Open Platform Production Test for 5G/mmWave Semiconductor Devices

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Problem Statement

High accuracy, high speed production test of packaged 5G mmWave devices presents significant test challenges for the manufacturer.

The need for accurate, repeatable multi-port beamforming mmWave device test for frequencies up to 53 GHz, including system level calibration, contribute to these challenges.

5G mmWave Test Overview

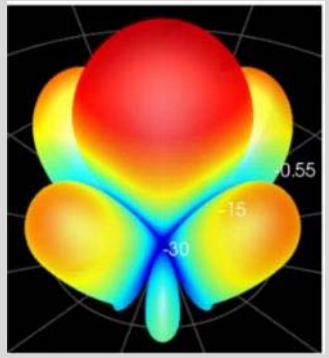
- 5G Operating Spectrum
  - Sub 6 GHz (low and medium bands)
    - <1 GHz
    - 1 GHz to 6 GHz
    - Easily addressed with traditional test methods and hardware
  - mmWave (high band)
    - 24.25 GHz to 52.6 GHz
    - 64 GHz to 86 GHz (future)
    - High band frequency ranges complicate many aspects of test
      - Instrumentation
      - Fixturing
      - Calibration
      - Cabling / interconnects

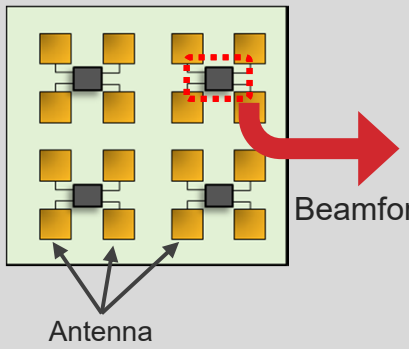
Target Component Example

Antenna / Beamformer IC / FEM

Antenna module

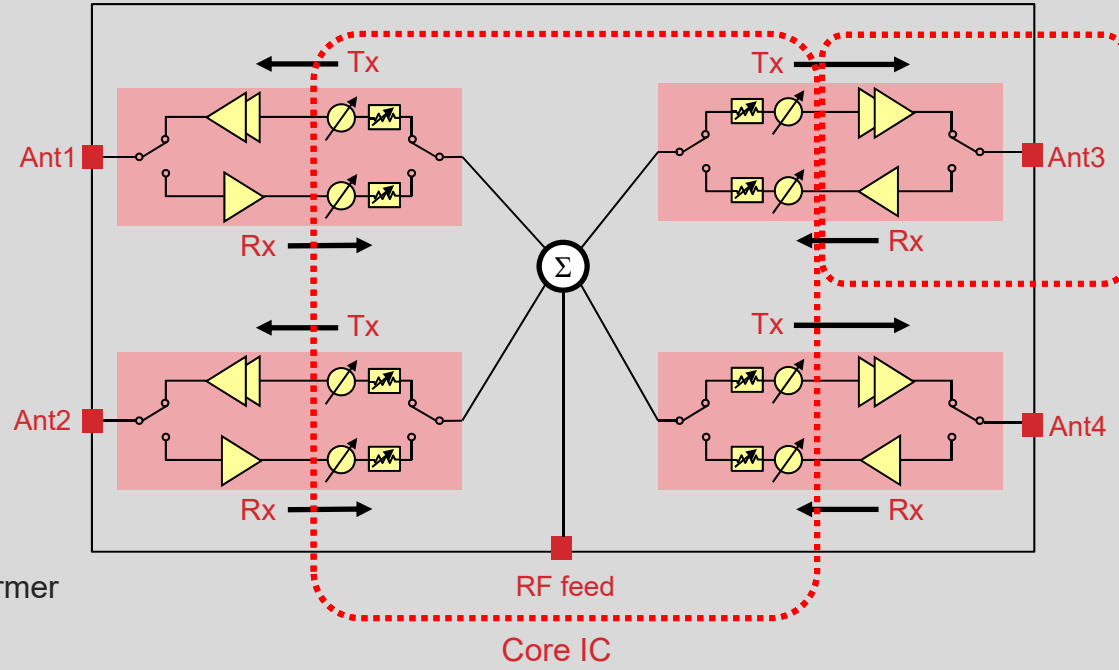
= Beamformer IC + Antenna elements





Beamformer

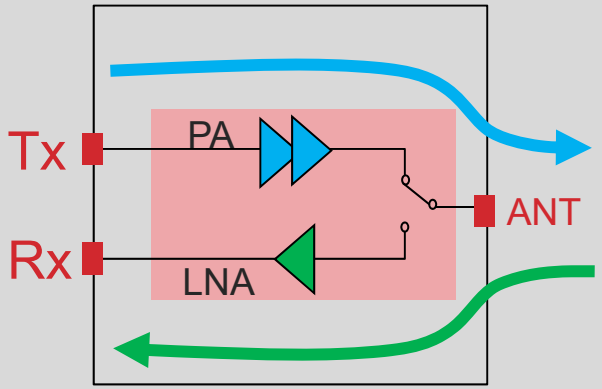
= Core IC+ FEM



FEM

FEM

= Front-end Module

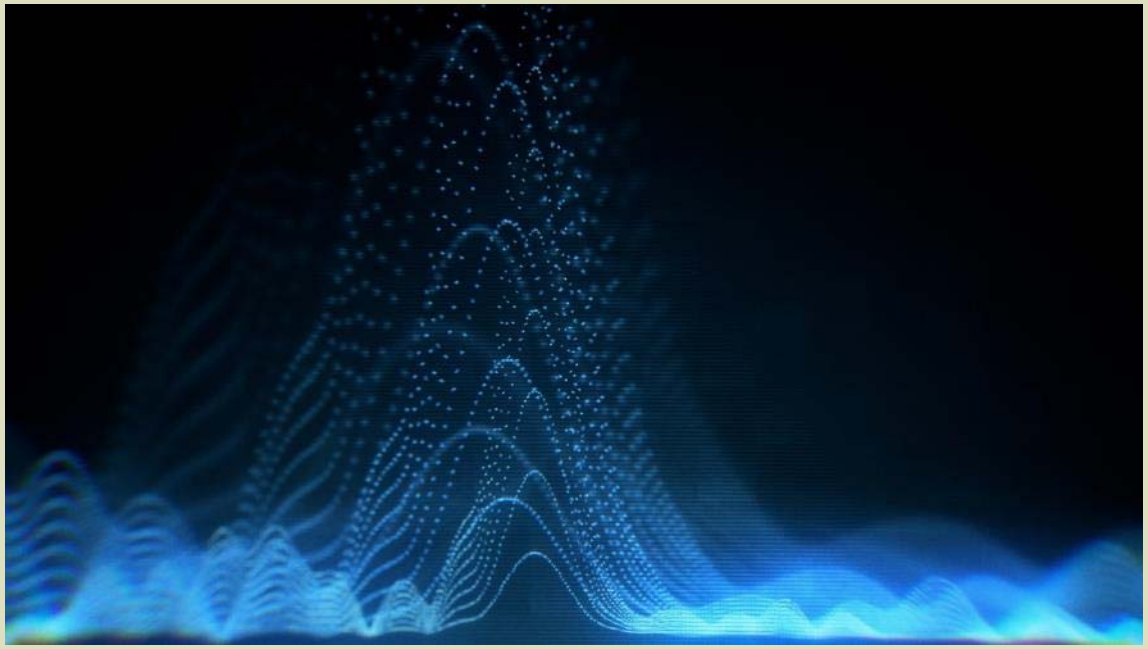


5G mmWave Test Overview

- mmWave System Performance Challenges
  - Cables
  - Calibration
  - Interconnects
  - Blind mate interface
  - Load board design / material
  - Instrumentation performance
  - Measurement repeatability and accuracy

