Solution for mmWave Wafer Probe Applications and Field Results

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Abstract:

Today cmWave (3-30 GHz) and mmWave (30-300 GHz) applications have become mainstream. The wafer is becoming the new final test package. Testing automotive radar on wafer at 80 GHz and 150 °C was previously a fantasy, but is now a reality. With high tech electromagnetic simulation tools and 110 GHz VNA's it's possible to design and fabricate hardware for these extremely high frequency, extreme temperature applications.

This paper will introduce a unique and robust high volume semiconductor test solution designed for wafers in the cmWave and mmWave frequency bands. This new WLCSP probe card technology incorporates the shortest impedance controlled path from the Tester to the Device Under Test (DUT) by eliminating the PCB interface and contacting directly with the DUT. The cantilevered leadframe technology carries the mmWave signals directly from the tester to the DUT. The Hybrid contactor leverages traditional spring probes for power and low speed signals transmission. Combining technologies provides the longest life, most robust solution available for high speed wafer testing.

An introduction to the cmWave and mmWave markets will be followed by the challenges that had to be overcome to take this technology from final test applications to wafer test. Optimization of the signal path for the best signal integrity and mechanical characteristics will be described. The full assembly will be broken down to describe functionality and field maintainability. Finally customer test data will be presented to prove the technology functions as expected in extreme frequency and temperature high volume semiconductor environments.

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Overview

- Introduction / Background – cmWave and mmWave Market/applications and xWave
- Objectives / Goals – Move from package test to wafer test
- Methods / Materials / Procedures – design considerations, mechanical simulation, electrical simulation, characterization
- Results / Relevant Findings / Key Data – tip design, force, insertion loss, impedance
- Customer Results/Feedback – Initial DC and RF test results
- Summary / Conclusion - viable cmWave and mmWave wafer level test solution
- Follow-On Work – Beta sites

mmWave Market

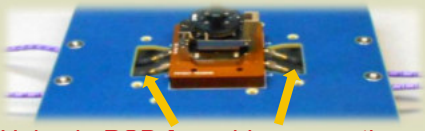
- ADAS
  - Advanced Driver Assistance System (Automotive Radar)
  - Short Range 24GHz and Short and Long Range 80GHz versions
  - CMOS – Low cost, High integration, catching up with SiGe
  - SiGe – High power/frequency performance ,High cost ,Low integration
  - GaN – Highest frequency, high cost, low integration, obsoleted by SiGe
- 5G telecom
  - 5G Backhaul – routers behind the tower
  - 5G End Node – Handheld phones/tablets/devices
  - Contacted test – external antenna arrays
  - AIP – Antenna In Package – Over the air test
  - 28GHz and 39GHz bands popular
  - Eband/Vband expected as next generation

mmWave Market

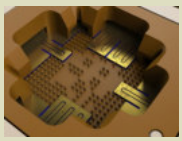
- UltraGig/WiGig
  - Fixed Wireless applications
  - Local area networks
  - Short range line of sight
  - beamforming
  - 57-64 GHz extended to 71 GHz
- Satellite Internet
  - Low orbit satellite internet systems
  - Global aircraft high speed internet connection
  - Terrestrial and orbiting devices
  - Ku (12-18 GHz) and Ka (26.5-40 GHz) bands
- High Speed Cloud Networks
  - SERDES - 54GBPS NRZ, 112GBPS PAM4
  - 3rd Harmonics reach 80GHz
  - RF theory applies to Digital applications

xWave Platform for mmWave Package Test

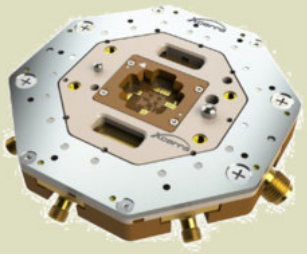
- Signal Integrity
  - Short impedance controlled coplanar waveguide (CPW)
  - 1 transition between Tester and DUT (connector to Leadframe)
  - DUT ball contacts CPW
- Integrated Solution (PCB/Contactor in One)
  - Includes Full RF Path from Tester to DUT
  - Pogo pins for Power and control signals
- Production Package Test Solution
  - Robust Leadframe lasts Millions of cycles
  - Mechanical assembly fully field maintainable
  - Includes calibration kit (s-parameters)
  - CTE matched materials for Tri Temp testing (-55 to 155°C)

