RF Module Test Challenges

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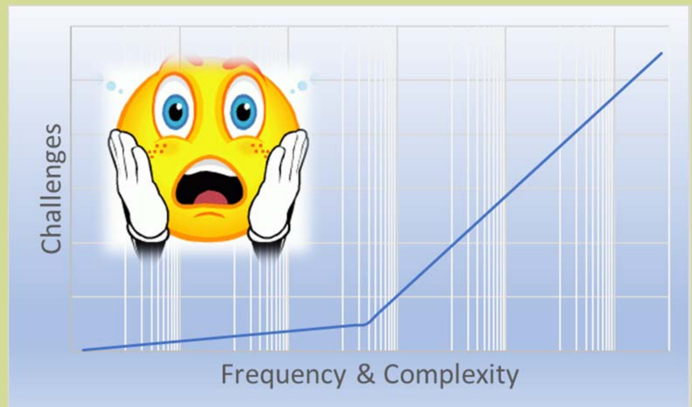
Suzhou ▪ October 23, 2018
Shenzhen ▪ October 25, 2018

Contents

- Where are we today?
- Trends
  - Frequency
  - Complexity
  - OTA Testing
- <6 GHz → mmWave Challenges
- Conclusions



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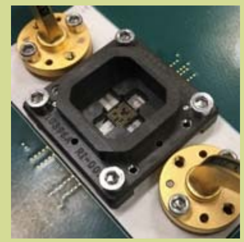
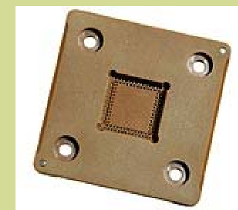
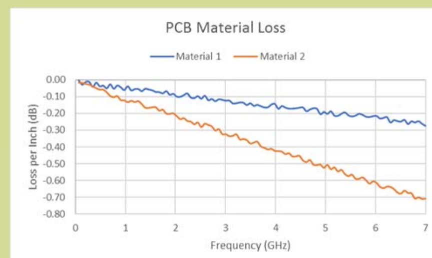
2018
2

Where Are We Today? – Sockets & Load Boards

- Sockets
  - The RF test socket - our friend for 30+ years
  - Socket manufacturers have pushed performance to 10 GHz and beyond, but with great performance comes great cost
  - Cleaning and maintenance challenges
- Load Boards
  - The old standbys: FR-4, MEGTRON 6, …
  - Multiple factors drive selection: Cost, circuit design, spec tolerances, temperature, power dissipation, …
  - Material selection has significant impact on signal loss at high frequencies







Where Are We Today? – Frequencies

- Frequencies typically <6 GHz
- Key applications driving volume
  - Mainstream LTE Cell Phone: <2.7 GHz
  - GPS Receiver: < 1.6 GHz
  - RF Remote Control: < 900 MHz
  - WLAN/Bluetooth/ZigBee/…: < 5 GHz
- 5G initial deployments will be < 6 GHz
- Test contacting at < 6 GHz is a solved problem

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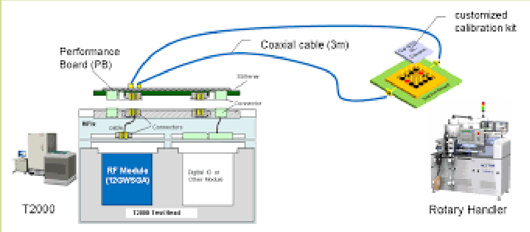
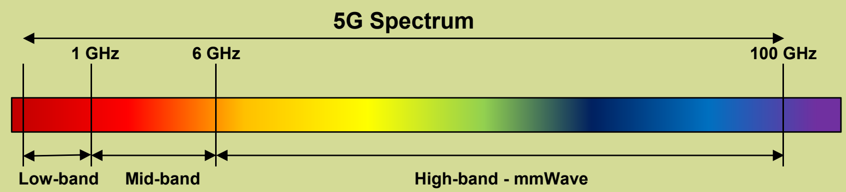
Where Are We Today? – Handling

