Over the Air Test Solution for New 5G / mm-Wave Band Wireless ICs

Yukang (Dylan) Feng

Staff RF Development Engineer
Cohu Interface Solution Group

TestConX

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- 5G & mm-Wave wireless ICs: New Standard
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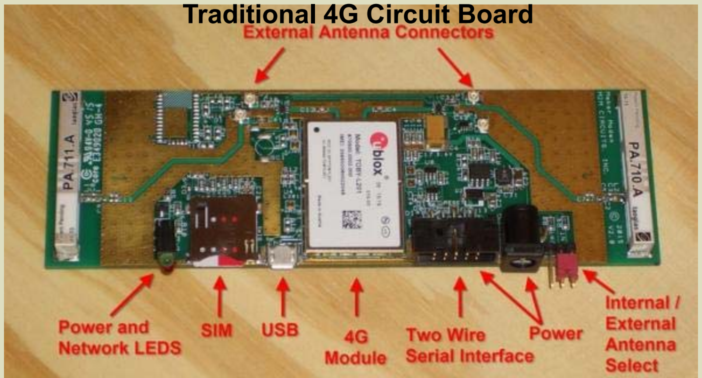
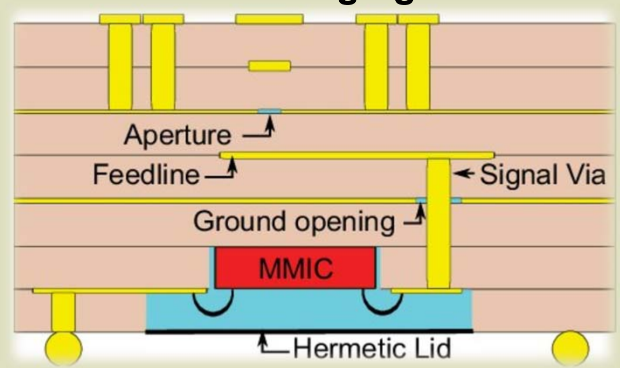
Overview of AiP-based wireless IC technology



https://www.eenewsembedded.com/news/4g-lte-%E2%80%98maker%E2%80%99-m2m-modem-project-hosts-u-blox-module

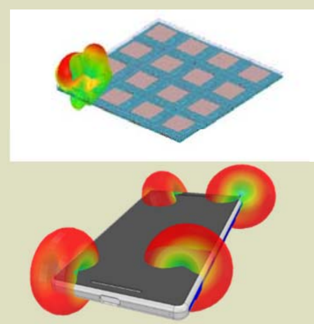
Classic AiP Packaging

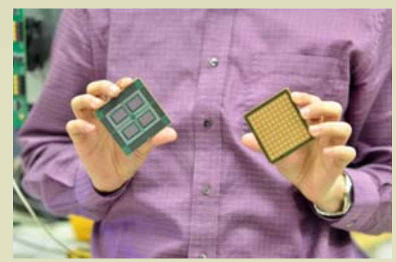


Akanksha Bhutani *122 GHz aperture-coupled stacked patch microstrip antenna in LTCC technology* 2016 10th European Conference on Antennas and Propagation (EuCAP)

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]

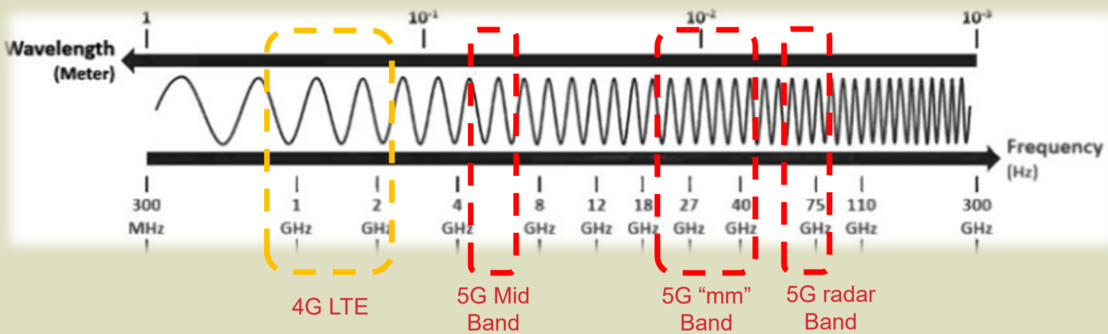




https://www.computerworld.com/article/3166554/5g-starts-with-chips-like-ibm-and-ericssons-silicon-antenna.html

Overview of AiP-based wireless IC technology

- 5G era ICs functions in much higher frequency



- 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

5G & mm-Wave wireless ICs: New Standard

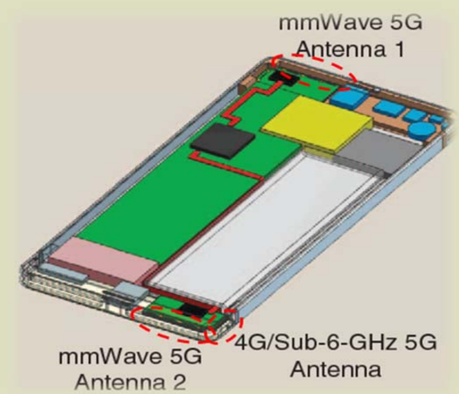
1. Needs much higher gain (directivity)

