SWTEST

PROBE TODAY, FOR TOMORROW

Probing 5G Devices Like It's No Big Deal

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FormFactor

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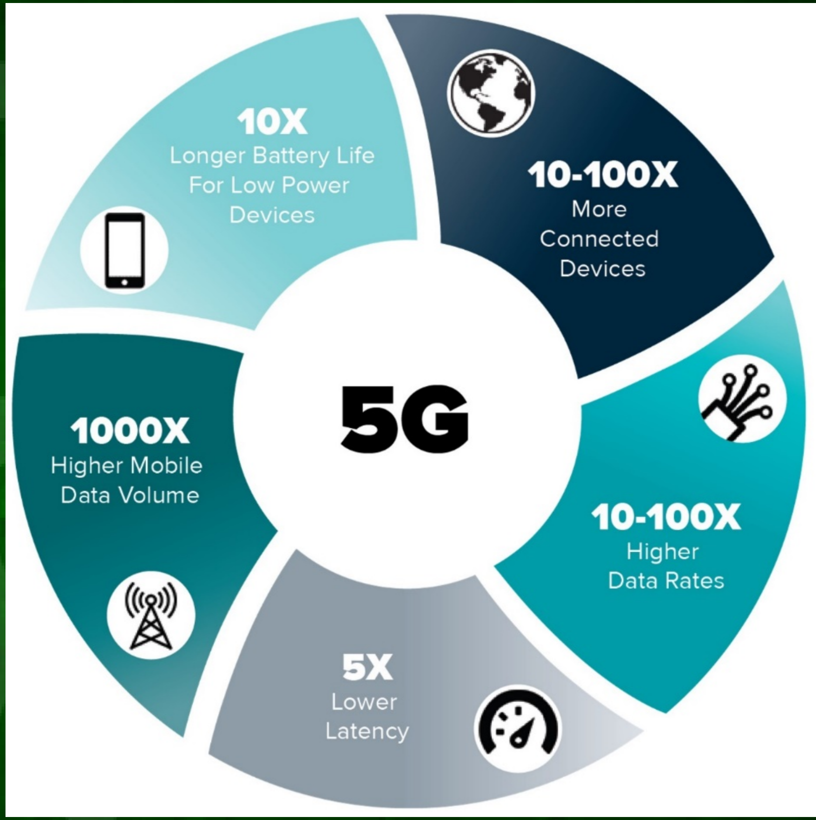
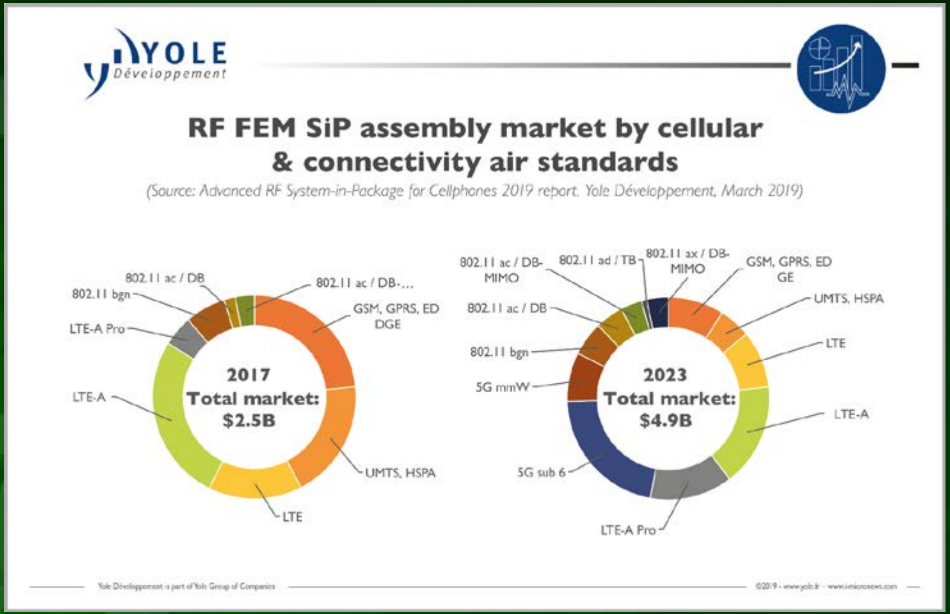
5G Devices are Upon Us!