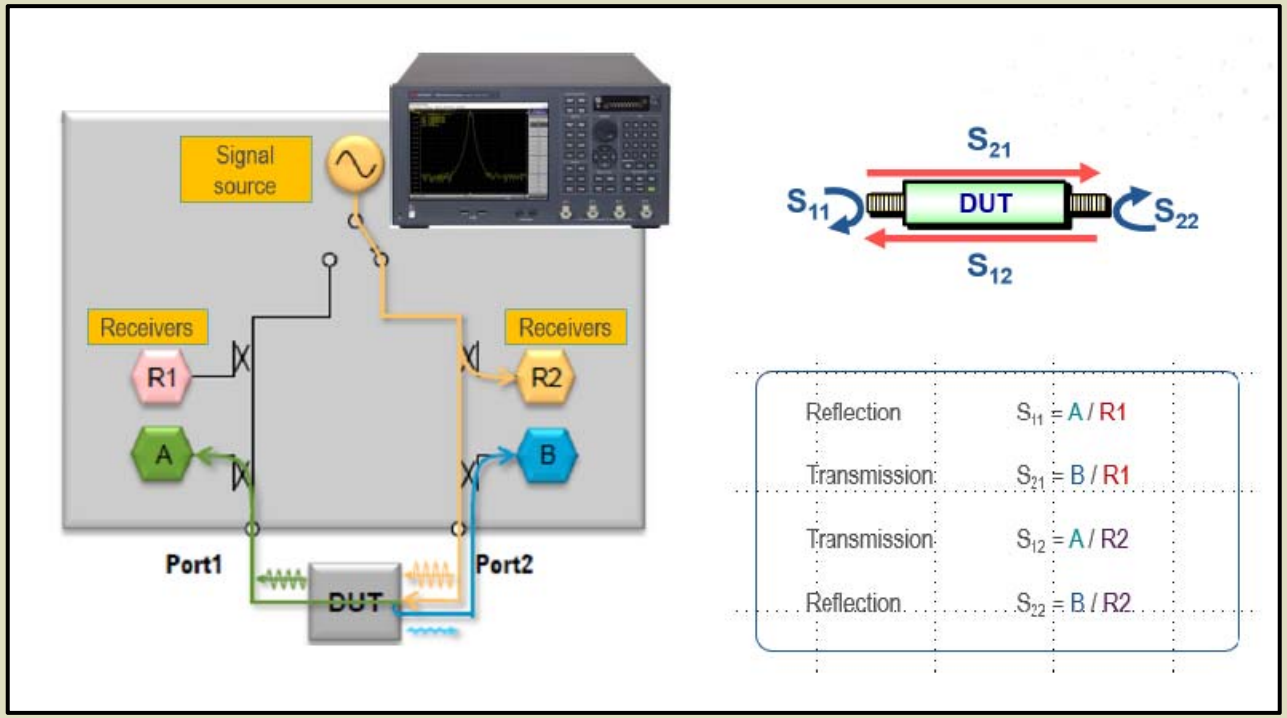
5G mmWave Test Requirements

- Critical Performance Tests
  - Device Transmit / Receive
    - VGA range and steps
    - Insertion and return loss
    - Phase Shifter range and steps
    - Output power gain and phase
  - Device Characterization
    - Noise Figure
    - EVA – Extended Vector Magnitude
    - ACP/ACPR – Adjacent Channel Power, ACP Ratio



5G mmWave Test Requirements

- mmWave Test System Measurement / Control Requirements
  - Device contact tests
  - Intermodulation distortion
  - S-parameter measurements
    - S11, S22, S12, S21
  - Gain and phase performance
    - OP1db / IP1db, OIP3 / OIP3
      - ❖ All channels, zero phase and max gain
  - DUT Power
    - Iddq, Iddq @ T/R Off/On, Iddq @ Sleep
  - SPI / I^2C interface for DUT register write/read
  - Limited additional digital test requirements

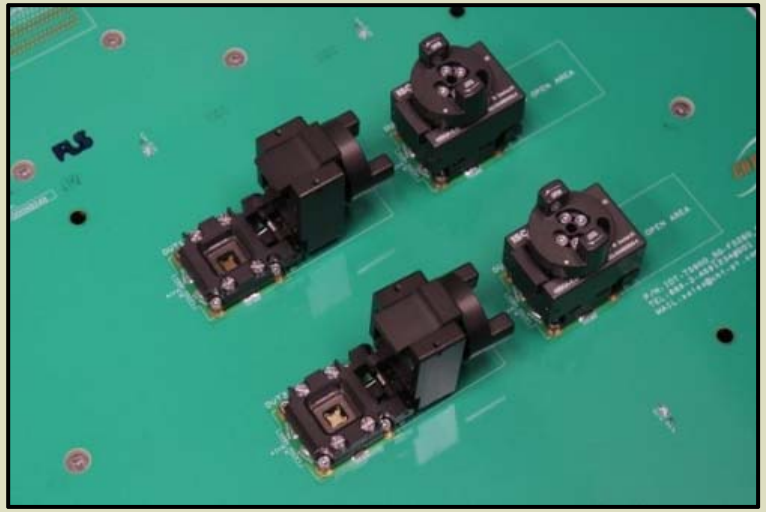


Manual mmWave Test Configuration

- Manual Test Challenges
  - Configuration
    - Manual wafer probe test setup
    - PNA-X instrumentation in production environment
    - Manual cable connect / disconnect
  - Impact
    - Throughput
      - ❖ Slow test times
      - ❖ Measured in minutes not seconds
    - Production repeatability issues
      - ❖ Prone to assembly error
      - ❖ Susceptible to damage

Production Test Challenge

- Multi-port, mmWave VNA instrumentation
  - Available from several vendors
  - Production test interface gap exists
- Key Requirements
  - Support for multi-site test capability
  - Receiver / tester interface that is reliable and repeatable
    - Supporting VNA measurements to 53 GHz
  - DUT interface compatibility
    - Wafer probers
    - Device handlers
    - Manual device insertion