- Any wireless transmission loss subjects to same rule

Free Space Path Loss (FSPL):

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

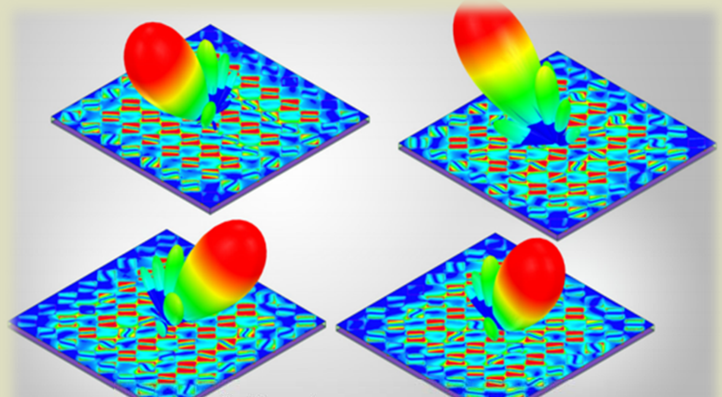
- ➢ 4G application, single patch antenna Gain ~ 5 - 7 dB
- ➢ From 2.8 GHz to 28 GHz, FSPL increases 10 dB
- ➢ 5G wireless ICs typically have higher gain antenna



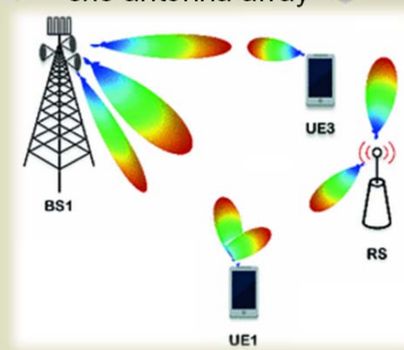
5G & mm-Wave wireless ICs: New Standard

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;



8x8 antenna array

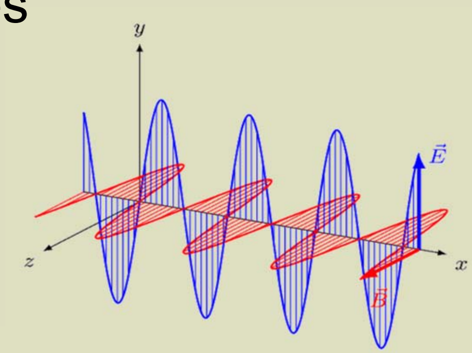


5G & mm-Wave wireless ICs: New Standard

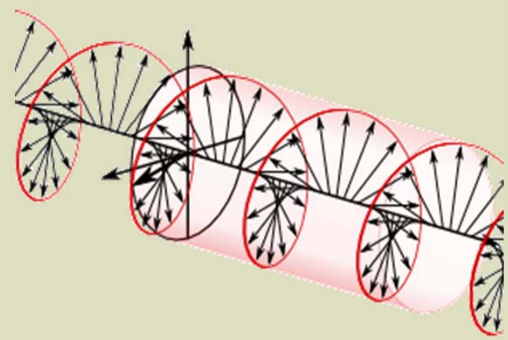
3. widely use antenna circular polarization