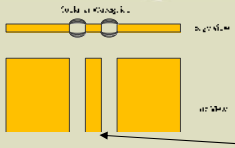


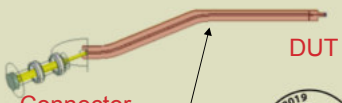
Holes in PCB for cable connections



DUT Pocket







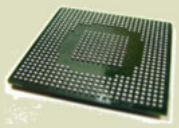
DUT

Connector

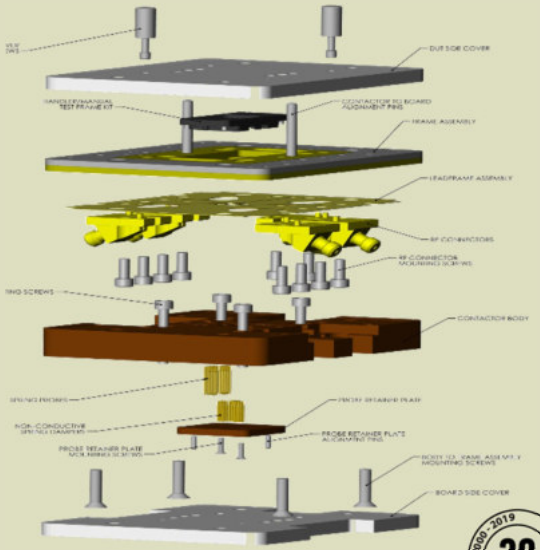
CPW

xWave Limitations for Wafer Test

- Frame limits xWave solution to Package test
  - Leadframe sandwiched between top frame and connectors
  - Top frame violates wafer infinite plane
  - Flat leadframe shorts adjacent sites

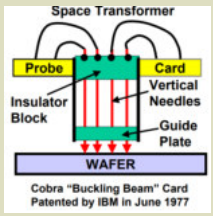


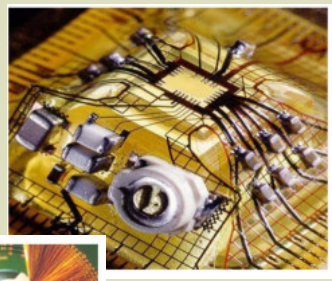
How to make xWave compatible with Wafer Test?

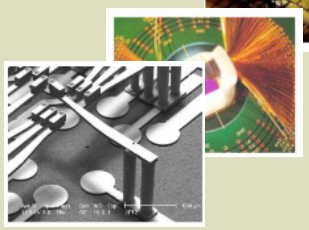


Current RF Probe Limitations

- Cantilever
  - No impedance control
  - Extremely High inductance
  - Limited to <2GHz
  - Decoupling components far from DUT
    - Vertical Probe
      - Shorter uncontrolled impedance path
      - Lower inductance than cantilever
      - Limited to <6GHz
      - Decoupling components ~1-2cm from DUT
      - Individually replaceable probes
        - Membrane
          - Impedance controlled to DUT
          - No additional inductance
          - Decoupling caps ~1-5mm from DUT
          - Limited compliance (~50um)
          - Fragile
          - Not field replaceable



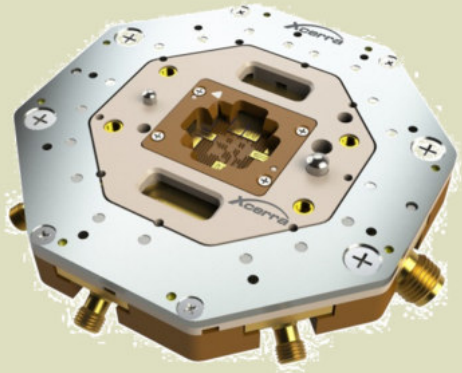




Images provided by William Mann Chair, Southwest Test Workshop

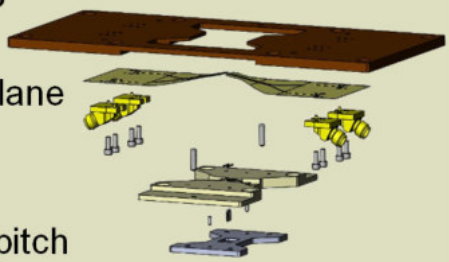
WLCSP xWave Design Goals

- Maintain as much as possible from package test xWave technology
  - mmWave Signal integrity
  - High compliance
  - Field maintainability
  - Robustness and longevity
  - Tri-Temp capability

