Measurement Challenges for Over-the-Air Test of Antenna in Package (AiP) ICs

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Abstract:

Over-the-Air (OTA) measurements are defined as standardized methods to evaluate performance of wireless semiconductors / transceivers / systems. In this paper, we will focus upon in-tester OTA measurement challenges in the upcoming fifth generation (5G) semiconductor designs which support the backbone of these wireless systems.

There are key technologies that will be used in high volume production 5G OTA measurements, including the test contactor design which support direct in-tester OTA characterization of these devices under test (DUT) which contain integrated antenna systems, coplanar waveguide (CPW) and micro-strip structures, waveguide to transmission line launches (and visa-versa), Anechoic chamber technology, as well as passive components to aid in signal manipulation in order to make characterization of the DUT easier.

There are definite design challenges for these OTA contactors in order to maintain the high levels of signal integrity required to maintain accurate OTA measurements at 5G centimeter (cm) and millimeter (mm) wave frequencies. High volume production of OTA semiconductors also requires the test contactor to have both mechanical ruggedness and precise electrical simulation and modeling which feedback into the mechanical design to assure high frequency performance necessary for accurate characterization of the DUT.

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Content

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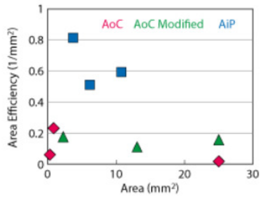
- AiP history
- AiP in current applications
- OTA requirement in mass production
- OTA solution advantage
- Different OTA solutions

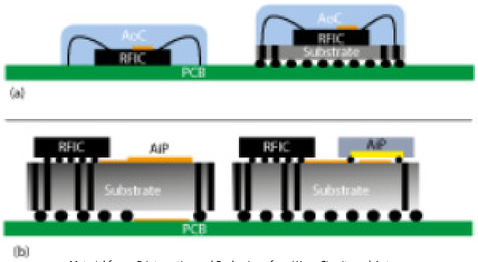
AiP History

What is AiP Technology?

- AiP technology is an extension of AoC antenna 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)
- 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 predicting the behavior of antennas in function of the distance r from them:

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 $1/_{r^5}$

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 $1/_{r^2}$

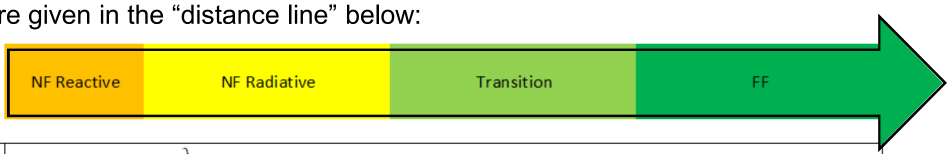
This model is only valid for $r > 2\lambda$

Where λ 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

– **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:



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

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).

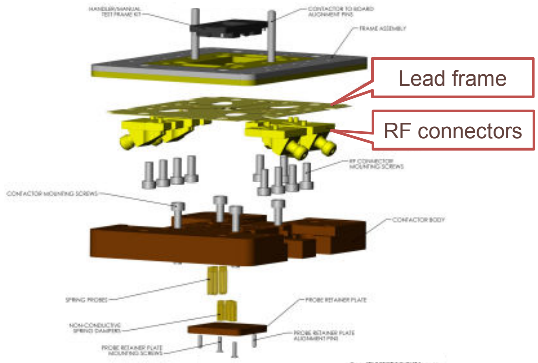
→ depending the application, you can select far field or near field measurement:
  - → If you want to measure an NFC (Near Field Communication) chip, you have to be very close to the DUT when you perform the actual measurement (In near field)
  - → If you want to measure a 5G chip with patch antennas 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).