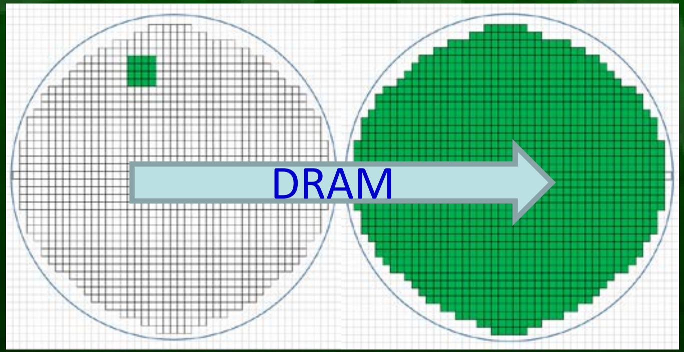
- We think we're used to having wireless devices all over the place, but 5G will take that much farther than cell phones and WiFi ever will on their own.
- A major difference? Short range infrastructure. You'll still have a phone in your pocket, and there will be traditional wireless networks, but 5G 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!

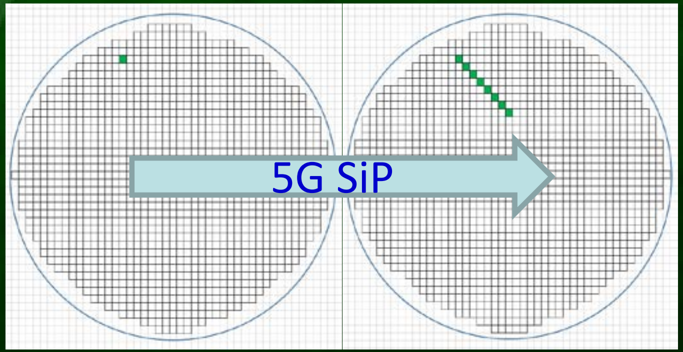


What Volume Production Means for 5G Test

- 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**

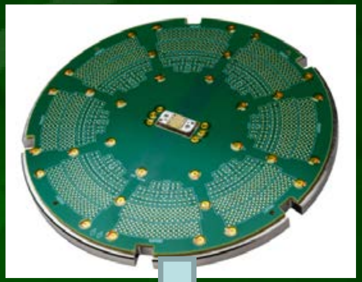


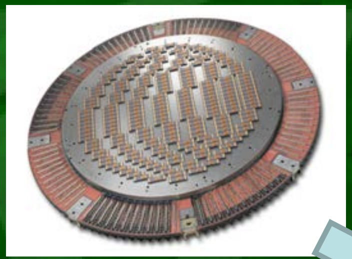


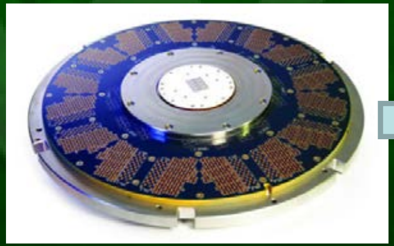


Meeting Basic Probing Needs

- **First step to production test for 5G devices: a <u>well-behaved</u> 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*