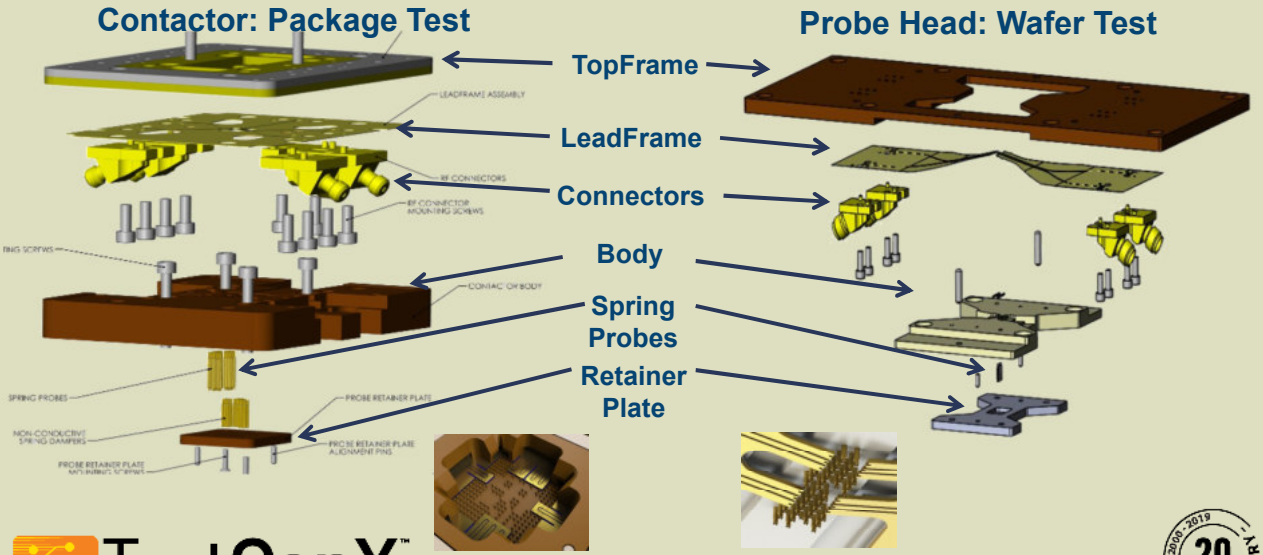


Objectives/Goals

- Move xWave Technology from package test to wafer probe
  - Move contact point of leadframe to infinite plane
  - Combine leadframe with fine pitch pogo technology
  - Reduce leadframe features to match bump pitch
  - Reduce leadframe force to limit contact marking on wafer bumps
  - Limit scrub to ensure no ball shear



xWave Wafer Level Final Test



xWave: Wafer Level Final Test

- Signal Integrity
  - Short impedance controlled coplanar waveguide (CPW)
  - 1 transition between Tester and DUT (connector to Leadframe)
  - DUT ball contacts CPW
- Integrated Solution (PCB/Contactor in One)
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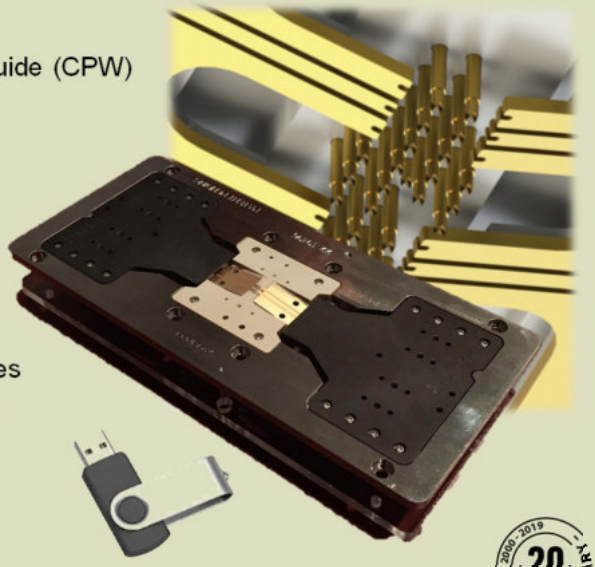
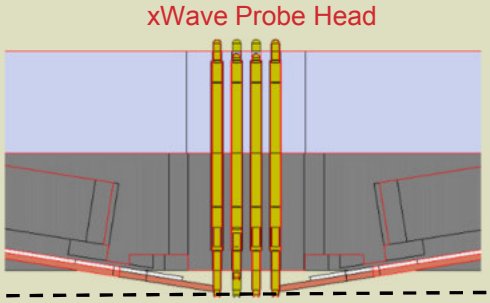
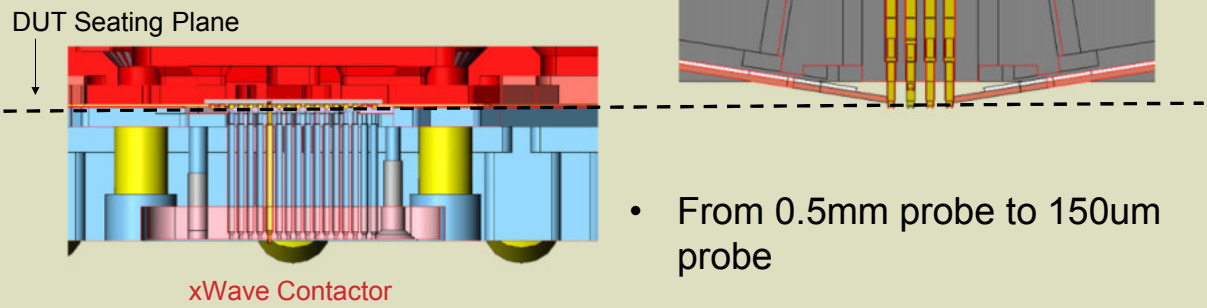


