OTA Test Solution for High Volume Production Test of AiP devices

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Abstract:

The variety of 5G Antenna in Package (AiP) devices and integrated antenna modules pose unique challenges to the production test cell. Test requirements call for Over the Air (OTA) test solutions in the mmWave (30 GHz - 100 GHz) frequency bands while most existing OTA solutions are designed only for the lab environment. This combined with the various antenna distribution and types including in custom packaging create challenges for defining production test hardware.

OTA test setups are also complicated by application variables, such as near field / far field, antenna integration level, and radiation orientation. The distance of the antenna from the device in the test setup could vary between a few millimeters to a few centimeters depending on the test frequency and whether it is tested in the near or for field environment. The antenna can be integrated at the die, package, or module level and the radiation direction of the antenna can be oriented to come out of the pad/ball side, over-mold side, or edge of the device or module. These variables can drive the test cell configuration beyond the norm and blur boundaries between the tester, contactor / probe head, and handler / prober to meet the test requirements.

This presentation will explore some unique integrated solutions for high volume production test of these leading-edge AiP devices. These unique interface solutions combine OTA and contacted test into a small environment that fits within the confines of the existing test cell. As will be shown, OTA test is realized through embedded antennae within the contactor / probe head or handler / probe interface, mmWave signals at various frequency bands are routed to the embedded antennae through waveguides, coplanar waveguides and/or connectors in the contactor / probe head and in the handler / prober interface.

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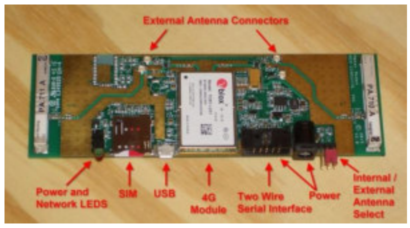
AiP (Antenna in Package) Definition

- AiP technology places an array of antennas on (or in) an IC package that houses a highly-integrated radio or radar transceiver die (or dies in the case of a multi-chip module)
- AiP replaces the traditional module that includes the RFIC on a PCB with both internal and external antenna connections (4G, GPS, Bluetooth, Wifi)
- AiP enables mmWave antenna arrays with lower loss and higher gain with no external PCB interface required

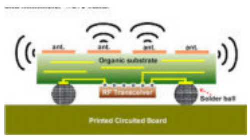
Traditional 4G PCB antenna module

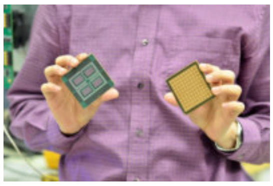


https://www.eenewsembedded.com/news/4g-lte-%E2%80%98maker%E2%80%99-m2m-modem-project-hosts-u-blox-module

AiP Packaging for 5G mmWave

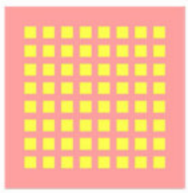
https://www.computerworld.com/article/3166554/5g-starts-with-chips-like-ibm-and-ericssons-silicon-antenna.html



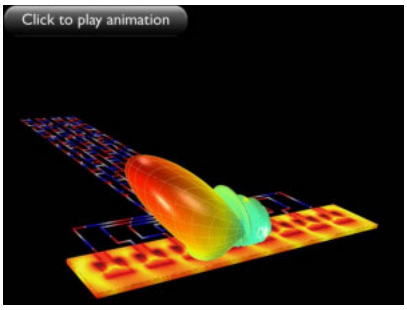


Phased Array Antenna Basics

- Antenna Arrays
  - 2x2, 4x4, 8x8, 16x16, etc
  - First number of transmitters, Second number of receivers
- MIMO
  - Multiple input multiple output
  - Sourcing protocol that provides multiple source signals simultaneously to an antenna array
- Beamforming
  - (beam steering, spatial selectivity, spatial filtering)
  - Sourcing individual antenna elements with different phases (time delay) to "steer" the radiation pattern
  - Constructive and destructive interference combine to form composite radiation pattern at desired direction
  - Focuses energy in desired direction to provide highest power to receiver



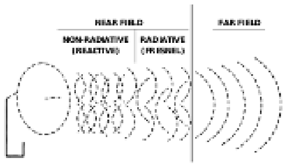
16x16 antenna array



https://www.comsol.com/blogs/designing-a-butler-matrix-beamforming-network-with-rf-modeling/