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

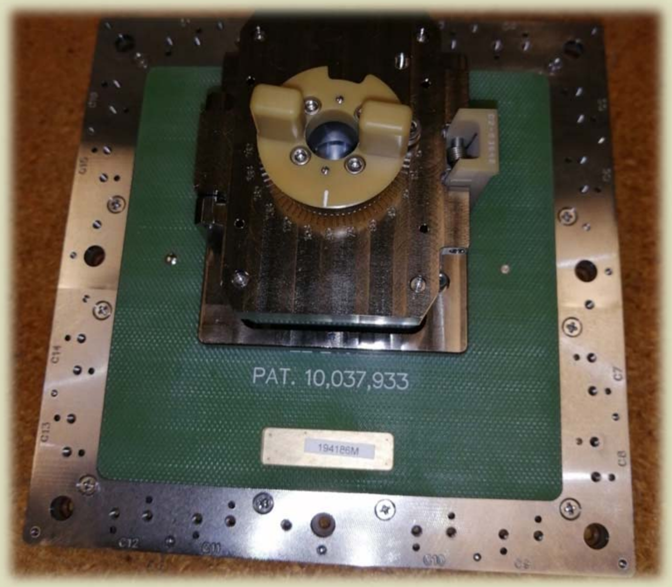
OTA test solutions for 5G / mm-Wave ICs

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

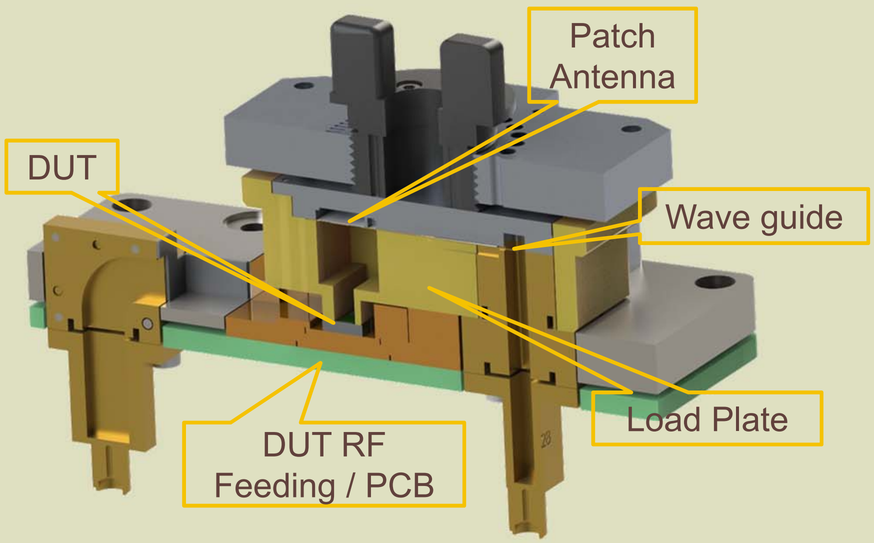
Solutions for 5G / mm-Wave OTA Test

5G / mm-wave OTA IC contactor features

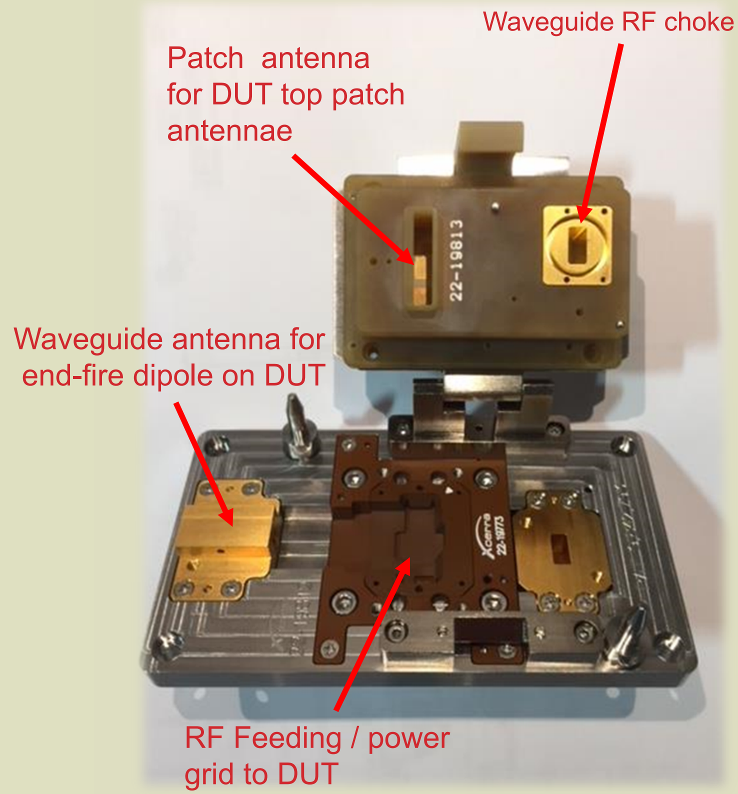


- RF test signal is feed to the DUT through contactor antenna
- Contactor antenna radiates uniformly DUT antenna array
- Contactor antenna radiation covers 5G frequency band (23–30 GHz & 38 – 45 GHz)
- Contactor antenna and DUT antenna couple in far field region
- DUT is installed in a wide band low 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

Solutions for 5G / mm-Wave OTA Test



Contactor Diagram (cross-section view)



Solutions for 5G / mm-Wave OTA Test

- 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

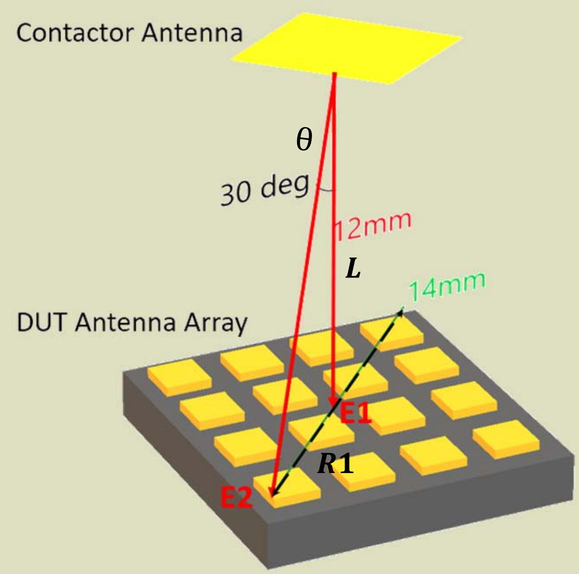
➡ **Bigger aperture provides bigger gain**