Move contact plane to infinite plane

- From Flat leadframe in DUT pocket to angled leadframe at infinite plane

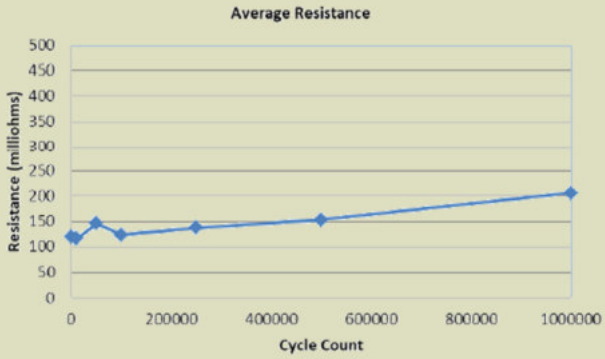




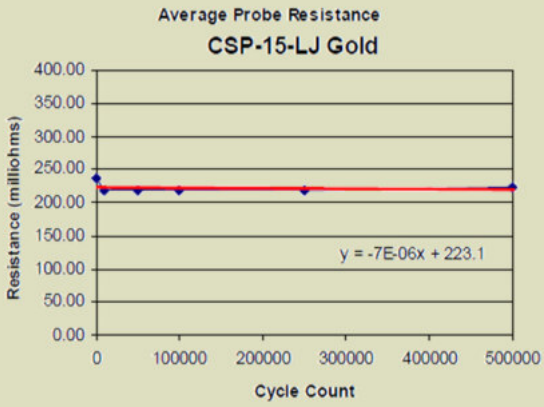
- From 0.5mm probe to 150um probe

Probe comparison

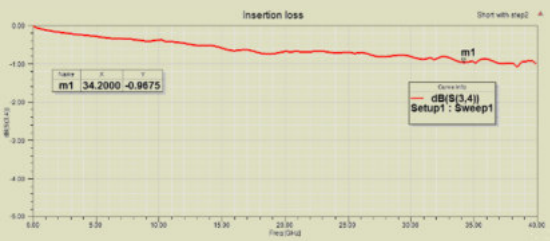
- xWave Contactor Probe

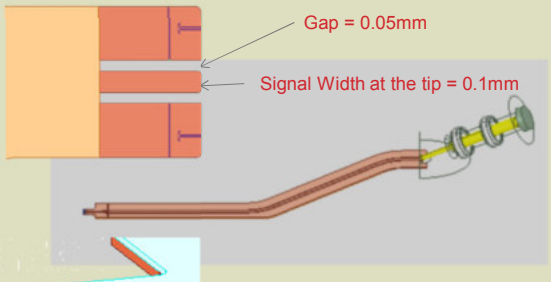


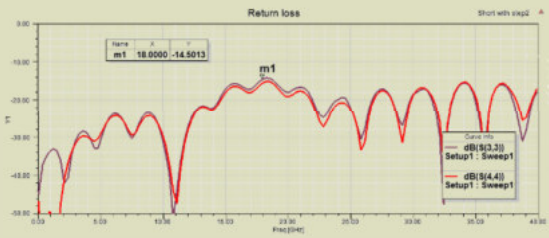
xWave Wafer Probe

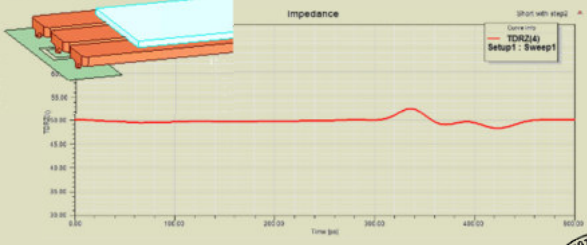


Electromagnetic Simulation



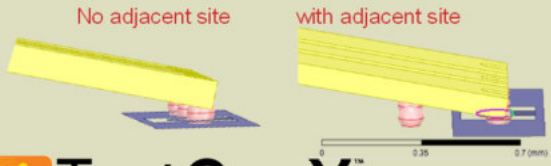


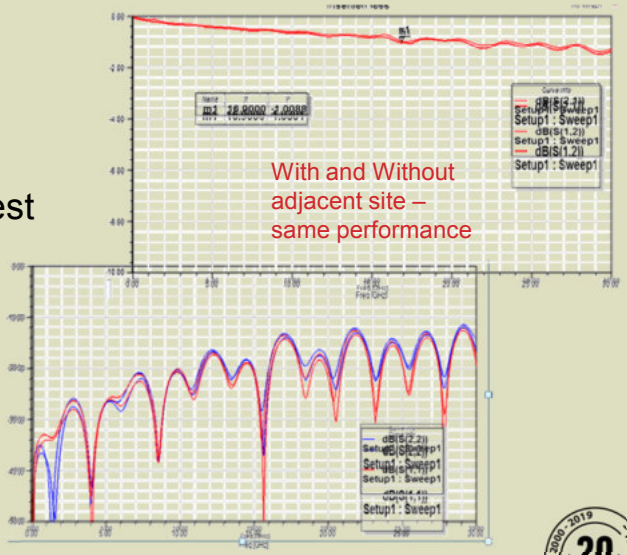




WLCSP xWave Signal Integrity

- Impact of Adjacent site
  - 15deg angle at free height
  - 5deg angle at test height
  - Proximity of adjacent site to test site
  - Same performance with and without adjacent site