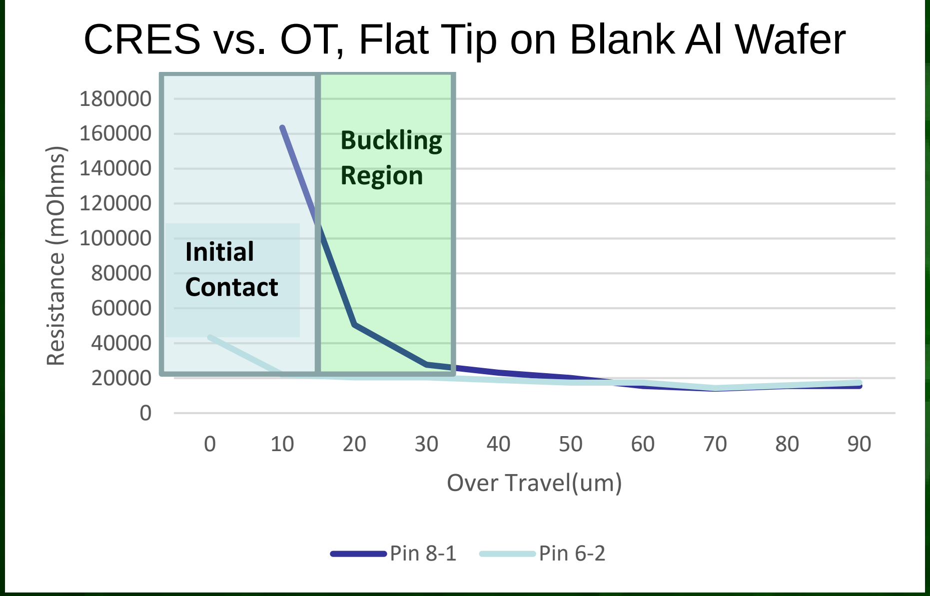




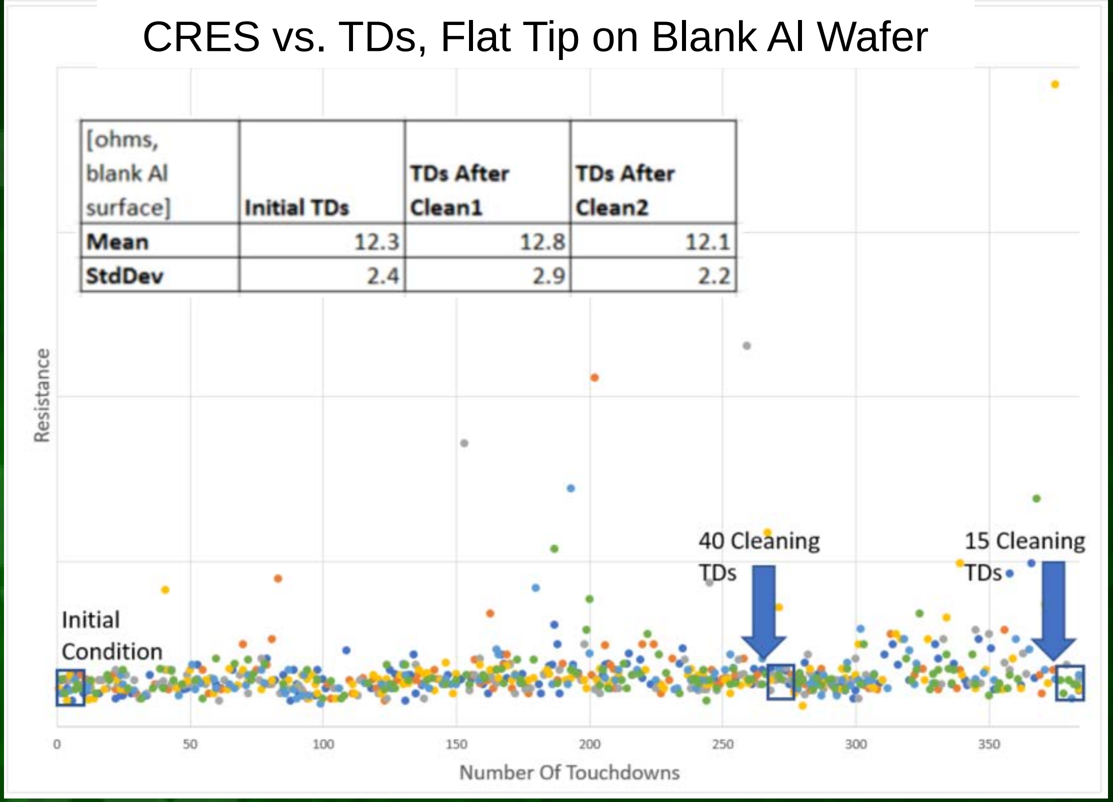
Technologies out there today demonstrate this good behavior – we'll cite some examples