Far-Field Vs Near-Field basics

- Near-field:
  - In near field the radiative power decreases with $^1/_{r^5}$
  - For $r < {}^{\lambda}/_{2\pi}$, reactive zone (or *inductive* region)
    - > E, H fields random, difficult to measure, and Power density of E,H fields need also phase relationships between the two as well as the angle between the E and H vectors at every point in space
  - For ${}^{\lambda}/_{2\pi} < r < 2\frac{D^2}{\lambda} \approx \lambda$, radiative zone (or *Fresnel* region)
    - > E, H fields all radiant energy, metal objects in this region can act as antennas and re-radiate incident fields
- Far-field:
  - The most common model where radiative power decreases with $^1/_{r^2}$
    - For $2\frac{D^2}{\lambda} \approx \lambda < r < 2\lambda$, transition zone
    - > E, H fields become more predictable, converging into plane waves in the far field (below)
  - For printed antennas like patch or dipole: ${}^{\lambda}/_{4} < D < {}^{\lambda}/_{2}$ so FF are surely reached for a distance $r > \lambda$.
  - For horn antennas ${}^{\lambda}/_{2} < D < \lambda$ so FF are surely reached for a distance $r > 2\lambda$.



Where $\boldsymbol{\lambda}$ is the wavelength, = c/(frequency * $\sqrt{\varepsilon r}$)
r = distance from the radiating structure
D = largest dimension of the radiating element

NF-FF zones in function of the frequency

- **NF and FF zones are directly linked to the wavelength and frequency**
- **We can find the distances for which we are in Far or Near Field**
  - These limits are given below:

Frequency [GHz]	Wavelength [mm]	$R = 0$	$R = \frac{\lambda}{2\pi}$	$R = \lambda$	$R = 2\lambda$
30	10	0	1.6	10	20
40	7.5	0	1.2	7.5	15
50	6.0	0	1.0	6.0	12
60	5.0	0	0.8	5.0	10
70	4.3	0	0.7	4.3	8.6
80	3.8	0	0.6	3.8	7.5

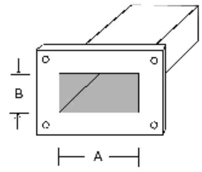
Best Distance for OTA Test

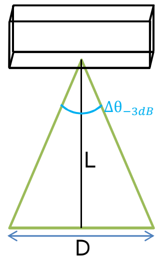
- Far-Field isn't Far away!

Beam width and Gain theory

- **Radiating aperture of section S=A*B:**
  - -3dB Beam width is given by:
  - $\Delta\theta_{-3dB} = \frac{\lambda}{A} * 50°$
    - The bigger aperture, the narrower beam
  - Gain is given by:
  - $Gain[dB] = 10.\log\left(\frac{4\pi S}{\lambda^2} * \eta_A\right)$
  - where ηA is the antenna efficiency (between 0 and 1)
    - The bigger aperture, the bigger gain

- **Small aperture = Wide beam = Small gain**
- **Large aperture = Narrow beam = High gain**



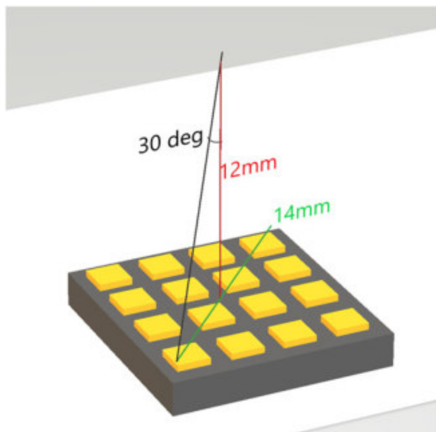


$$L = \frac{D/2}{\tan\left(\frac{\Delta\theta_{-3dB}}{2}\right)}$$

AiP Beamwidth Calculation Example

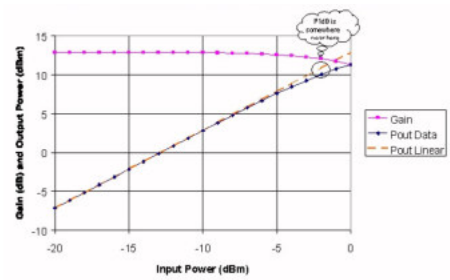
- **Patch antenna array on top of the chip:**
  - The radiation beam has to cover the whole chip area (14mm diagonal)
  - The distance between the radiating aperture/antenna is given by its beam width by the equation:

$$L = \frac{D/2}{\tan\left(\frac{\Delta\theta_{-3dB}}{2}\right)}$$

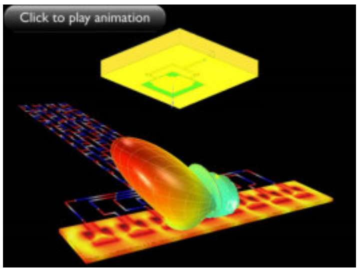


Measurement Challenges for AiP Applications

- **Typical FEM Test Specifications:**
  - Effective / Incident Radiated Power (ERP, EIRP, Gain)
  - Compression Point (P1dB)
  - Error Vector Magnitude (EVM)
  - Adjacent Channel Leakage Ratio(ACLR)
  - 3rd Order Intercept Point (IP3)
  - Spurious Free Dynamic Range (SFDR)
  - Power Added Efficiency (PAE)
- **OTA FEM Test Specification**
  - Gain
  - Phase?
  - Beamforming?
  - OTA testing test plans are currently in development
- **Contactor requirements:**
  - Temperature / Humidity
  - Phase and Amplitude Stability
  - Minimal Reflections
  - Low Loss and Impedance Matching
  - Signal Isolation

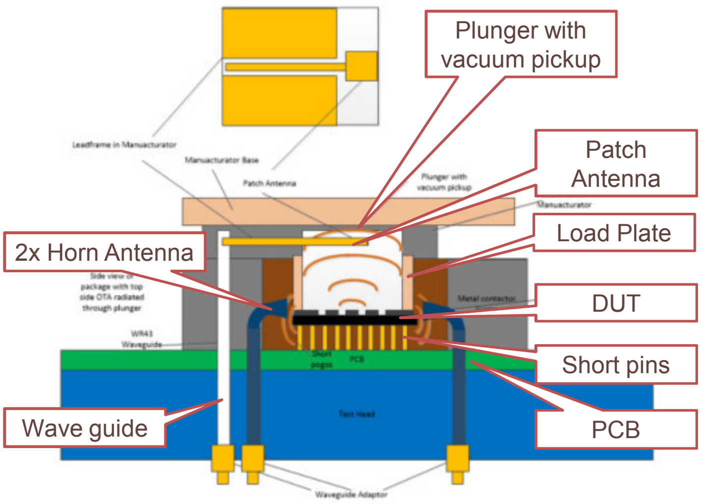


https://www.microwaves101.com/encyclopedias/compression-point



OTA for High Volume Production Test

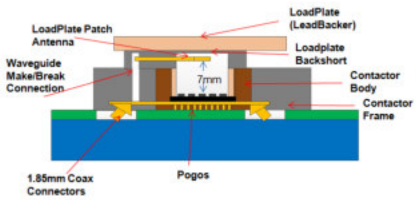
- **OTA xWave:**
  - Leadframe Patch antenna built into manual actuator
  - Waveguide antennas built into contactor
  - Compatible with vertical and horizontal radiation
  - Connector or waveguide interface to tester
  - Leadframe for High speed contacted test
  - Pogo pins for low speed and control signals

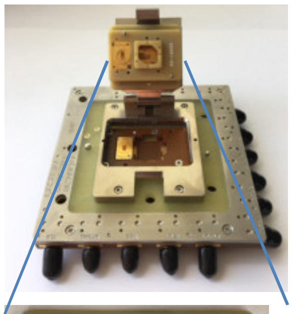


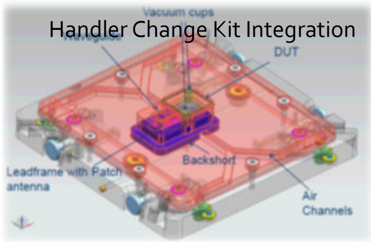
Patch and Horn Combination

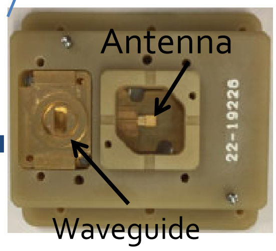
72GHz OTA xWave Contactor for Pick and Place

- ❑ xWave Contactor with Integrated Patch in Workpress/Leadbacker
- ❑ Broadband Performance and Wide Beamwidth
- ❑ Far-field Communication with NO IMPACT TO TEST CELL