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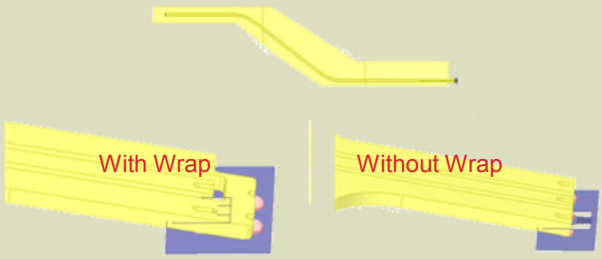
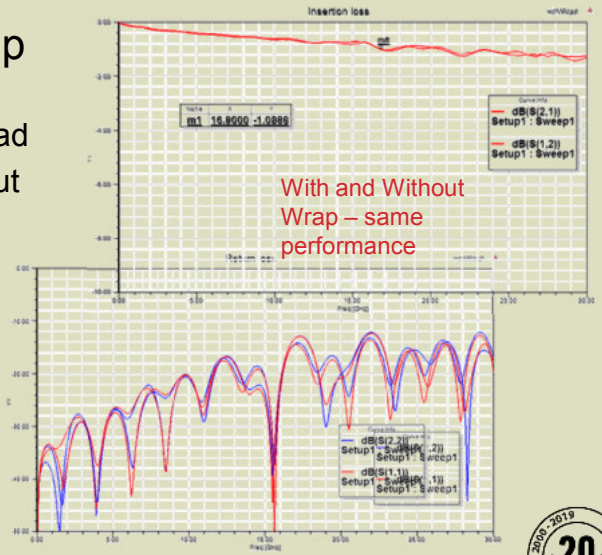
WLCSP xWave Signal Integrity

- Eliminated CPW ground wrap
  - Relies on DUT to maintain ground potential on either side of signal lead
  - Same performance with and without ground wrap





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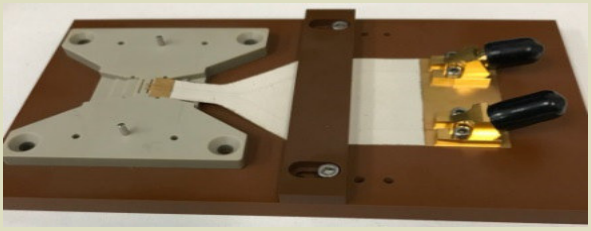
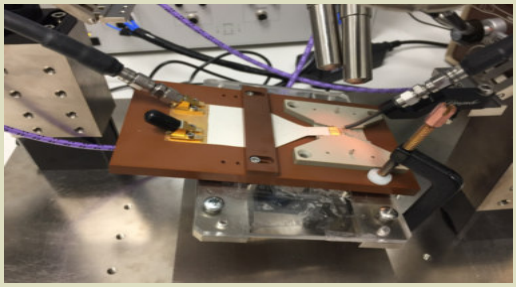
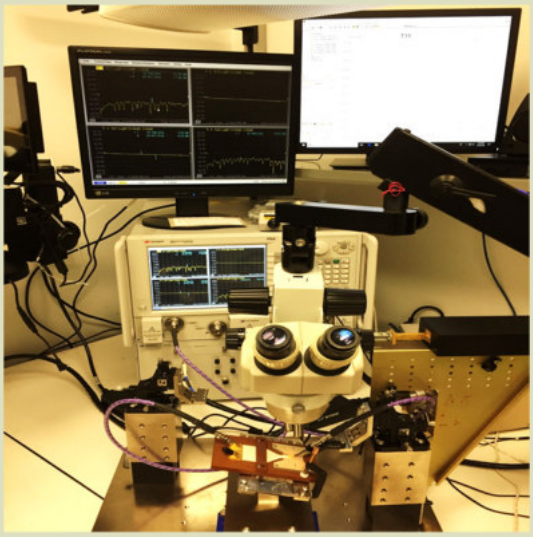
Prototype RF Lab Measurement