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**



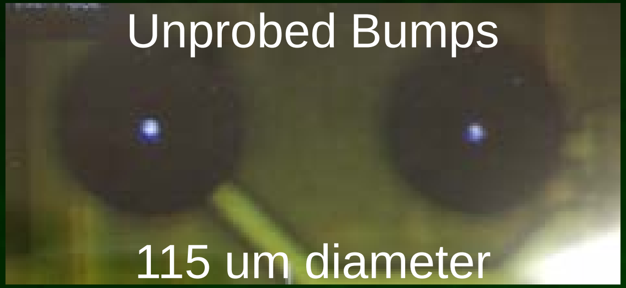
- As a function of overtravel, resistance values stabilize as soon as the probe reaches its buckling point (2 probes shown reach same stable value)

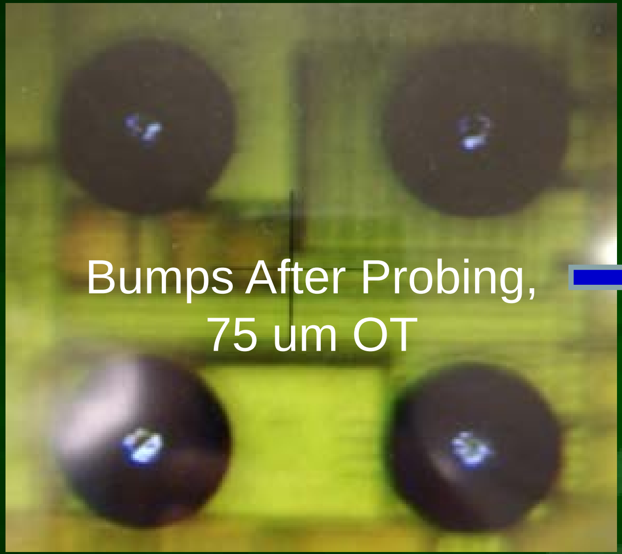


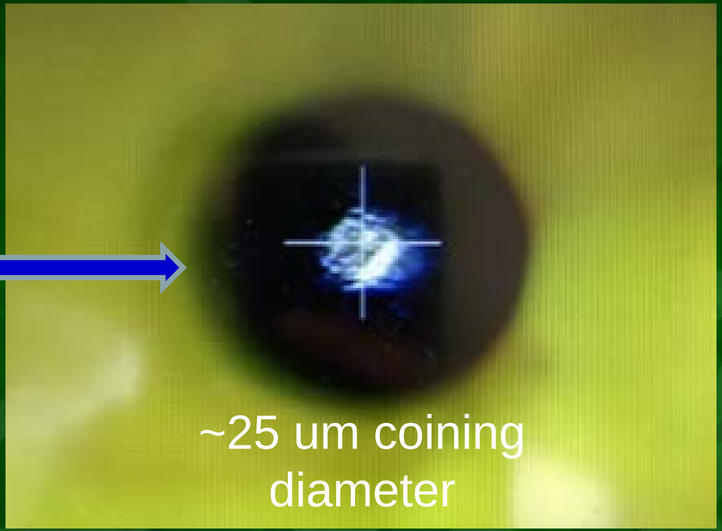
- As a function of touchdowns, resistance values are relatively constant without any cleaning over many probing cycles, and can be returned to baseline values with an ordinary cleaning recipe