- Standard handler configurations adapted for RF
- RF shielding and socketing requirements can impact cost, parallelism, and UPH
- Lower parallelism allows for flexibility on integrating RF test equipment
- System RF calibration process must be carefully designed



Key Trends – Frequencies ↑

- Frequencies are going up to 100GHz
- 5G frequencies are priority in the Test industry
- 28GHz and 39Ghz are key for the cellular providers
- Unlicensed frequencies are seeing some prominence
- Non- automotive applications are enjoying some relevance



Band	Range	Licensed	Shared	Unlicensed
Low-band	< 1 GHz	600 MHz US 700 MHz EU		
Mid-band	1-6 GHz	AWS (Band 66) 2.5 GHz 3.3-4.3 GHz 4.4-4.99 GHz	3.5 GHz CBRS US 3.7-4.2 GHz US 5.9-7.1 GHz US	5-5.9 GHz
High-band	> 20 GHz	24.25-29.5 GHz 27.5-28.35 GHz 37-38.6 GHz 38.6-40 GHz	37-37.6 GHz 57-71 GHz	64-71 GHz

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6

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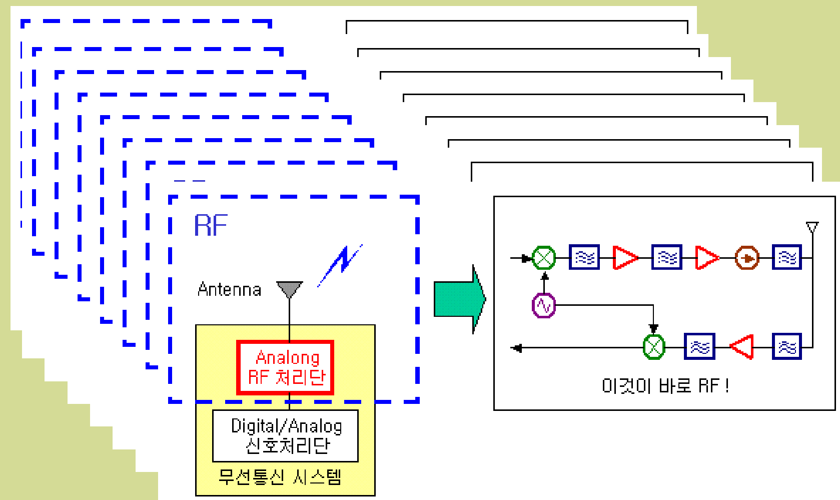
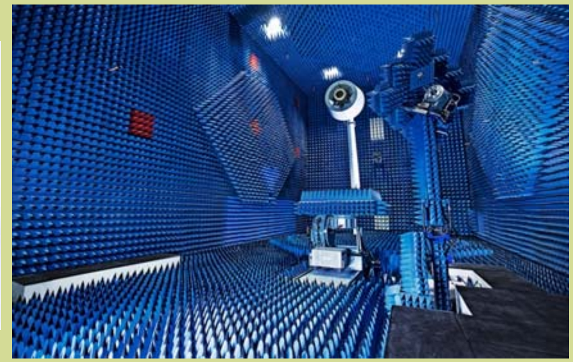
Key Trends – Complexity ↑

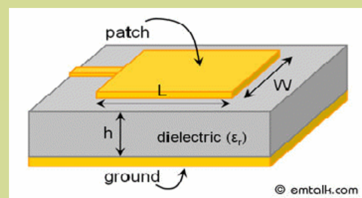
- RFCMOS Devices can achieve significantly more complex functions at higher frequencies at lower cost
- Complexity is seen in many areas such as high port counts, higher frequency, multi-band, etc. Designs are transmit, receive, I/O transceivers
- Other useful features at these frequencies are possible - devices with antennas built-in to reduce interconnecting cost; small packages
- Traditional contacting socket/load board methods of ATE testing are less applicable and require innovation at the test cell to solve the issues of signal integrity/validity