-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**

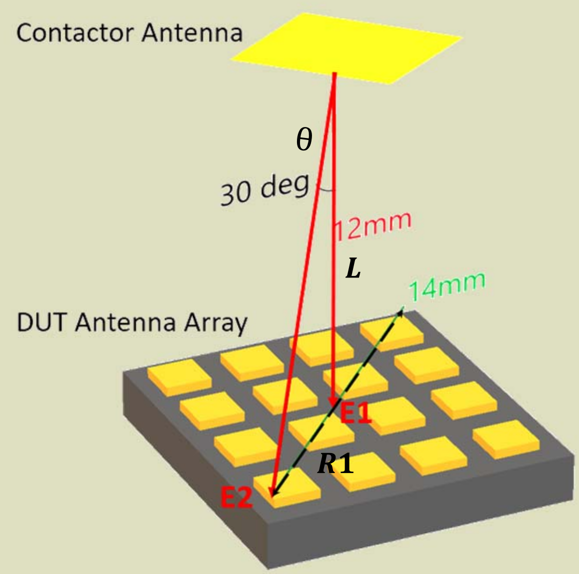


Solutions for 5G / mm-Wave OTA Test

- Contactor antenna design guideline

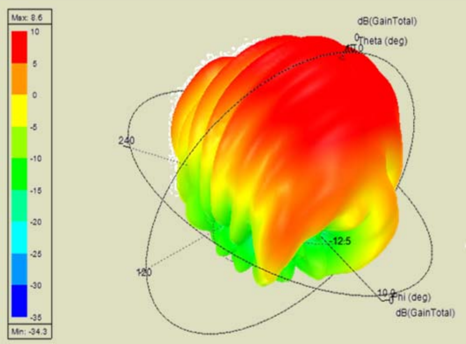
- For example, contactor antenna with -3 dB beam width 60°
- DUT antenna array diameter: 14mm diagonal
- Antenna coupling distance L:

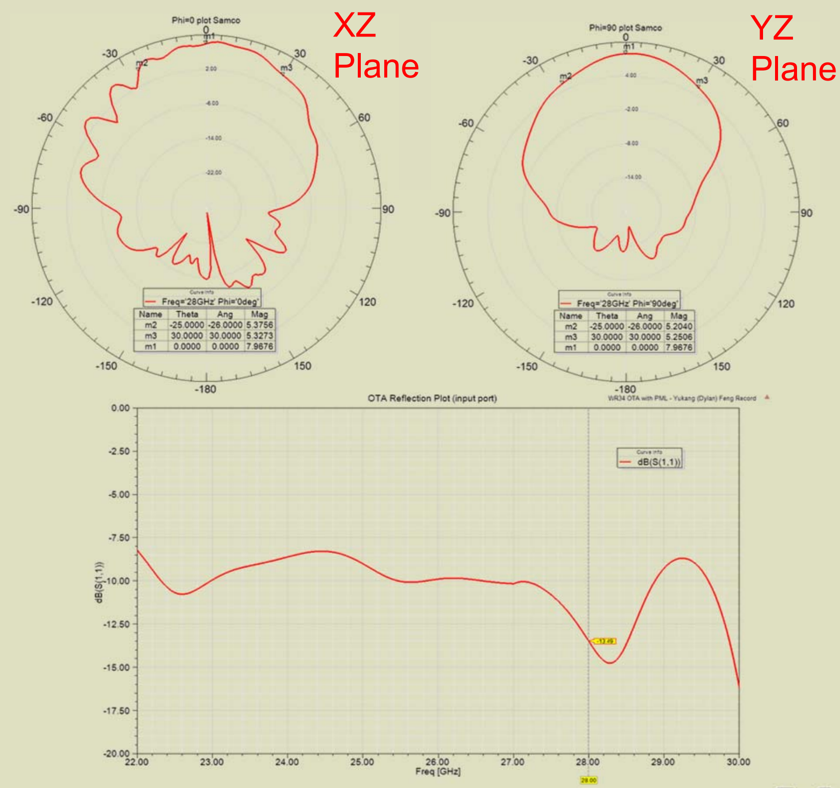
L = 7/ tan(30°) ≈ 12mm



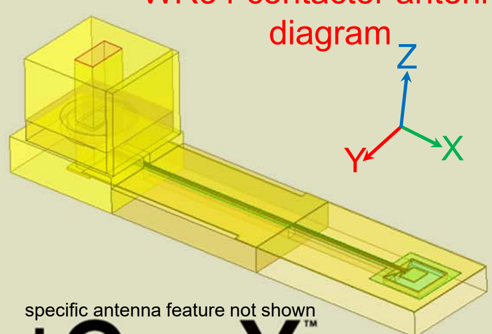
Solutions for 5G / mm-Wave OTA Test

- **WR34 band Contactor EM Simulation**





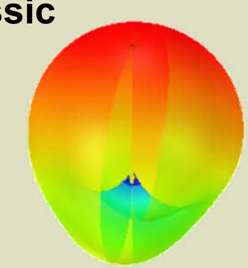
WR34 contactor antenna diagram

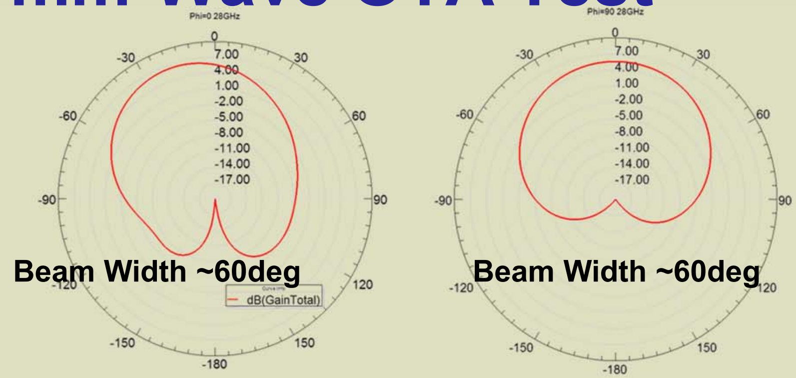


specific antenna feature not shown

Solutions for 5G / mm-Wave OTA Test

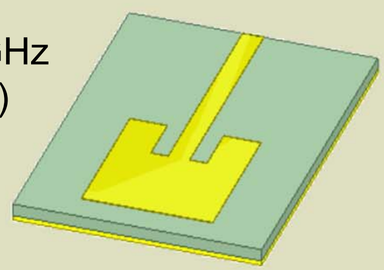
- **Modeling DUT with a classic single patch antenna**

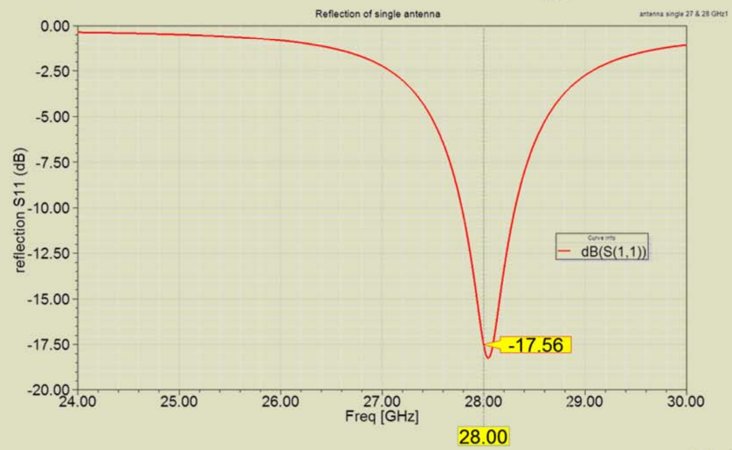




Substrate:
- Pre-preg (PPG) Thickness 50x5=250um
- PPG dielectric constant ε=3.35,
- Loss Tangent δ=0.002

Unit Patch:
- Modified to radiate at 28GHz
- 2.92mm (L) x 2.64mm (W)
- Cu thickness 15um





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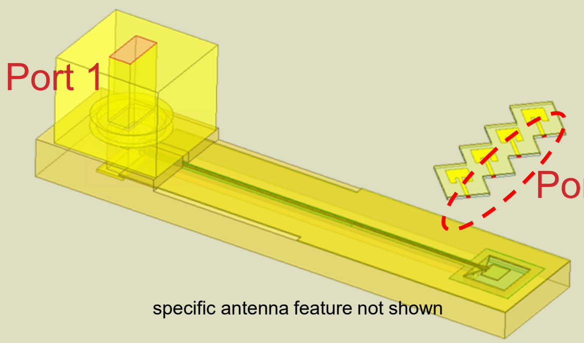
Solutions for 5G / mm-Wave OTA Test

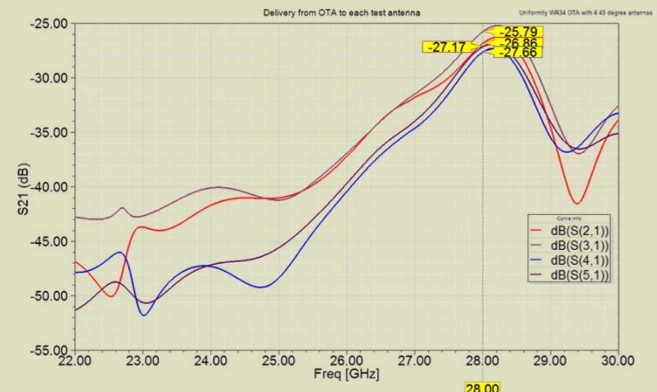
- **Radiation Uniformity & Beam Width Evaluation**