***Absolute resistance values not representative, sub-optimal tip type for flat Al surface**

Exhibit B – Probe Marks



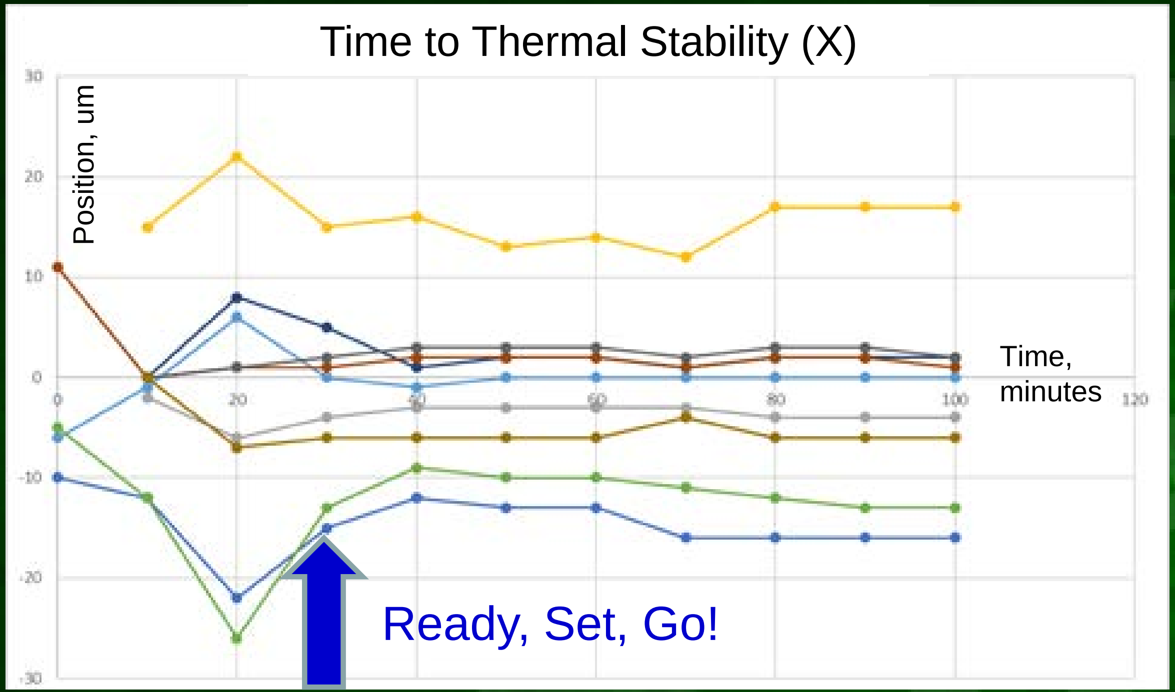




How to achieve this? Relatively low contact force (<3 g at peak overtravel), spread over a broad tip surface (>50 um on a side).

- **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**

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

Parameter	Z-only	10 um Octagon	
Interval	10	25	TDs
Touches	10	2	Per Cycle
OT	50	50	um
Wear rate	0.1	2.4	um/1000 cleaning TDs
EOL	150000	31250	Cleaning Cycles
	1500000	781250	Touchdowns

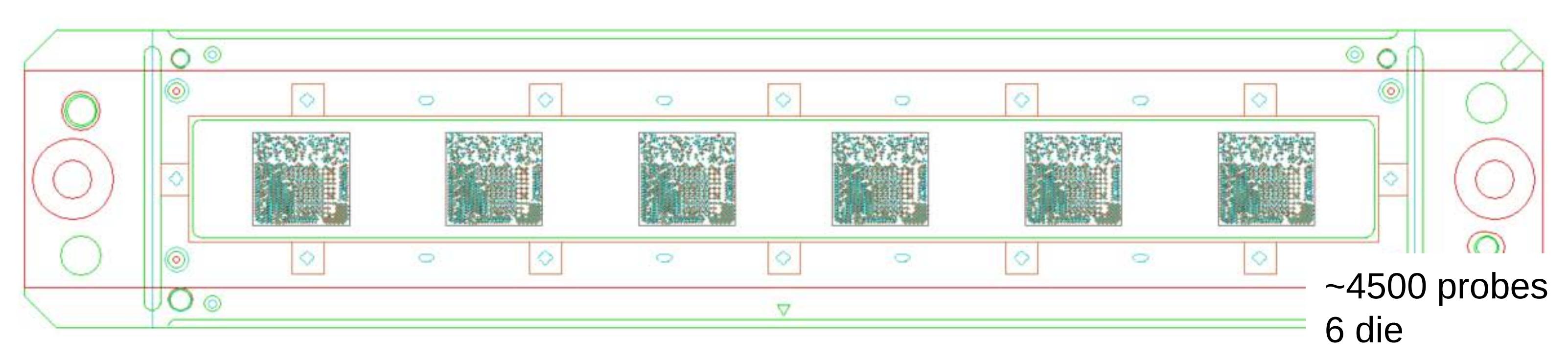
- **Given expected 5G device volumes, quick wear out of probe cards won't be acceptable**

