Over the Air Test Solution for Antenna in Package Applications

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Abstract:

As we step in 5G area, cell phone makers are turning to AIP ICs. Antenna in Package (or AiP) is a new trend in IC packaging which makes smaller and high integrated ICs that consists of ICs and antenna inside a package. Antenna in Package allows integration of all the complex RF components, together with the base-band circuitry into a complete self-contained module that greatly facilitates the work of the system integrator. As the customer demand for AiP ICs, device size is getting smaller and smaller. AIP design is a system integrator which no longer needs to design complex RF circuits at the application PCB level and makes the overall size of the complete application reduced.

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Cohu Inc.

June 2-5, 2019

Content

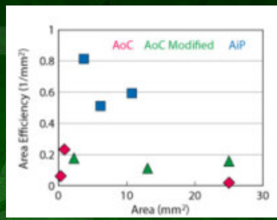
- Antenna in Package (AiP) history
- AiP in current applications
- Over the Air (OTA) requirement in mass production
- OTA solution advantage
- Different OTA solutions

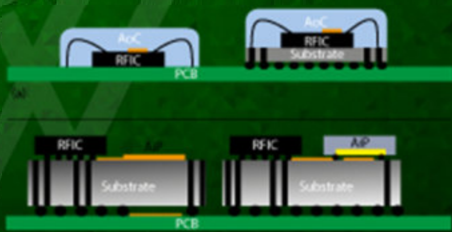
AiP History

What is AiP Technology?

- **AiP technology is an extension of Antenna on Chip (AoC) solution technology that implements an antenna or antennas on (or in) an IC package that can carry a highly-integrated radio or radar transceiver die (or dies in the case of a multi-chip module)**
- **The typical gain of AiPs is two to four times higher than AoCs, due to the use of low loss and lower Dk substrates instead of CMOS-grade silicon**

AiP Packaging for mmWave





Material from 3D Integration and Packaging of mmWave Circuits and Antennas: Opportunities and Challenges, Signal Integrity Journal, February 12, 2016

Far-Field Vs Near Field basics

Different models allow prediction of the behavior of antennas as a function of the distance r from the antenna:

Near-field > Where we Test (Defined as the close-in region of an antenna where the angular field distribution is dependent upon the distance from the antenna)

3 different zones:

a) 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

b) 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

c) 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)

In the case **b)** and **c)** which interests us, the radiative Power density decreases in $^1/_{r^5}$

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

Far-Field Vs Near Field basics

Far-field (Fraunhofer region): Defined by radiation patterns which do not change shape with distance, and E- and H-fields are orthogonal to each other and the direction of propagation as with plane waves.

- The most common model when we deal with wave propagation > real life with 5G + radar applications
- Radiative Power density decreases in $^{1}/_{r^2}$
- This model is only valid for $r > 2\lambda$

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

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NF-FF zones in function of the frequency

– **As the NF-FF zones are directly linked to the wavelength, and so to the frequency, we are able to find the limit distances for which we are in Far or Near Field**

- These limits are given in the "distance line" below:

NF Reactive | NF Radiative | Transition | FF

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 Contactor OTA Test

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Far-Field Vs Near Field Conversions

- ❑ Since OTA contactors for high-volume production test cannot contain the necessary volume to be able to measure full far field performance of the DUT (similar to an anechoic chamber), it is desired to test in a near-field condition if possible.
- ❑ Near Field responses can be post-processed and then converted to a far-field point source measurement response (there is some discussion as to the accuracy related to each type of methodology, and the data requirements for the transformation).

→ depending the application, you can select far field or near field measurement:

→ If you want to measure an NFC (Near Field Communication) chip, you have to be very close to the DUT when you perform the actual measurement (In near field)

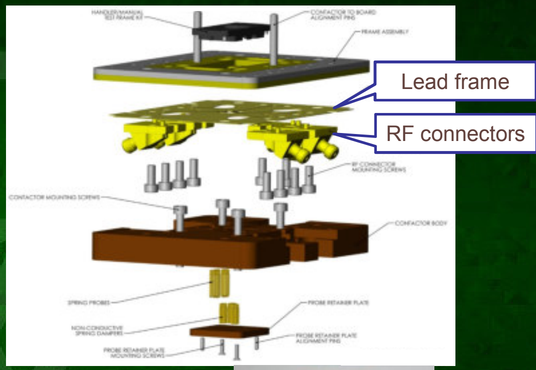
→ If you want to measure a 5G chip with patch antennas on it (which aims to be used in a smartphone for Far Field communications) then you should ***perform a FF measurement (at least in the transition zone at about 7mm away from the DUT for 60GHz***… even if *NF to FF mathematical transformations* exist but are very complex to put in place).