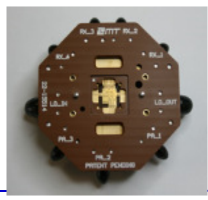
Measurement Challenges

- ❑ Chipset OTA measurements on AiP or AoC require specific parametric measurements:
  - ➢ Error Vector Magnitude (EVM)
  - ➢ Packet Error Rate (PER)
  - ➢ Adjacent Channel Power (ACP)
  - ➢ Spurious Free Dynamic Range (SFDR)
  - ➢ Effective / Incident Radiated Power (ERP, EIRP)
  - ➢ Eye Diagram parametrics (trise / tfall / jitter / eye closure, etc.)
- ❑ 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 – Lead frame, is a thin layer of metal frame to which semiconductors are attached during the package assembly process.**
- ❑ **We use lead frame to transmit signals and replace PCB in our contactor**
- ❑ **We build structures on lead frame to execute different RF performances**

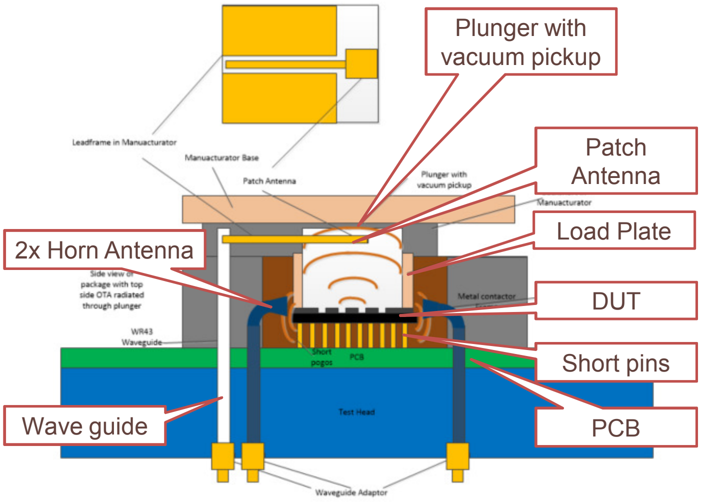




Different Application Structures (Continued)

This is one patch antenna to test antenna on the top DUT.

Two waveguide horn antennas test antennas on DUT side. All connect to waveguides to tester side.

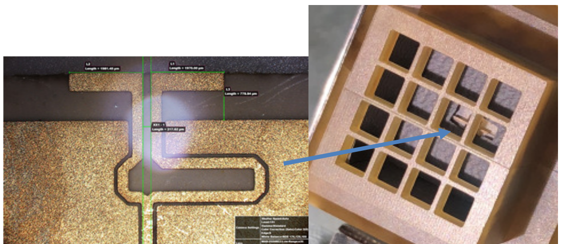


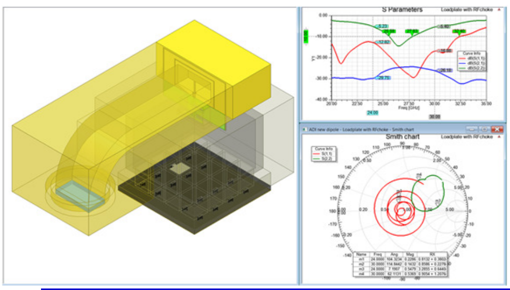
Patch and Horn Combination

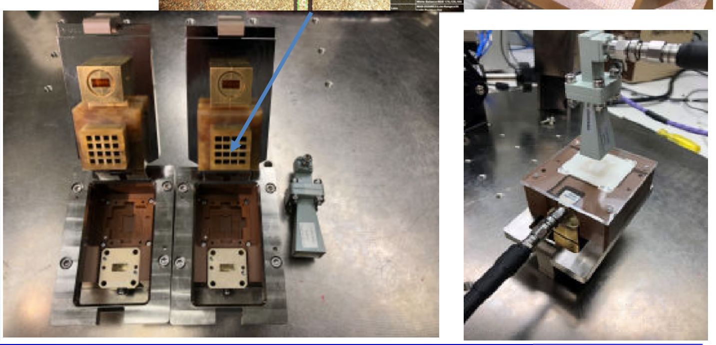
28GHz xWave 5G OTA Contactor for 16 Channel AIP