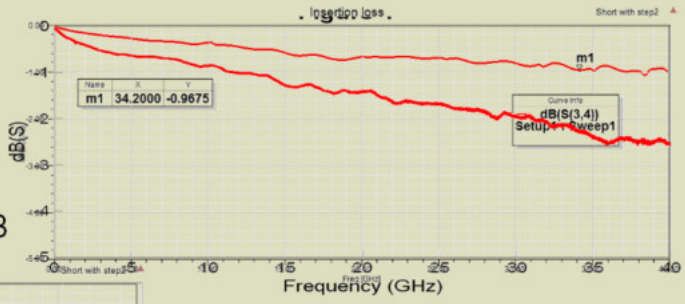


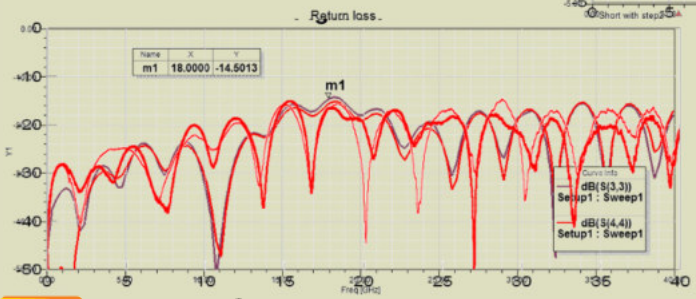




Simulation to Measurement Correlation

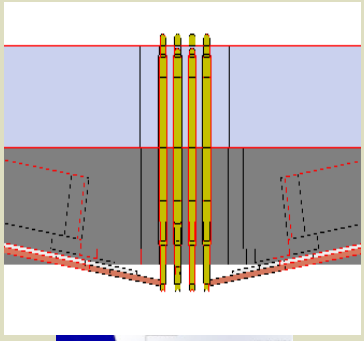
- Simulation and Measurement linear
- More insertion loss in measurement
  - Longer path length in measurement
- Return loss correlates and <-15dB

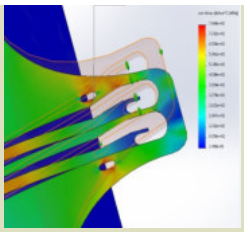




WLCSP xWave Mechanical Design

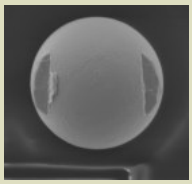
- Force
  - Leadframe – 8g @ 150um overtravel
  - 250um total leadframe compliance
  - Adjustable based on leadframe cross section and cantilever anchor point
  - Sufficient force without spring damper
- Thermal
  - Designed for Tri-Temp
  - Same materials as standard xWave
  - All materials are matched coefficient of thermal expansion (CTE)



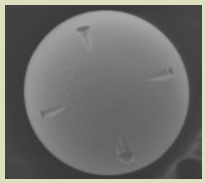


WLCSP xWave Mechanical Design

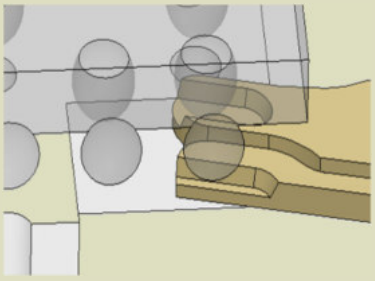
- BGA Contact feature
  - Leadframe - U shape edge contact to ball
  - ~10um knife edge scrub
  - Pogo – 4 point crown
  - 250um compliance