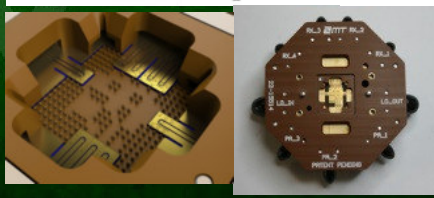
Measurement Challenges

- ❑ Chipset OTA measurements on AiP or AoC require specific parametric measurements:
  - ➢ 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)
- ❑ Contactor Measurement Performance / Accuracy is dependent upon many variables which need to be considered in the design:
  - ➢ Temperature / Humidity
  - ➢ Phase and Amplitude Stability
  - ➢ Signal Reflections from Contactor Surfaces (use radar absorbing material)
  - ➢ Insertion Loss and Impedance Match
  - ➢ Signal Isolation

OTA Platform based on Lead Frame Technology

- Core technology – xWave Lead Frame, is a thin sheet of metal which allows us to design structures to meet various device interconnect requirements.
- We use lead frame to transmit signals and replace PCBs in our contactor. Complete menu of standard pogos still available for low freq signals.
- In addition to traditional structures used for contact test, the Lead Frame also acts a medium to fabricate antennas and other coupling structures
- xWave Leadframe based contactors support device pitch down to 100um and multiple Sites





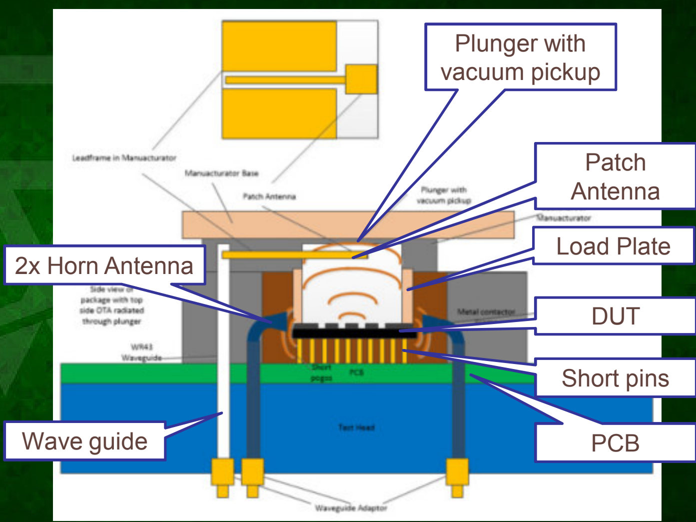
Different Application Structures (Continued)

Multiple Options for Antennas:

Horns, Patches, Dipoles

Multiple Options for Interconnect to Tester:

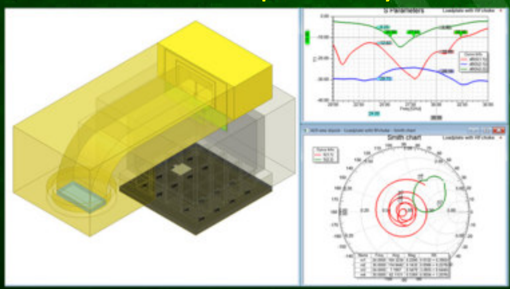
Coax, Waveguide, PCB contact

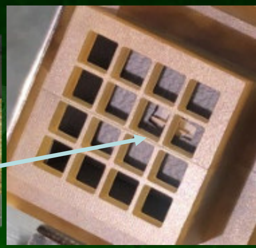


Patch and Horn Combination

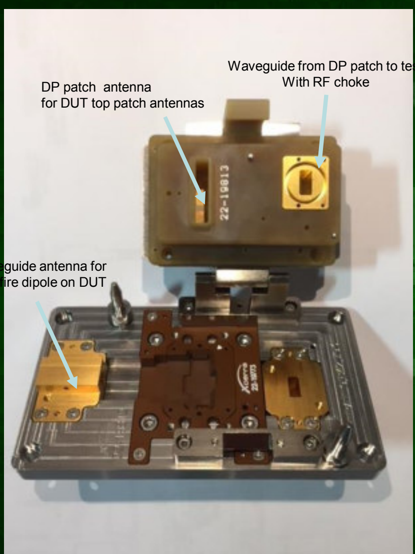
28GHz xWave 5G OTA Contactor for 16 Channel AIP