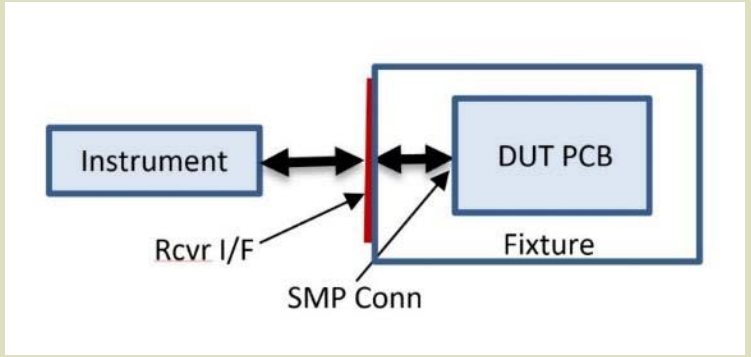
Test System Architecture

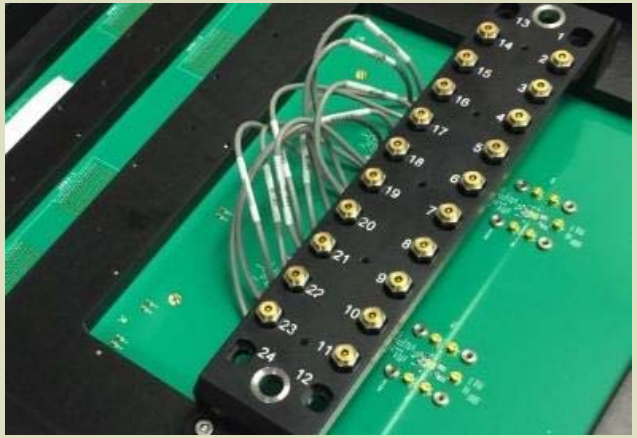
- Key System Level Functionality

Instrument / Device	Purpose	Comments / Details
VNA	S-parameter Gain/phase Distortion	44 GHz / 53 GHz Gap free Vector correlated
Source Measure Unit	Device power Power monitoring	4-Quadrant operation Precise power control /measurement
Dynamic Digital	Contact test Iddq Communications	Parametric measurement unit (PMU) per channel
Static Digital	Device ID User defined	TTL, LVTTL compatible interface
Chassis	Power Cooling	High power and cooling Smart monitoring functionality
Software	Test program development Test equencing	Development environment and test executive Semiconductor device tools (I-V curve, Shmoo)

Receiver Interface

- VNA RF Interface
  - Blind mate 2.92mm SMK connectors
  - 24 blind mate connectors support testing of up to 4, 6 port devices
- Digital and Power Interfaces
  - General purpose pogo pin blocks
- Blind mate to Load Board Transition
  - Semi-rigid cables connect to through-hole Mini SMP RF connectors
  - Part of the load board's assembly





Blind mate connectors

DUT Load Board

- Configuration
  - 4 devices, 5 ports each for packaged test
- Manual and automated insertion
- Load board construction
  - 10 layers
  - Rogers 3003 laminate
- Simulation results showed excellent performance to 50 GHz

Load Board (Top Side)

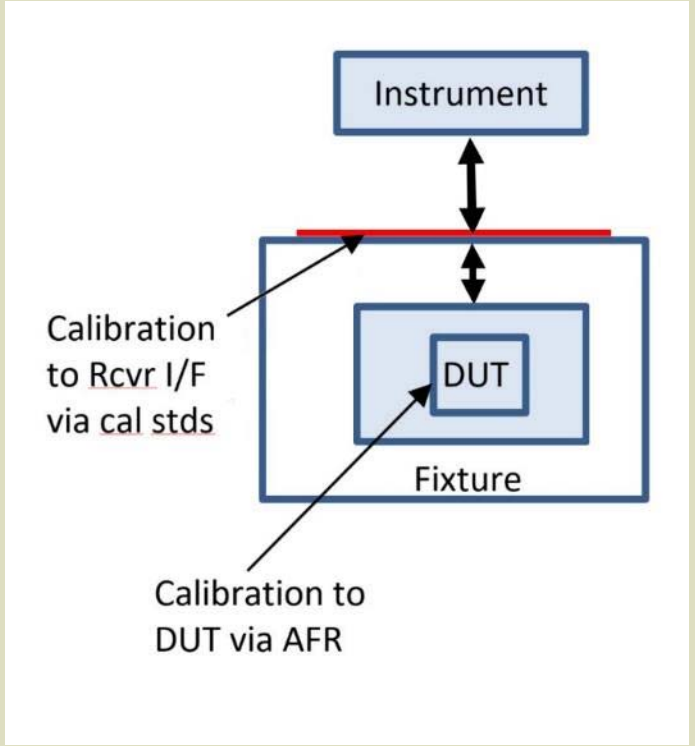
Receiver / Load Board Assembly

Test Set / DUT Calibration

- Calibration Objective
  - Isolate and measure performance of the device under test (DUT)
  - Remove linear error from the test system
- Sources Contributing to Signal Path Error
  - Signal interconnect points: cables, connectors, blind mate interfaces
  - DUT board traces and sockets
- Calibration Methodology
  - Calibrate RF path up to the DUT board using traditional methods
  - Characterize DUT board path
    - Implement industry accepted practice of fixture de-embedding
    - Use test coupons to characterize DUT RF path
  - Utilize Touchstone data to generate combined path characterization