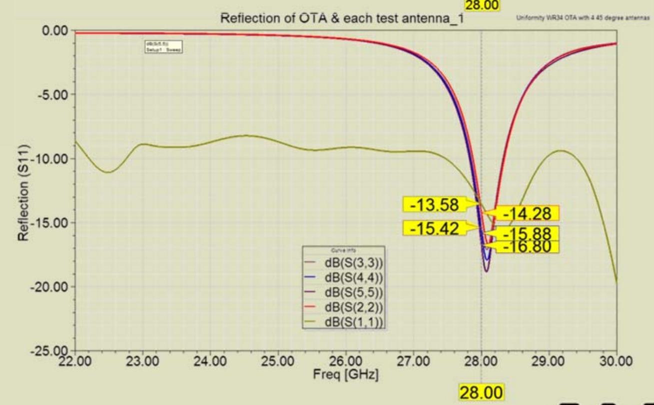
Conditions:
- Four identical 28GHz patch antennas forming an array
- 5.4 mm away from each other over a 20 mm range
- Each antenna has an individual port (port 2-5)



specific antenna feature not shown

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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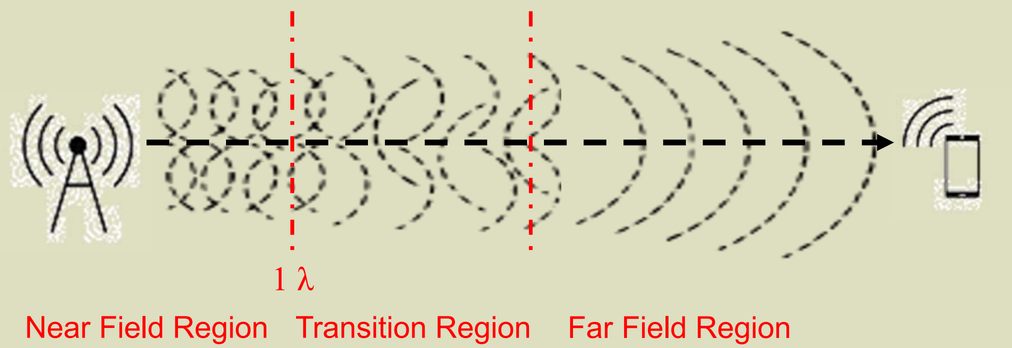
Solutions for 5G / mm-Wave OTA Test

- **Determinate Contactor Antenna & DUT Distance**

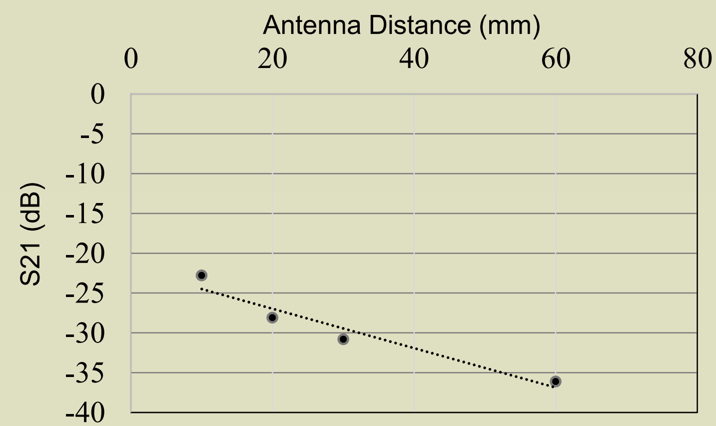


At 28 GHz, λ = 10.7 mm,
according to Friis' Equation (Far Field)