- 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





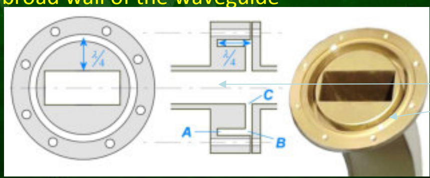
OTA for 5G : Dual- Band (26.5-29.5 GHz / 37-40 GHz)



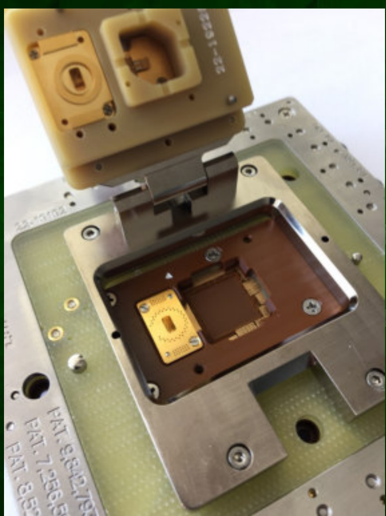
- A production interface solution that enables OTA testing with a dual-polarized patch antenna and integrated waveguide antenna for the “end fired” DUT dipole test
- This solution integrates the OTA Contactor with patch and waveguide antennas.

What is a Waveguide RF Choke?

- **With mechanical tolerance build-ups in contactor manufacturing and probe head connection to the contactor, waveguide from the MA (or tester) to the contactor body may not have full contact closure of the WG flanges:**
  - Therefore, a WG RF choke allows air gap to exist while keeping E and H fields contained, and prevents signal loss via radiation
    - Flange ring depth ¼ wavelength and essentially a resonant short circuit stub
      - High impedance in series with metal-metal connection minimizes current across it
    - Distance from WG through gap to the ditch also ¼ lambda
      - gap forms a ¼ lambda transformer transforming the high impedance at the top of the ditch to a low (ideally zero) impedance at the broad wall of the waveguide



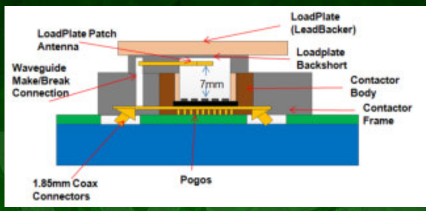
OTA for 5G : 60 GHz Contactor with integrated Patch Antenna

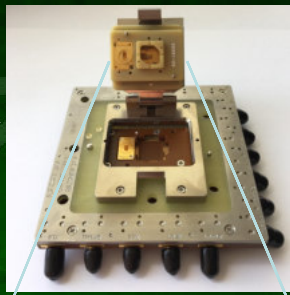


- **A production interface solution that enables OTA testing of a 60 GHz single-chip integrated Antenna in Package has been delivered to a customer.**
- **The solution integrates the OTA Contactor with patch antenna.**

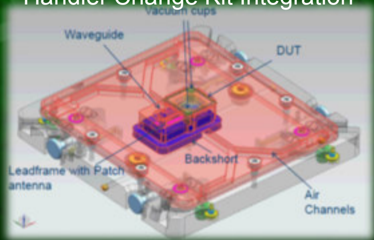
72GHz xWave OTA Contactor Pick and Place Handler (MT2168)

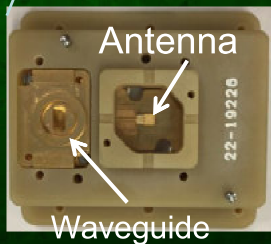
- xWave Contactor with Integrated Patch in Workpress/Leadbacker
- Broadband Performance and Wide Beamwidth
- Far-field Communication with NO IMPACT TO TEST CELL