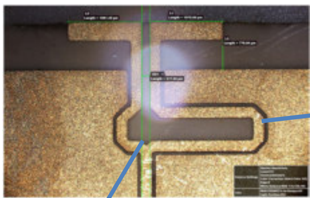


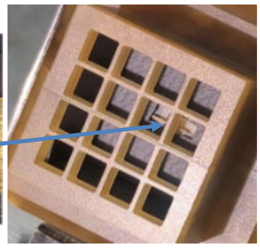


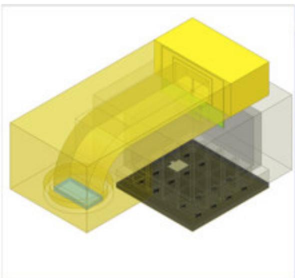


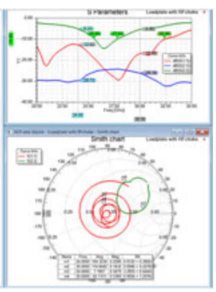
28GHz xWave 5G OTA Contactor for 16 Channel AIP

- ❑ **24GHz to 30GHz broadband performance**
- ❑ **Dipole antenna in Lid**
- ❑ **Absorber lined plunger cavity**
- ❑ **Waveguide feed from tester through contactor into lid**
- ❑ **RF choke interface to lid**
- ❑ **3 months from concept to delivery**

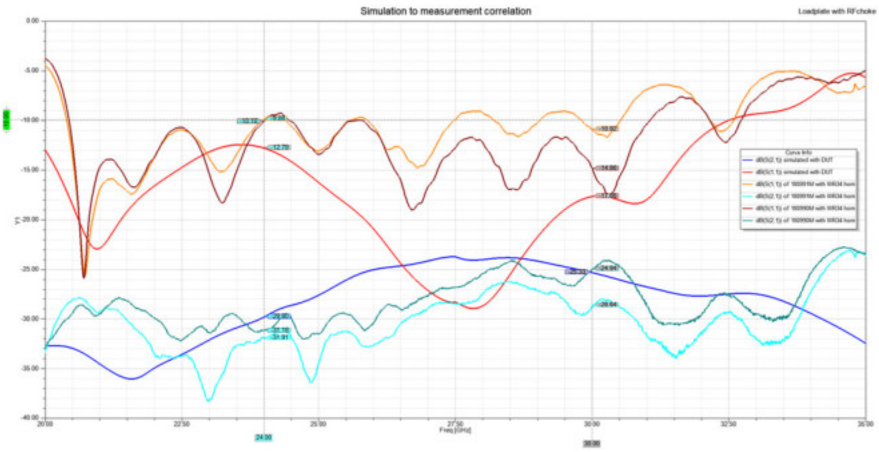






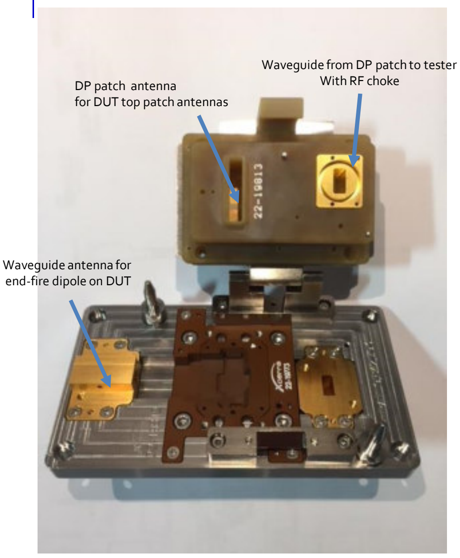


Measurement results

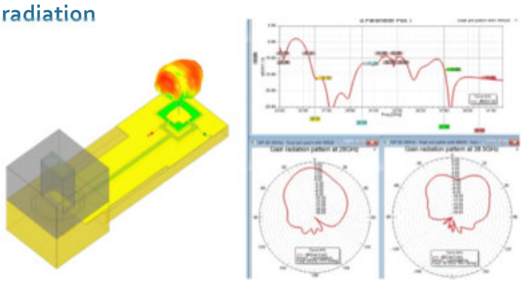


– Red is S_{11} simulated and Orange/Brown are S_{11} measured
– Blue is S_{21} simulated from contactor to ADI chip and Sky/Dark blue are S_{21} measured from contactor to Horn antenna.