- 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

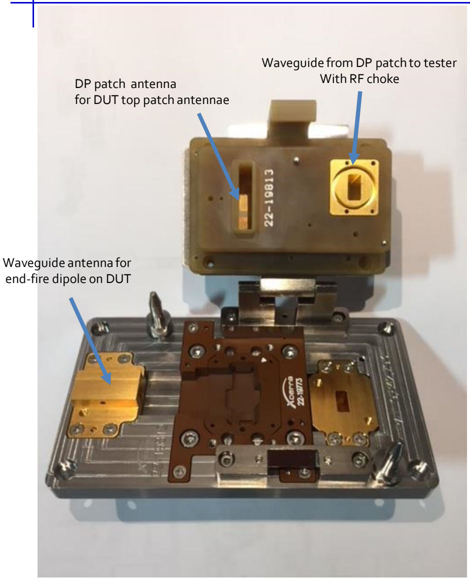
- 3 months from concept to delivery







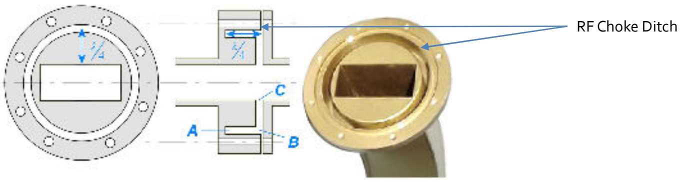
OTA for 5G : Dual- Band (26.5-29.5 GHz / 37-40 GHz)



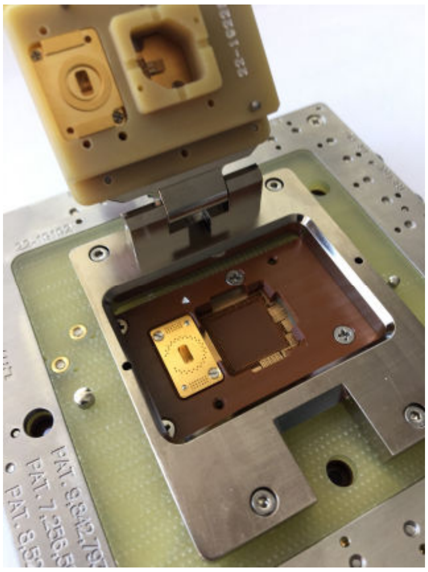
- A production interface solution that enables OTA testing with a dual-polarized patch antenna and integrated waveguide antenna for the "end fired" DUT dipole test
- This solution integrates the OTA Contactor with patch and waveguide antennas.

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 is 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



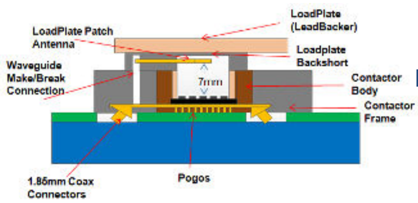
OTA for 5G : 60 GHz Contactor With integrated Patch Antenna

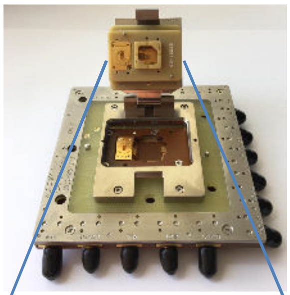


- A production interface solution that enables OTA testing of a 60 GHz single-chip integrated Antenna in Package has been delivered to a customer.
- The solution integrates the OTA Contactor with patch antenna.

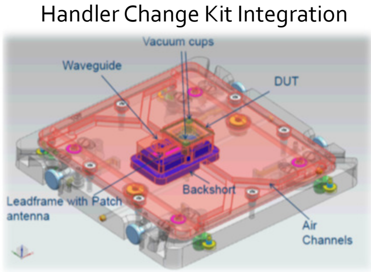
72GHz xWave OTA Contactor Pick and Place Handler (MT2168)

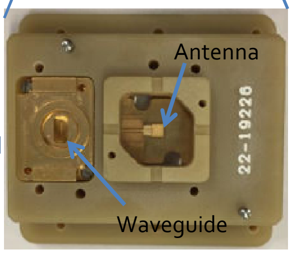
- xWave Contactor with Integrated Patch in Workpress/Leadbacker
- Broadband performance and wide beamwidth
- Far-field communication without impact to standard ATE Test Cell