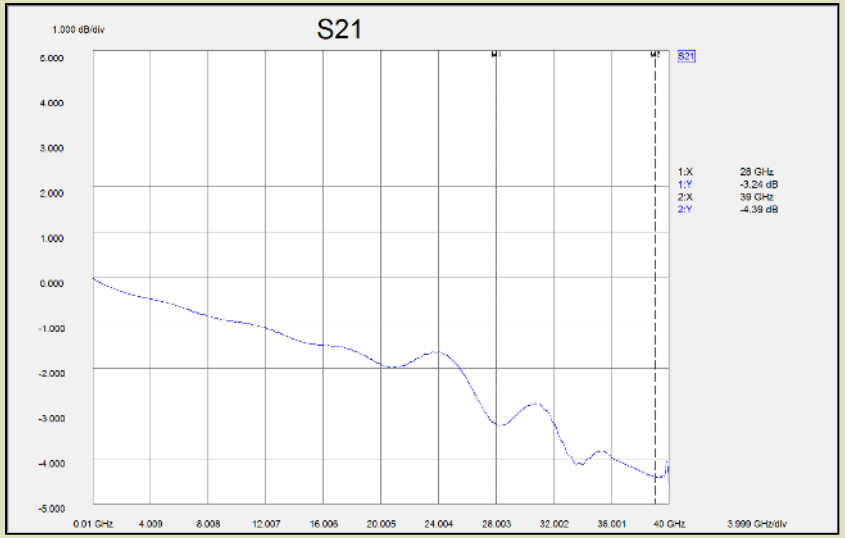
Test Set / DUT Calibration

- Accurate VNA / S-parameter measurements at the DUT
  - Requires calibration to a reference plane
  - Reference plane is ideally at the DUT
- One-port Automatic Fixture Removal (AFR) method was employed
  - Extracts S-parameters from the open fixture using time domain gating
  - DUT removed from socket
- Overall methodology
  - Calibration to the receiver interface using calibration standards
- Apply the extracted S-parameters from the one-port AFR measurement
  - Measurement reference plane is moved from the receiver interface to the DUT interface