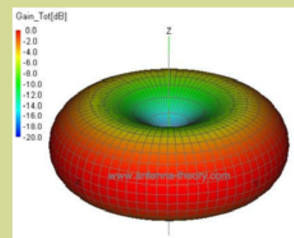


Key Trends – Over-The-Air

- Over the Air Devices must be tested with different antenna types and in new environments – many traditional antenna test environments and antenna types may not be suited to high volume production, non-contacting breaks traditional ATE implementations
- Physical space and time is always at a premium in ATE – low cost is still a requisite. Some approaches may not work well being too expensive and slow
- Determining what “measurement hardware” and specifications to use requires many new considerations for millimeter frequencies







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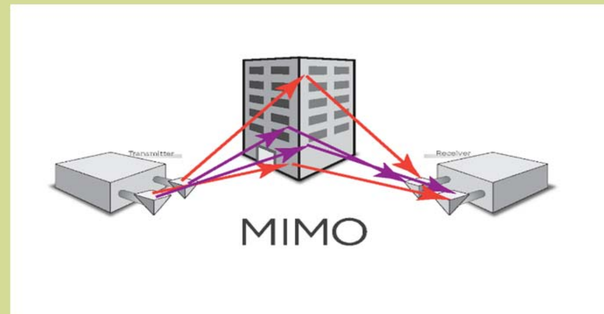
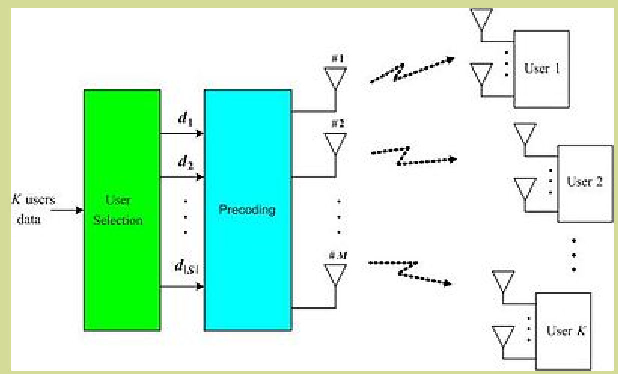
8

Key Trends – Antenna Arrays

- Over the Air testing brings system level testing to the forefront requiring antenna expertise along with substantial mechanical effort
- Devices may have antennas located on side, top, or bottom which leads to significant interface issues for what connections might be required in order to test
- Many considerations are involved with AIP such as self-heating (DC watts-in for RF power-out), DC current required during transmit, what to measure, or even what can be measured
- Large port count is common, and where there are many antennas of several types, an effective test strategy for over-the-air is complex – air connections and a traditional chamber approach may commit to a path where no multi-site is possible





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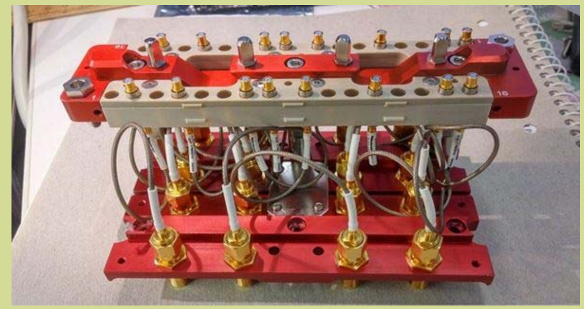
Key Trends – Connection Choices

- System complexity – how to handle multi-site when:
  - Much higher frequencies/functions will require many connections that keep getting smaller
  - Reliable blindmate is possible to 1.85mm but large connector count takes up much space
  - Cabling is lossy and gets worse at higher frequencies requiring different ideas to solve, maybe going to waveguide in certain cases
- Cost-effective testing involves many combinations – over the air or direct contacting – consider actions carefully to avoid expensive schedule slips
- Many times good socket design will solve problems whether pogo pin, elastomeric, or a hybrid that may incorporate waveguide or other innovations
- What seems necessary now will evolve as 5G matures