Dual-Band Dual-Polarized mmWave 5G AiP Test

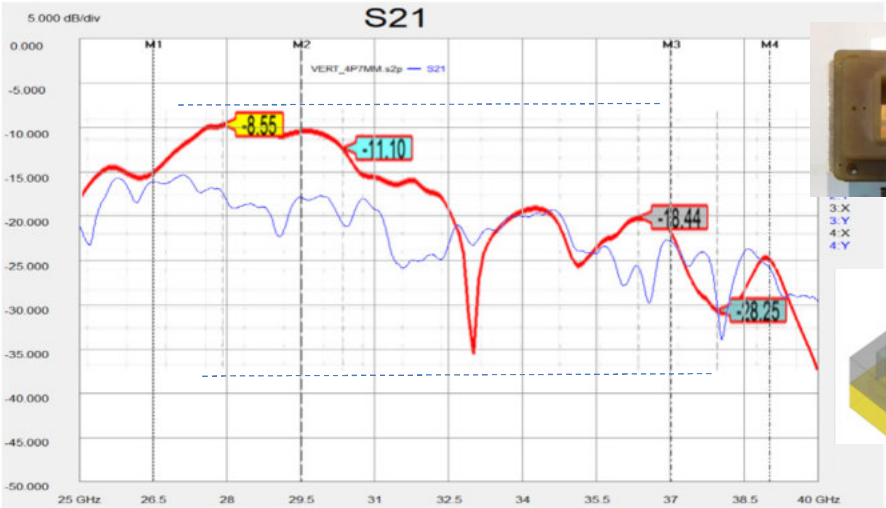


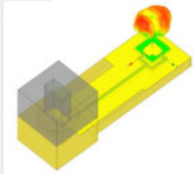
- A production interface solution for 5G that enables OTA testing
- Dual-polarized patch antenna to communicate to Dual-polarized DUT
- Dual band antenna design to be compatible with 28GHz and 39GHz 5G standards (26.5-29.5 GHz / 37-40 GHz)
- Wideband waveguide antenna for horizontal radiation of dipoles in DUT
- Integrates patch and waveguide antennas to be compatible with multiple radiation



5G OTA xWave Insertion Loss Correlation

Sim Red
Meas Blue

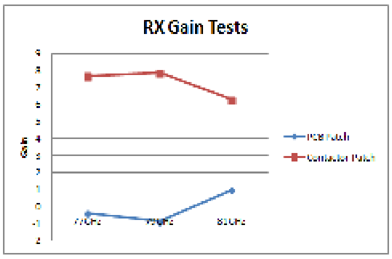




81GHz OTA Automotive Radar Testing

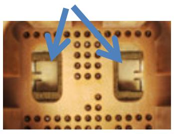
- xWave Contactor allows downward radiation toward test head
- Integrated with Cohu tester and 81GHz Kestrel tester module
- Performance of xWave better matches end application with higher gain performance

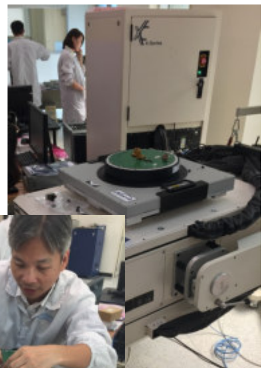
	RX Gain Tests		
	Low Band	Mid Band	High Band
Test Fixture	77GHz	79GHz	81GHz
PCB Patch	-0.37	-0.87	0.96
Contactor Patch	7.65	7.85	6.27



PCB Patch

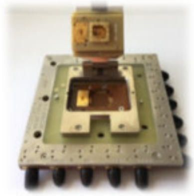
Dual Tx/Rx Patch antenna in contactor





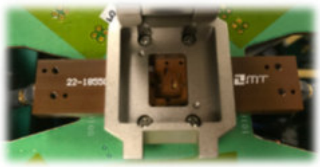
Conclusion

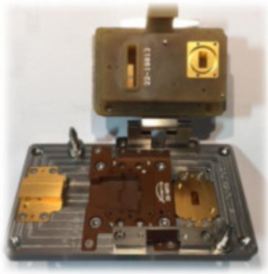
- As AiP technology moves up to cmWave and mmWave, antenna in socket designs are required to make high volume production practical



- xWave OTA allows characterization and high volume test of AiP solutions
  - Enables gain, phase, beamforming and other OTA measurements

- Options available to match any OTA AiP Application
  - Frequency Range
  - Radiation direction
  - Antenna type
  - Connector type





Thank You