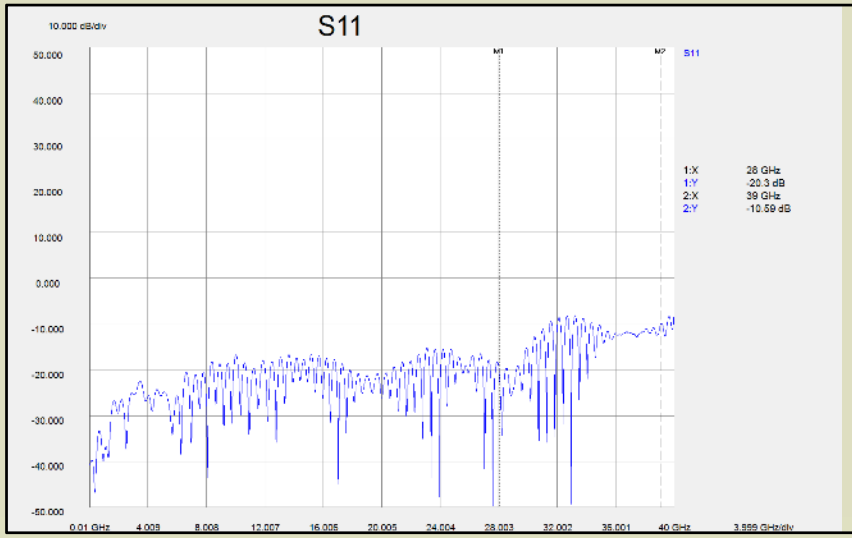


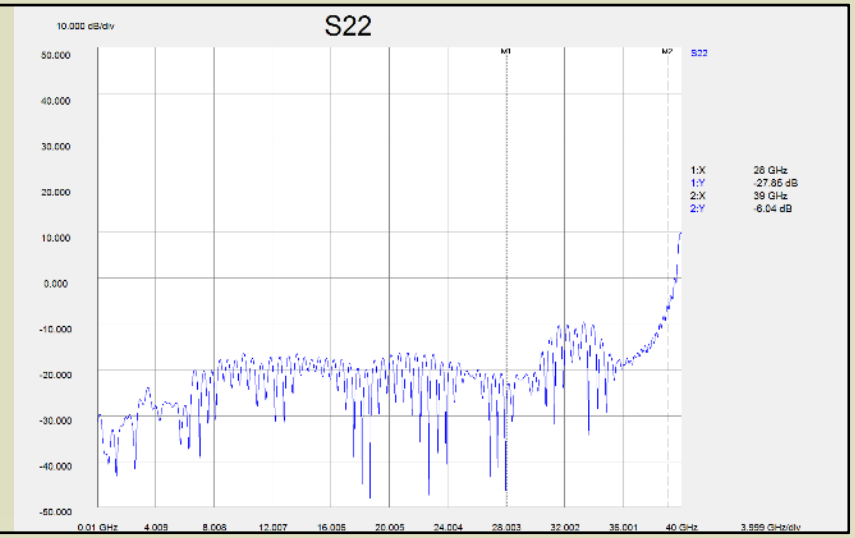
Device Test

- Multi-port, production devices were tested at 28 GHz and 39 GHz
- RF performance of the receiver and load board in conjunction with AFR calibration
  - Exhibited excellent S parameter characteristics over the range of test frequencies
- Repeatable and reliable RF measurement performance



Transmission Measurements





Reflection Measurements

Test Execution Throughput

- Speed Is King
  - Parallel port VNA S-parameter measurements deliver exceptional test efficiencies and test time reductions

Manufacturer	Model	Ports	Sites	Total Test Time (sec.)
MTS	TS-900e-5G	6	Single	13.3
MTS	TS-900e-5G	12	Dual	14.4
Competitor A	Big Iron Tester A	4	Single	75
Competitor B	Big Iron Tester B	4	Single	132

DUT Test Summary
Contact Test
SPI Addressing
Intermodulation Distortion
DUT Register Write/Read Tests
S-parameters, S11, S12, S21 and S22
POR Iddq, T/R Off/On Iddq, Sleep Iddq
Gain and phase performance vs. programmable gain settings