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

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

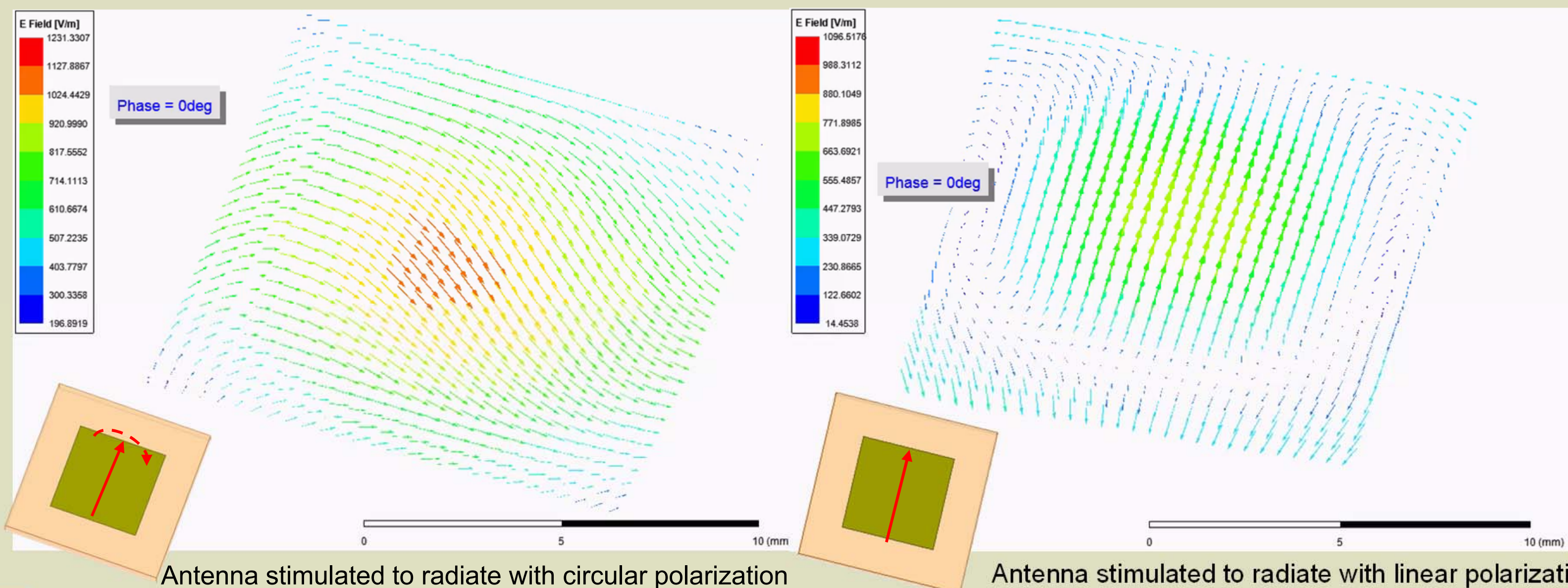


Solutions for 5G / mm-Wave OTA Test

- **OTA power delivery efficiency verification: circular & linear polarization**

  Two identical patch antennas

  Each stimulated with circular and linear polarization



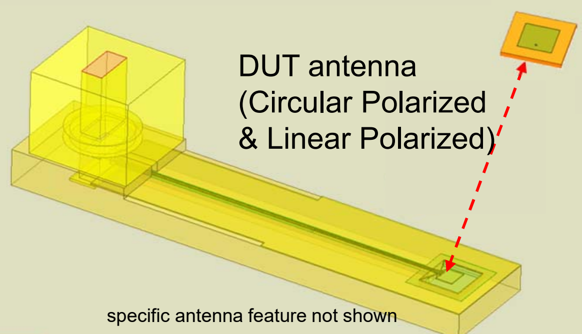
Antenna stimulated to radiate with circular polarization

Antenna stimulated to radiate with linear polarization

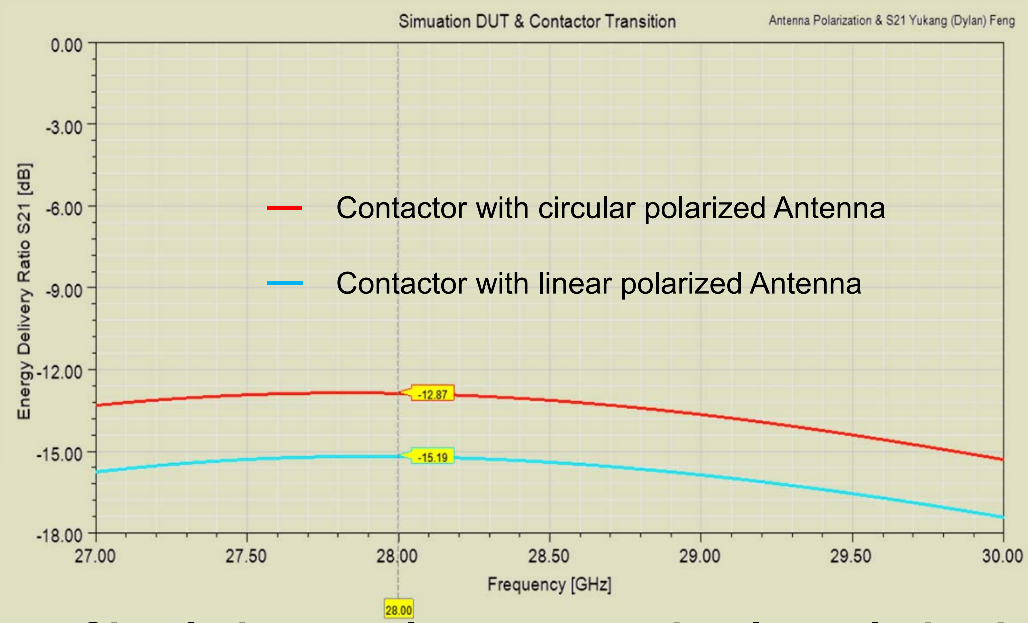
Solutions for 5G / mm-Wave OTA Test

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)



