5G Devices are Upon Us!

- We think we’re used to having wireless devices all over the place, but 5G will take that much farther than cell phones and WiFi ever will on their own.

- A major difference? Short range infrastructure. You’ll still have a phone in your pocket, and there will be traditional wireless networks, but 5G infrastructure will show up all over populated areas. And the handsets will have multiple mmWave devices inside.

- This will generate a huge number of wafers to test!
What Volume Production Means for 5G Test

- A long time ago in a galaxy far, far away, people tested DRAM devices 16 or 32 at a time
- DRAM wasn’t found in everything at that time, but now it’s all over the place
- Those people that were testing 16 or 32 devices at a time would be broke if they did it that way today, but probe technologies advanced to often allow test of a full wafer in one shot
- It won’t scale exactly the same way, but 5G devices may follow a similar path – since they’ll be everywhere, low parallel testing will be an unacceptable bottleneck

- Potential Scenarios:
  - Total Handset Volume is 1.5B
  - 10% handsets are 5G FR2
  - 4 AiP per handset
  - 600M AiP per year
  - 90% yield
  - 5 second test time
  - 85% test cell OEE for x1, 80% for x8
  - Probe card lifetime = 1M TDs

- Worldwide Testers:
  - X1: 125 testers
  - X8: 16 testers

- Annual Probe heads
  - Single Site: 667 probe heads
  - X8: 89 probe heads

Lesher, Rhodes - FormFactor
Meeting Basic Probing Needs

• First step to production test for 5G devices: a **well-behaved** probe technology

• What constitutes well-behaved anyway?
  
  A. Stable contact
  B. Gentle probe marks
  C. Thermal stability
  D. Ease of repair
  E. Long lifetime
  F. Scalability
  
  ➔ **Minimal tantrums**

Technologies out there today demonstrate this good behavior – we’ll cite some examples.
Exhibit A – Contact Resistance

- Any probe technology needs stable contact resistance – for 5G devices or otherwise
- Stability is demonstrated as a function of overtravel and as a function of touchdowns

- As a function of overtravel, resistance values stabilize as soon as the probe reaches its buckling point (2 probes shown reach same stable value)

- As a function of touchdowns, resistance values are relatively constant without any cleaning over many probing cycles, and can be returned to baseline values with an ordinary cleaning recipe

*Absolute resistance values not representative, sub-optimal tip type for flat Al surface
Exhibit B – Probe Marks

- 5G devices will be packaged just like anything else, so their contacts must be in good condition.
- Vertical MEMS probes with flat tips are able to combine the stable CRes just shown with an otherwise light touch on solder bumps or capped pillars.
- The large surface area of the tip creates a coining on the top of the curved solder surface, and solder is not displaced outside of the original diameter.

How to achieve this? Relatively low contact force (<3 g at peak overtravel), spread over a broad tip surface (>50 um on a side).

Unprobed Bumps
115 um diameter

Bumps After Probing, 75 um OT
~25 um coining diameter
Exhibit C – Thermal Stability

- There must be an option to test at extremes of temperature, since 5G devices will be used in environmentally challenging locations
  - Ex: outside on a pole under bright sunshine in Phoenix
- Data shown here collected on Uflex + UF3000 test cell for 3-6 GHz RF application
- Proximity soak (-200 um) yields 90% of movement within 30 minutes – short time to thermal stability
- 9 um maximum movement from 25C start to 125 C finish, on long axis of probe head
- Contact soak from t=0 appears allowable due to low magnitude of total movement
  - Ready to probe well before 30 minutes – quick setup
- Demonstrated capability over 25→125C temperature range; higher temperatures remain reasonable
Exhibit D – Repairability

• Blinding flash of the obvious – bad things sometimes happen when probing

• Vertical MEMS can be quite forgiving of these incidents
  – They can withstand an occasional excessive overtravel event and return to original position
  – They can be replaced one by one in the event of more serious damage
    • High current/thermal damage
    • Breakage for any reason
  – They can all be replaced in the event of wearout
Exhibit E – Long Lifetime

- Given expected 5G device volumes, quick wear out of probe cards won’t be acceptable

- 150 um of wear length with a well-selected material set addresses this

- Wear rates can be fractions of a micron per 1000 cleaning TDs

  - Data here shows conservative and aggressive recipes – there is room for optimization for specific applications

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<th>Parameter</th>
<th>Z-only</th>
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Exhibit F – Scalability

Some simple, mathematical-ish relationships:

- More contacts, smaller die area → finer pitch
- Higher volumes → higher parallelism

Vertical MEMS with frequency-capable guide plates can reach down to 106 um grid array pitch. And probe heads are able to support 8+ sites for complex, transceiver-type devices.
High Speed Characteristics

- 10 GHz demonstrated performance
- Why this isn’t enough:
  - You can test at super high speeds with Pyramid and analytical probes, but not at high enough parallelism
  - You can reach higher parallelism with Pyranana, but not at 5G speeds

- Builds on well established vertical MEMS and membrane technologies, but doesn’t get there on its own
- Inductance is partially balanced out with this approach, but not enough for higher speed signals

Parallelism

Bandwidth

Pyranana 10 GHz

Pyramid 80 GHz

5G
Inductance, and How to Stop It

• In distributed model of a transmission line, generally R and G are ignored and $Z_0=(L/C)^{0.5}$.

• With perfect balance for each transition and transmission line, there is no reflected power and all of the power is transmitted – *This never actually happens!*

• Vertical probes represent a long path length dominated by high inductance. To compensate:
  – Shorten the path length
  – Offset with distributed capacitance
  – Strategic grounding
Offsetting Inductance – Shorter Probes

• Inductance depends on length.
• The higher the frequency the shorter the wavelength. Lower than \(1/10\)th of a wavelength is distributed to lumped element transition.
• To get to higher frequency, make it smaller/shorter, but this has a cost (stiffer, less useful springs, pitch limitations)
• Vertical MEMS probes can minimize compromises
  – *Still compliant, still pitch capable, least inductive*

Pogo Pins:
  often longer than 5 mm, much stiffer as they get shorter, unbalanced inductance
Offsetting Inductance – Parasitic Capacitance

• The length of residual inductance is what really matters.
• The inductance of a coax cable center conductor is not relevant because the capacitance to the shield compensates.
Offsetting Inductance

• Bringing ground close to the probe tip along with parasitic capacitance to ground dramatically reduces residual inductance
  – The physical length and mechanical attributes of the MEMS probes are decoupled from their electrical length and attributes, by an order of magnitude
Results

• Together, this is where it takes us:
  – 75 mm length array
  – >250 RF paths up to 45GHz
  – >4500 contacts
  – *Still on good behavior as a probe technology!*
S-Parameters – Probe Head and Start of PCB

Probe head – PCB interface Tier 1

Probe head – PCB interface Tier 2
One Additional Item

• With inductance often comes mutual inductance which can degrade isolation dramatically.
• Measured Isolation is better than 30dB for typical device layouts to 40GHz.
• For special cases, isolation can be increased even further
Wrap Up

• The advances to higher frequencies are now applicable *IN CONJUNCTION* with well-behaved probe technology
  – Solid mechanical foundation
  – Electrically resilient
  – And now supports 5G signals up to 45 GHz
Thank You!

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