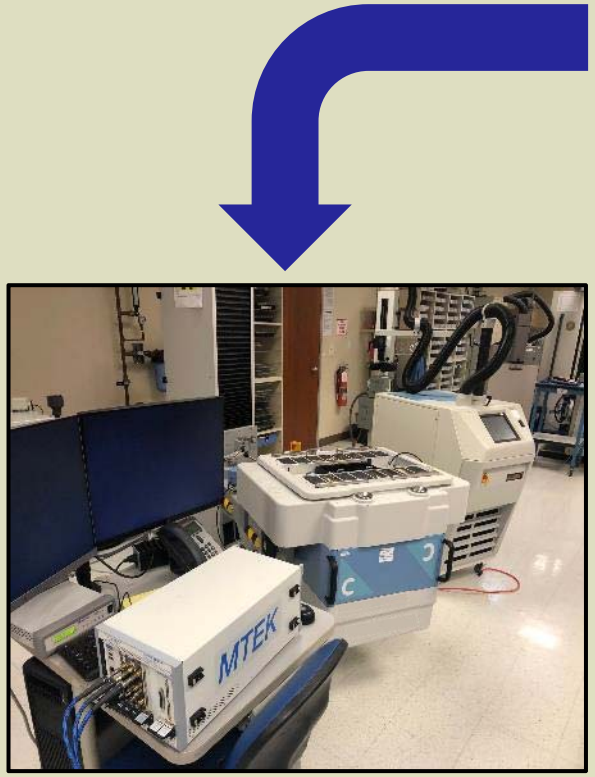
Key Functional Performance Criteria

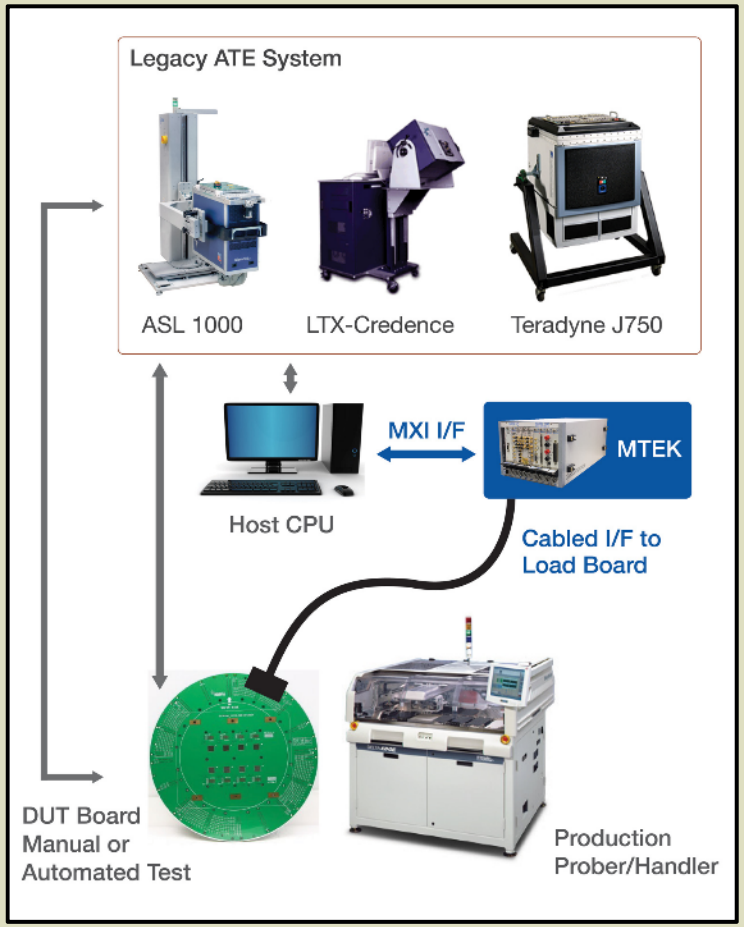
- Key mmWave Performance Considerations

Parameter	MTS / Keysight	Competitor A	Competitor B	Competitor C
Vector Corrected Measurements	Yes	No	No	No
0-53 GHz Available	Yes	No	No	No
Gap Free Measurements (0-53 GHz)	Yes	No	No	No
Open Architecture	Yes	No	No	Yes
> 4 Ports mmWave	Yes - 20 Ports (53 GHz)	No	No	Yes - 8 Ports (21 GHz)
PNA-X Measurement Science Compatable	Yes	No	No	No

Extending Big Iron Test Capabilities

- Provides advanced test capabilities to legacy ATE platforms
  - Protects customer investment
    - Uses existing test programs
    - Uses existing data logging, production tools
    - Same docking solutions (prober, handler)
  - Extends ATE capabilities
    - RF
    - Digital
    - Analog
    - TIA
  - Avoids cost of purchasing new test systems





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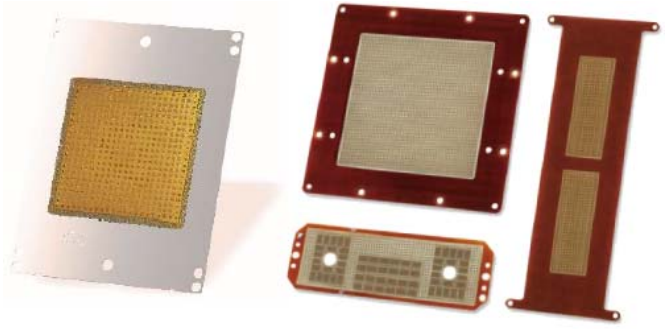
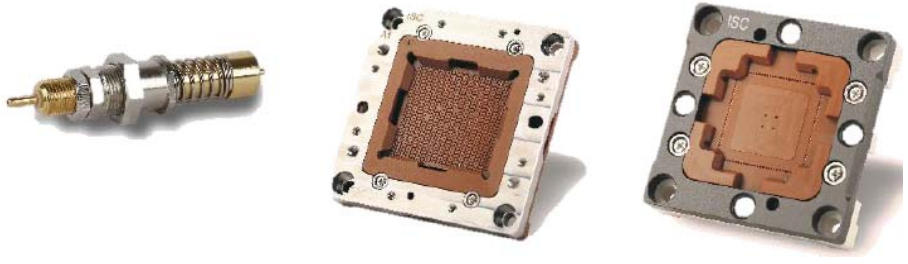


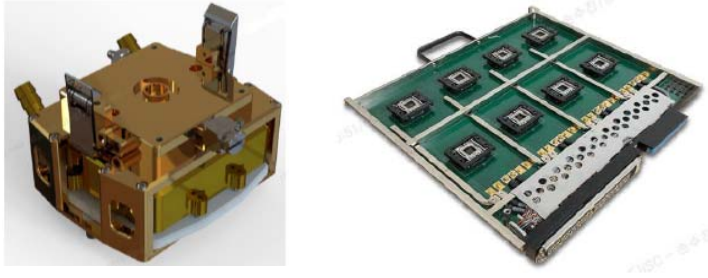
POGO SOCKET SOLUTIONS

- Excellent gap control & long lifespan
- High bandwidth & low contact resistance



THERMAL CONTROL UNIT

- Extreme active temperature control
- Safety auto shut-down temperature monitoring of the device & thermal control unit
- Full FEA analysis & Price competitiveness