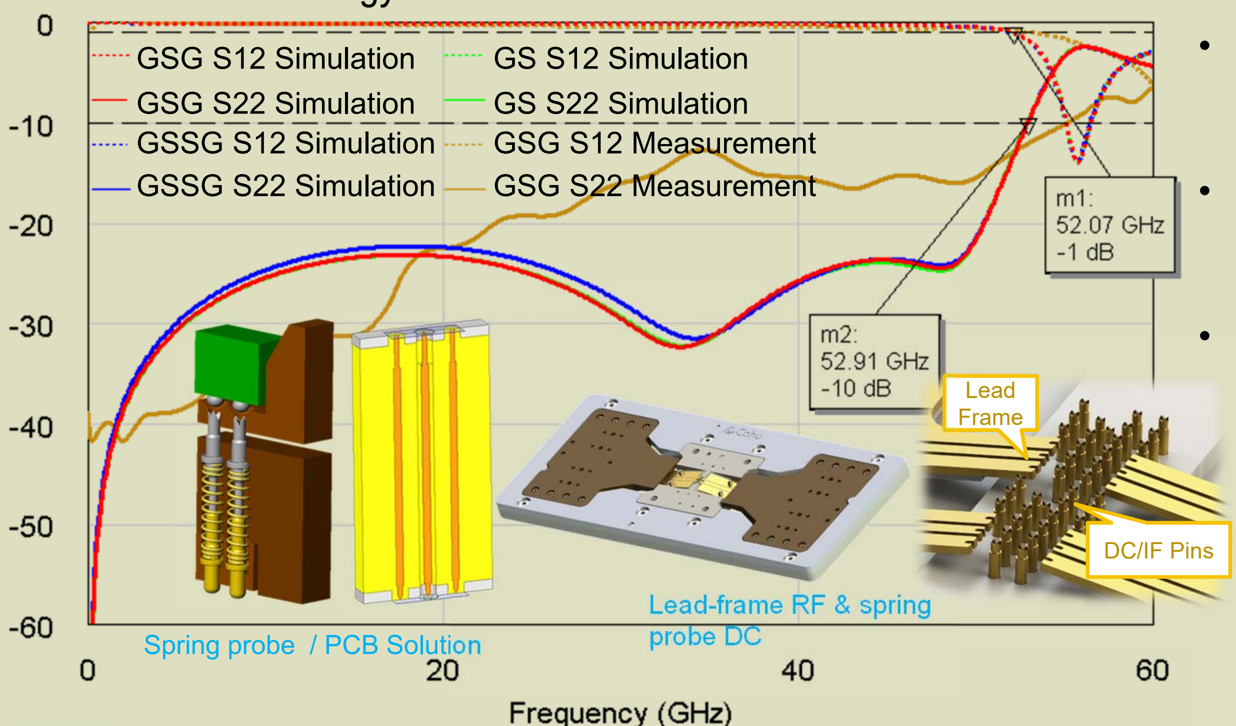
specific antenna feature not shown



Simulation result suggests circular polarized antenna is necessary in OTA testing

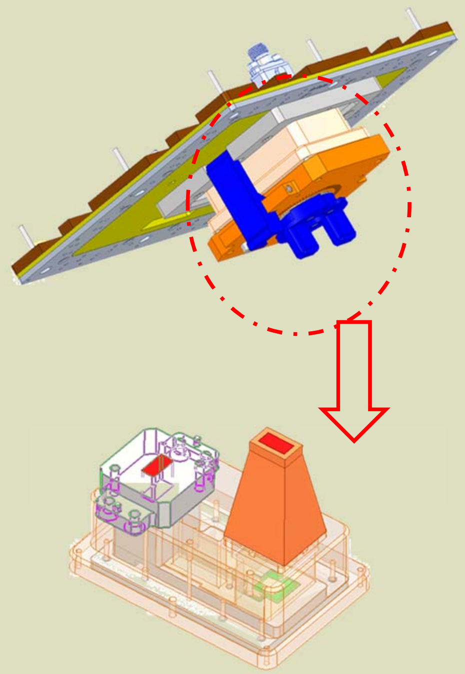
Solutions for 5G / mm-Wave OTA Test

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

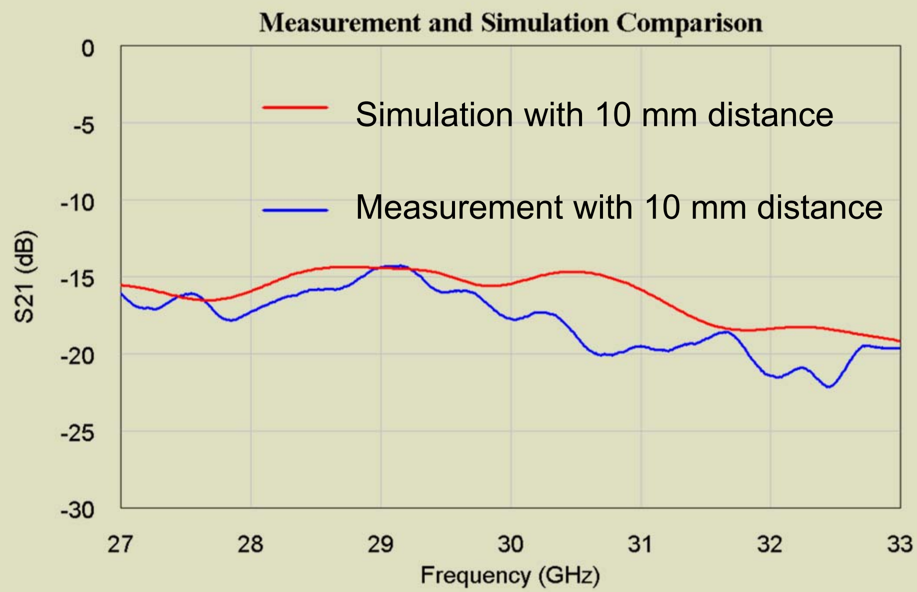


- Cohu's Pogo solution provides wideband & low loss performance till 67 GHz
- xWave leadframe technology provides higher band RF connection in 60+ GHz band
- xWave technology uses a 3-D transmission metal trace directly routes the RF signal from coaxial connection (2.92 mm / 1.85 mm connector) to DUT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

OTA test solution: Lab Measurement



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



Conclusions

- In 5G & mm-wave 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

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