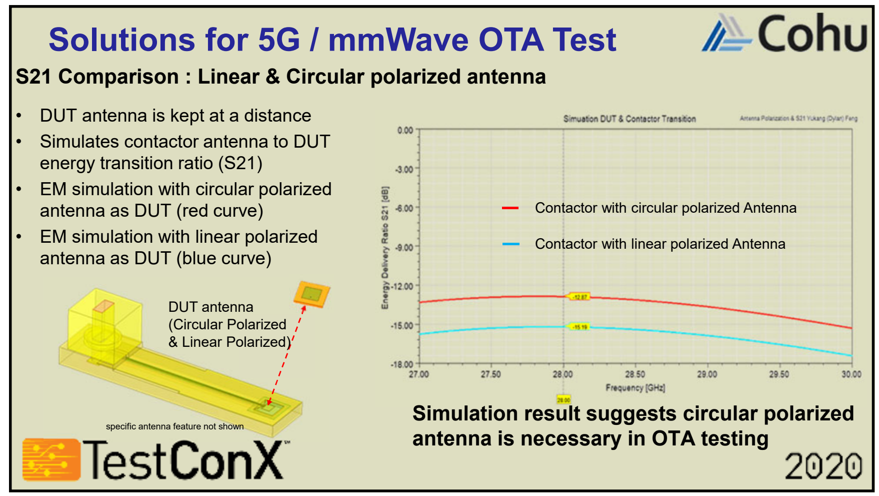

Solutions for 5G / mmWave OTA Test
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S21 Comparison : Linear & Circular polarized antenna
DUT antenna is kept at a distance
Simulates contactor antenna to DUT energy transition ratio (S21)
EM simulation with circular polarized antenna as DUT (red curve)
EM simulation with linear polarized antenna as DUT (blue curve)
DUT antenna (Circular Polarized & Linear Polarized)
specific antenna feature not shown
Contactor with circular polarized Antenna
Contactor with linear polarized Antenna
Frequency [GHz]
Simulation result suggests circular polarized antenna is necessary in OTA testing
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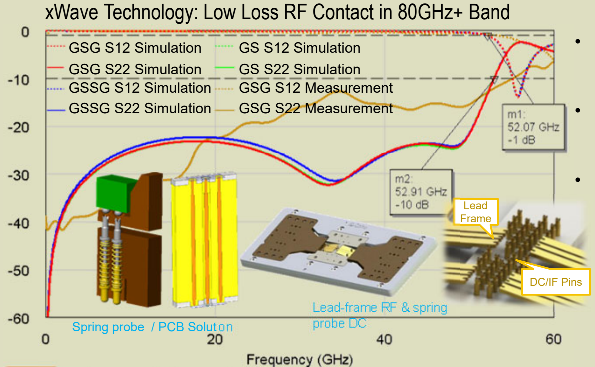
Solutions for 5G / mmWave OTA Test

xWave Technology: Low Loss RF Contact in 80GHz+ Band



- Cohu's Pogo solution provides wideband & low loss performance till 67 GHz
- xWave leadframe technology provides higher band RF connection in 60+ GHz band
- xWave technology uses a 3-D transmission metal trace directly routes the RF signal from coaxial connection (2.92 mm / 1.85 mm connector) to DUT with minimum parasitic inductance / capacitance and wide bandwidth

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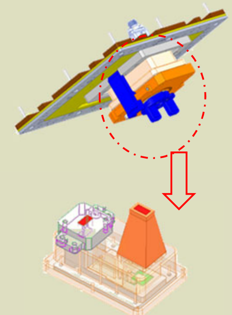
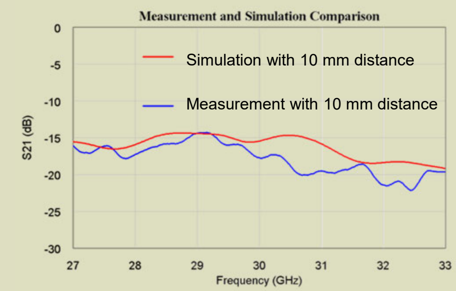
OTA test solution: Lab Measurement



S21 measurement at 10mm distance between WR28 contactor antenna and WR28 Horn Antenna



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Conclusions

- In 5G & mmWave Era, wireless ICs work in much higher band, which requires higher antenna gain and electrical beam steering.
- Phase array has became a new standard in wireless IC design
- To test 5G wireless ICs, contactor antenna needs to provide wide beam width and uniform radiation
- To coordinate widely used circular polarization DUT antenna array, the contactor antenna must be able to radiate with circular polarization
- This research suggests the DUTs should be kept in transition region or further distance from contactor antenna
- Low-loss wideband RF feed is also a necessary in the OTA test

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Reference

- [1] Y. P. Zhang, D. Liu, *Antenna-on-Chip and Antenna-in-Package Solutions to Highly Integrated Millimeter-Wave Devices for Wireless Communications* IEEE Transactions on Antennas and Propagation, Volume: 57 , Issue: 10 , Oct. 2009

- [2] D. Kam, D. Liu, A. Natarajan, *Low-Cost Antenna-in-Package Solutions for 60-GHz Phased-Array Systems* 19th Topical Meeting on Electrical Performance of Electronic Packaging and Systems, 25-27 Oct. 2010

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Thank you for watching!

Please feel free to email me for any question
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