BURN-IN SOLUTIONS

- Direct inserting on the board without soldering
- Higher performance BIB solution

CONTACT
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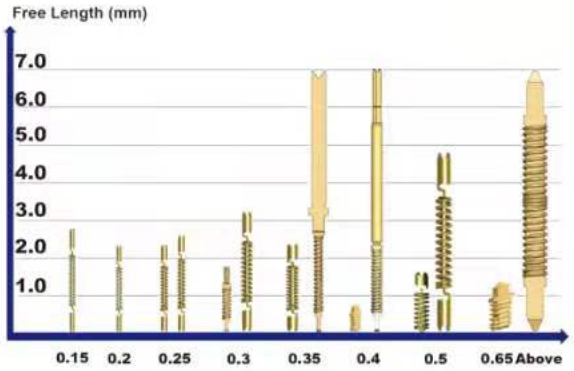
IWIN Co., Ltd. The test probe for high signal integrity at extremely high speed test

Spring probe by stamping



250 kinds of spring probe pin

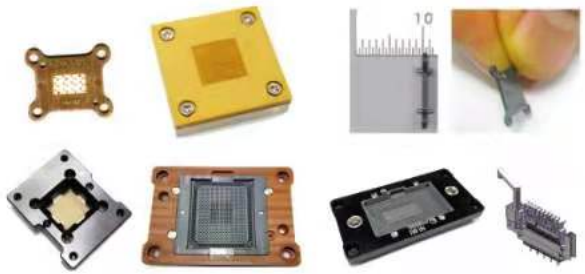
300 kinds of test socket (44,000 Pin count socket possible)

One piece spring probe

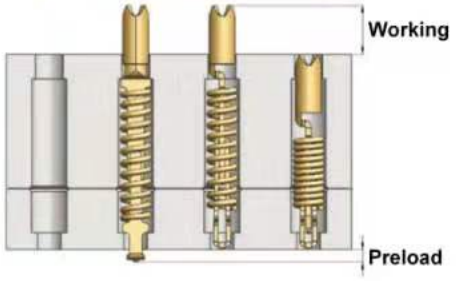
Three piece spring probe

High speed product → 0.63mm free length spring probe pin available

Finest Pitch → 0.15mm Pitch



Spring probe by stamping

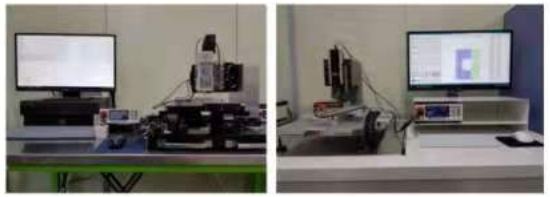


Patented

Pitch(mm)	Free Length(mm)	Current Carrying(Amps)
0.15/0.2/0.25	2.17~	0.5~
0.3	1.5~	1.5~
0.35	2.08~	1.8~
0.4	0.8~	2.5~
0.5	1.5~	3.0~
0.65	1.13~	9.0~
0.8	3.14~	3.0~

Automation

Pin assembly and Quality control



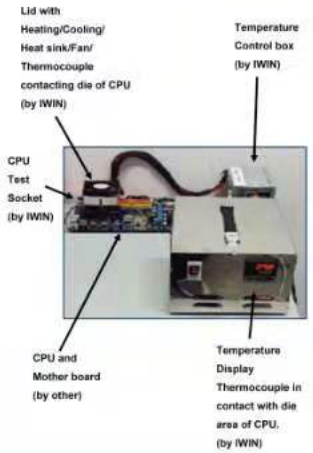
Top Figure: Socket CRES, Force, Stroke test

Bottom Figure: Data displayed

Top Figure: Socket CRES test

Bottom Figure: Data display 5,903 pins socket

Socket and Lid



Pin assembly

(Fully automated machines)

- Stamped piece parts attached to a reel fed into the assembly machine

- Assembled pins can be attached to a reel, or, supply in separate for socket assembly.

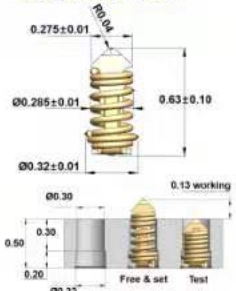
Spring probe pins for High speed

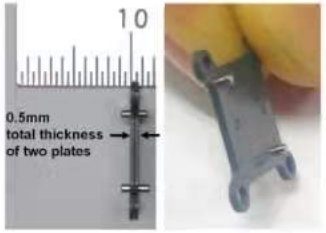
Extremely short spring probes by stamping

One piece spring probe

Three piece spring probe

Design approach





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High Performance Probe solution

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