Handler Change Kit Integration

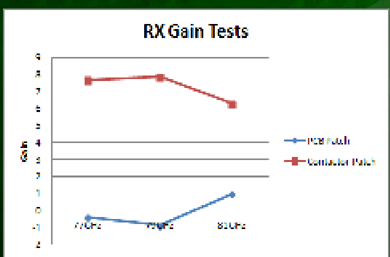




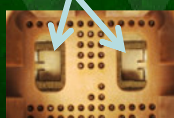
81GHz OTA Automotive Radar Testing

- xWave Contactor with integrated Patch Antennas outperforms PCB patches
- Uses 81GHz Kestrel tester module cabled directly to patches in contactor
- Integrated with Cohu MX tester

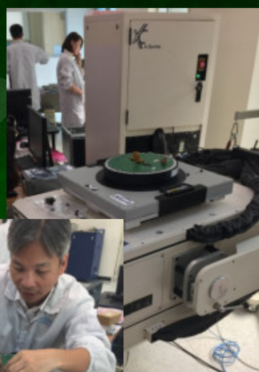
	RX Gain Tests		
	Low Band	Mid Band	High Band
Test Fixture	77GHz	79GHz	81GHz
PCB Patch	-0.37	-0.87	0.96
Contactor Patch	7.65	7.85	6.27



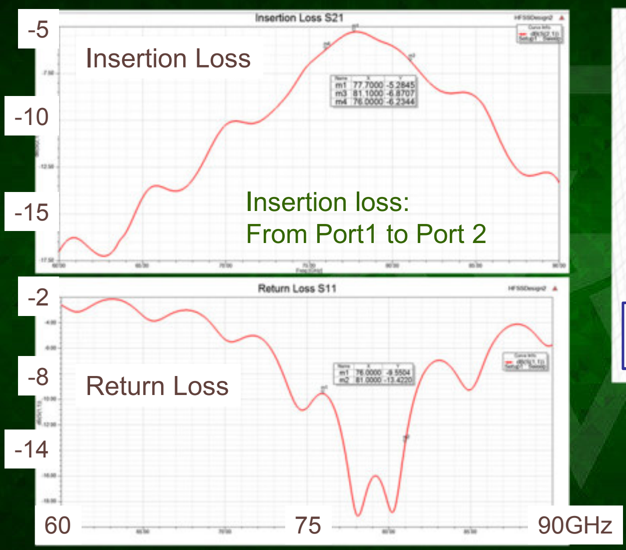
Dual Tx/Rx Patch antenna in contactor

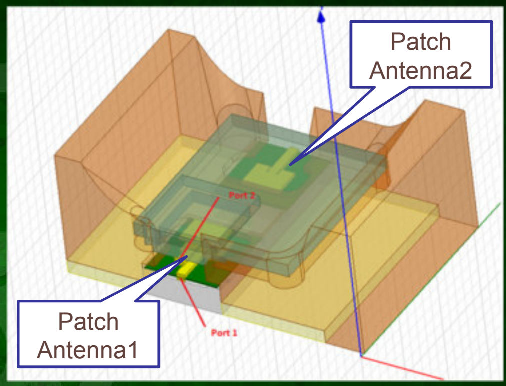


PCB Patch



OTA Simulation @ 80GHz





Modeled OTA Solution with Patch Antenna in Contactor

Unique OTA Architecture

- **Real Life Test plus more**
  - Actual radiated OTA test > real life performance characterization of AiP chip
  - Leadframe incorporating Co-Planar Waveguide (CPW) replace PCB traces > lower loss
  - Waveguide transition to planar antenna > lower loss
  - Eliminate cables by using waveguide interfacing on the tester side > lower loss
  - Utilize RF waveguide chokes to provide for tester interface mechanical tolerances
- **Longer life cycle**
  - Lead frame life cycle is well over **1 million** insertions
- **Tighter tolerance**
  - Precise machining process used for contactor manufacture

Conclusion

- As OTA testing for 5G AiP technology moves up to cmWave and mmWave, advanced antenna in socket designs are required to make high volume production practical
- Using unique ruggedized CPW lead frame technology along with integrated patch, dipole, or waveguide antenna in socket makes for very stable and reliable OTA test
- Antennas integrated into a contactor design should be located and optimized for varying radiation patterns and directivity specific for each unique chip design. They may need to be located on or outside the top, sides and/or bottom of the AiP chip under test.