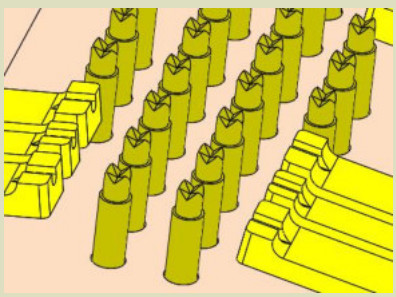


Leadframe



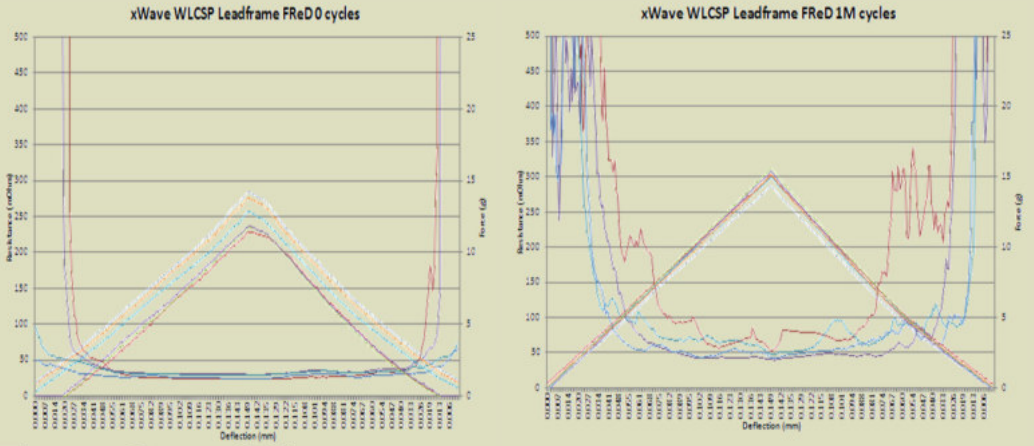
probe



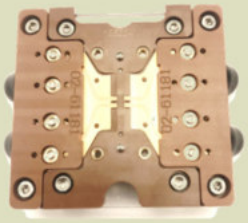


WLCSP xWave Life Cycle

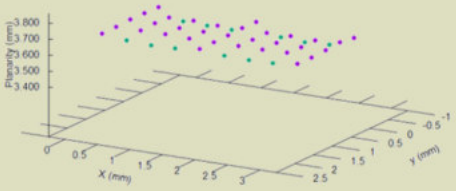
- Stable low contact resistance through 1M cycles
- No force degradation over 1M cycles



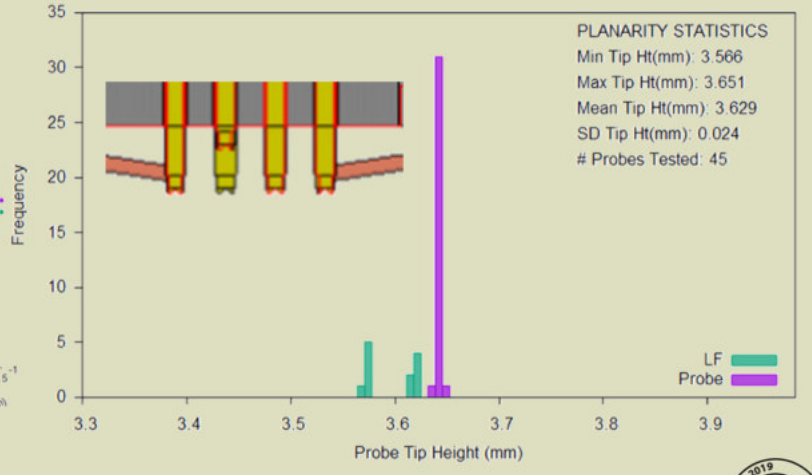
Probe Head Planarity



22-20236 SN185573M Planarity (Full Skew)



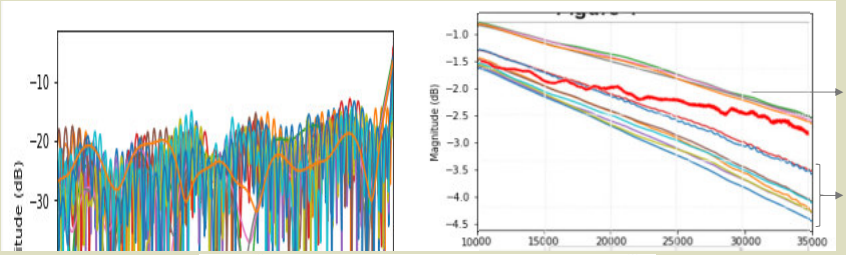
50-60um between leadframe and pogo free height by design



Package Test and Wafer Test in One

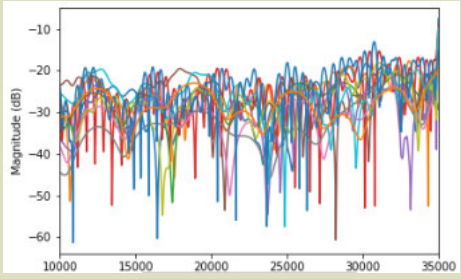
- Same hardware can be used for both packaged test and wafer test
  - Manual Alignment Frame (MAF) attaches to Probe head to convert to final test
  - Manual Actuator (MA) attaches to MAF
  - Simple change over from Wafer to Packaged parts for QA or RMA's

Customer Results: S11, S21 TDR 1 port AFR 0-35GHz



Only probe head, no cabling

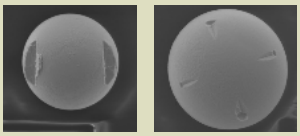
Main difference is cable length



Correlates to Cohu Internal measurements

Customer Results: First trials

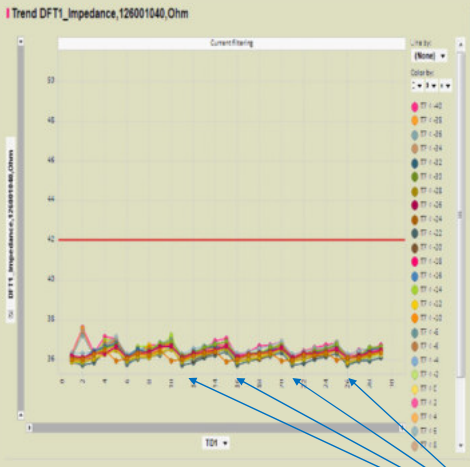
- Day 1
  - Prober setup OK(single only)
    - Site and bump pitch/location is OK
  - DC trials: both sites OK
    - No overdrive needed to get contact
    - DC measures analysis on going for different overdrive steps
    - No obvious DC probe mark on bump, or very slight (prober camera)
  - RF trials : site 1 OK
    - Requires ~100um overdrive to get RF contact
      - Prober measured 55um difference height DC vs RF
      - Cohu expecting 60um overdrive RF vs DC for contact. Nominal 150um would be ok for most cases.
    - No obvious RF probe mark on bump, or very slight (prober camera)