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10

Key Trends - Handling

- An OTA Environment will likely include
  - Handlers for parts or robots to handle modules
  - An associated socket with the features required like waveguide paths for signals and transparency to the device frequencies
  - A loadboard to route all the other signals required such that it will not interfere with the "over the air"
- Reference antennas in the test system may end up being positioned in many possible orientations to meet device requirements.
- Several different types may be required for the interface to the device since device antennas may not be just one type
- Companies considering a high volume approach to test may want multi-site. These techniques are not refined due to hardware limitations, possible interference among the test devices, and overall cost.
- A test cell will be expensive if innovative approaches for what-to-test are not considered

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11

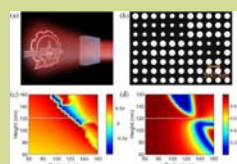
<6 GHz → mmWave – Form Factors

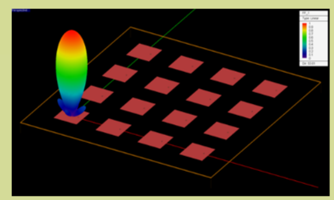
<6 GHz – Form factor

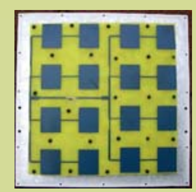
- Module's "like a chip"
- Standard handler

mmWave – Form factor

- Many custom 3D non standard form factors
- Standard handler not viable -> Robotics?
- Do we need to manipulate the package in 3D







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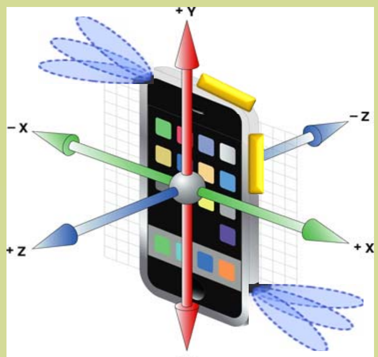
<6 GHz → mmWave - Calibration

<6 GHz - Calibration

- Connected: more pins, more BW, more parallelism
- Lower cost
- Bandwidth
- # RF pins



mmWave - Calibration

- How to calibrate when the antenna “IS THE PACKAGE”
- OTA and antennas and multi-dimensional movement has never been a requirement for HVM testing

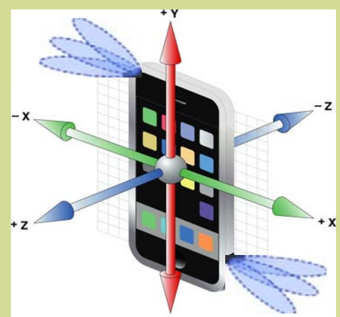
<6 GHz → mmWave – Beam Forming/Steering

<6 GHz – Beam forming/steering

- Not a requirement
- MIMO tested using traditional method – OK
  - 93K Wave Scale and T2000 12GWSGA solution already exist for MIMO


mmWave – Beam forming/steering

- Beam forming and beam steering have never been a production test requirement
  - Requires antenna expertise (very short supply)
  - Requires OTA HVM expertise (perhaps look to automotive radar solutions?)



Conclusions

<6 Ghz

- Load boards
  - Required several years for industry to production"ize" < 3 GHz RF load boards – especially RF parallel testing
  - Helped with 6 GHz, but was still tougher
- RF Connector and socket technology had to adjust
- Calibration was and continues to be a challenge
- For sub 6 GHz the challenges can categorized as "more of the same"

mmWave

- New socket technology needed
- New load board technology needed
- New connectors
- Manipulating and handling 3D custom form factors?
- AiP, OTA, calibrations and testing
- Beam forming/steering?