Handler Change Kit Integration

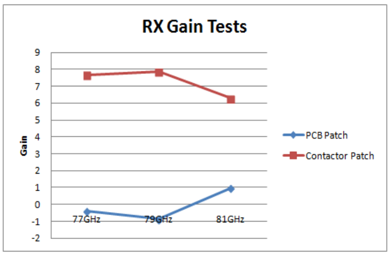




81GHz OTA Automotive Radar Testing

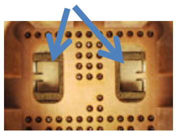
- xWave Contactor with integrated Patch Antenna's outperforms PCB patches
- Uses 81GHz Kestrel tester module cabled directly to patches in contactor
- Value added system integration with Cohu MX tester

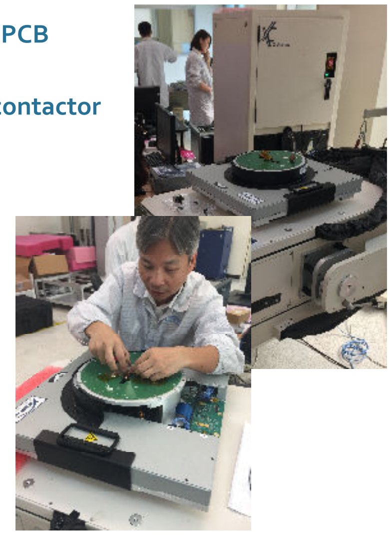
	RX Gain Tests		
	Low Band	Mid Band	High Band
Test Fixture	77GHz	79GHz	81GHz
PCB Patch	-0.37	-0.87	0.96
Contactor Patch	7.65	7.85	6.27



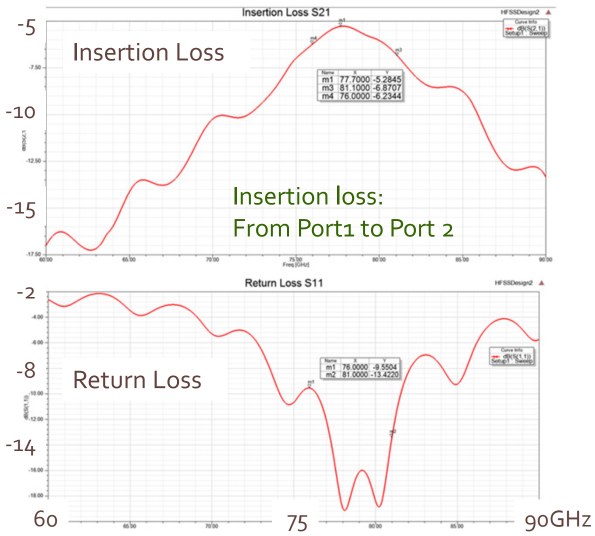
Dual Tx/Rx Patch antenna in contactor

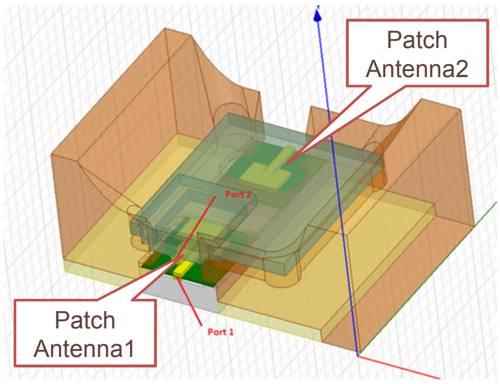
PCB Patch





OTA Simulation @ 80GHz





Modeled OTA Solution with Patch Antenna in Contactor

Cohu OTA Contactor Advantages

- **Rea Life Test plus more**
  - Actual radiated test > real life performance characterization of AiP chip
  - 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 million insertions
- **Less tolerance**
  - Precise machining process used for contactor manufacture

Conclusion

- **As OTA testing for 5G AiP technology moves up to cmWave and mmWave, the Cohu xWave contactor design makes package in socket test possible for high volume production**
- **Using unique ruggedized CPW lead frame technology along with integrated patch, dipole, or waveguide antennae in socket makes for very stable and reliable OTA test**
- **The antennas integrated into a contactor design can be optimized and located into the contactor for use with varying radiation patterns and directivity for each unique chip design. They can either be located out the top, sides and/or bottom of the AiP chip in test.**

Thank You for coming to my presentation! תודה שבאתם למצגת שלי!