Customer Results DFT1 impedance: Existing vs Cohu

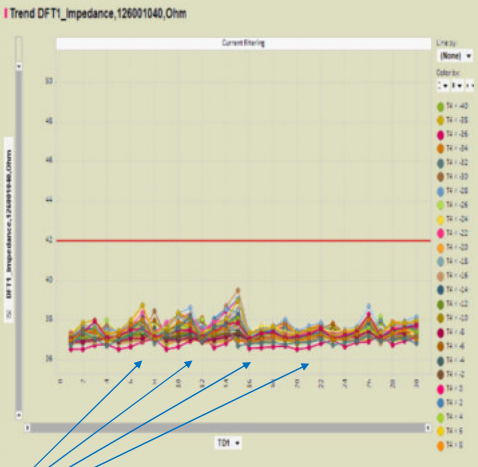
Existing probe card

Pos Y=-26, cleaning, 30 Run, OD=200



Cohu probe card

Pos Y=-98, cleaning, 30 Run, OD=190

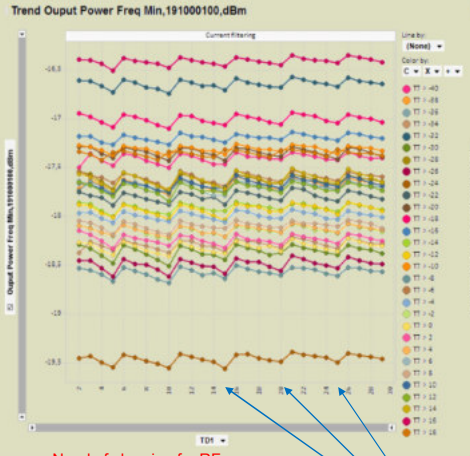


Cleaning every 150 touch down

Customer Results: RF measure: Existing vs Cohu

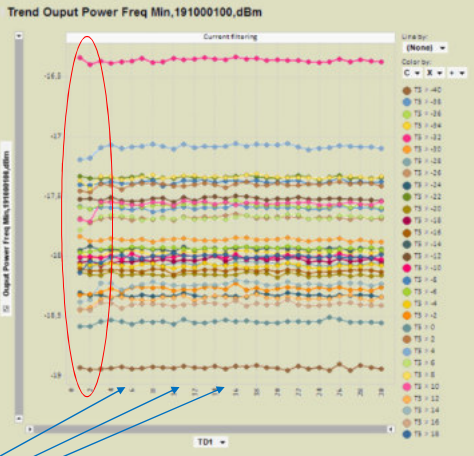
Existing probe card

Pos Y=-26, cleaning, 30 Run, OD=200



Cohu probe card

Pos Y=-74, cleaning, 30 Run, OD=150



Need of cleaning for RF measure

- No impact of cleaning on RF
- Small drift seen on first runs (to be checked)

TestConX™ Cleaning every 150 touch down

Customer Results: Wrap-Up / X-Wave Pros & Cons

- Excellent Insertion Loss and Return Loss performance.
  - IL < 4dB @ 30GHz (including cable),
  - RL < 15dB @ 30GHz,
  - X-Wave design up to 110GHz.
- X-Wave is designed to reduce probe mark.
  - Avoid hitting center of ball,
  - May remove need for ball re-flow.
- Fully repairable on Field at low cost.
  - Part maintenance has been demo'ed.
- Good RF Repeatability
  - < 0.05dB over 30 program loops.
- Good RF Repeatability on multiple touch-down
  - About 0.2dB variation observed on 30 cycles.
- Capability to perform manual retest of singulated die.
  - Need microscope to insert the tiny device.
  - Good unit at first test.

- Probe core is more expensive than current solution.
- Lead-frame alignment is made manually (few tens of um).
  - Need to assess stability during prober operation.
  - Need to understand what it means for production.
- During trial a larger drift has been observed on DFT1 Impedance test.
  - When pogo hits multiple times at same place, the electrical contact is degraded,
  - Behavior seems no more true when prober steps or when pogo hit more the center of the ball.
  - Need more investigation.

TestConX™

Summary/Conclusion

- 5G, ADAS, Wireless, Satellite cmWave and mmWave markets growing rapidly and moving from package to WLCSP at speed
- Overcame infinite plane and force profile to take the mmWave technology from final test applications to wafer test.
- WLCSP test data shows same electrical and mechanical performance as package test data
- Customer trials shows positive results