- **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

Exhibit F – Scalability

Some simple, mathematical-ish relationships:

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



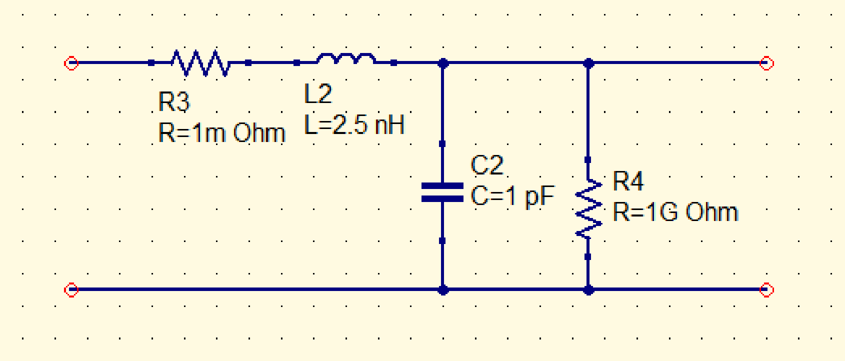
Vertical MEMS with frequency-capable guide plates can reach down to 106 um grid array pitch. And probe heads are able to support 8+ sites for complex, transceiver-type devices.

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 Pyrana, 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

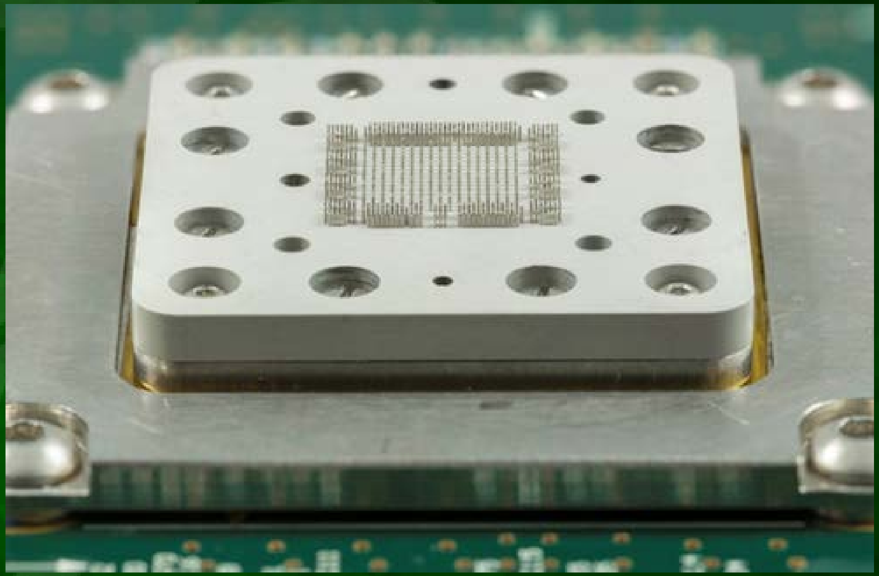
Inductance, and How to Stop It

- 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

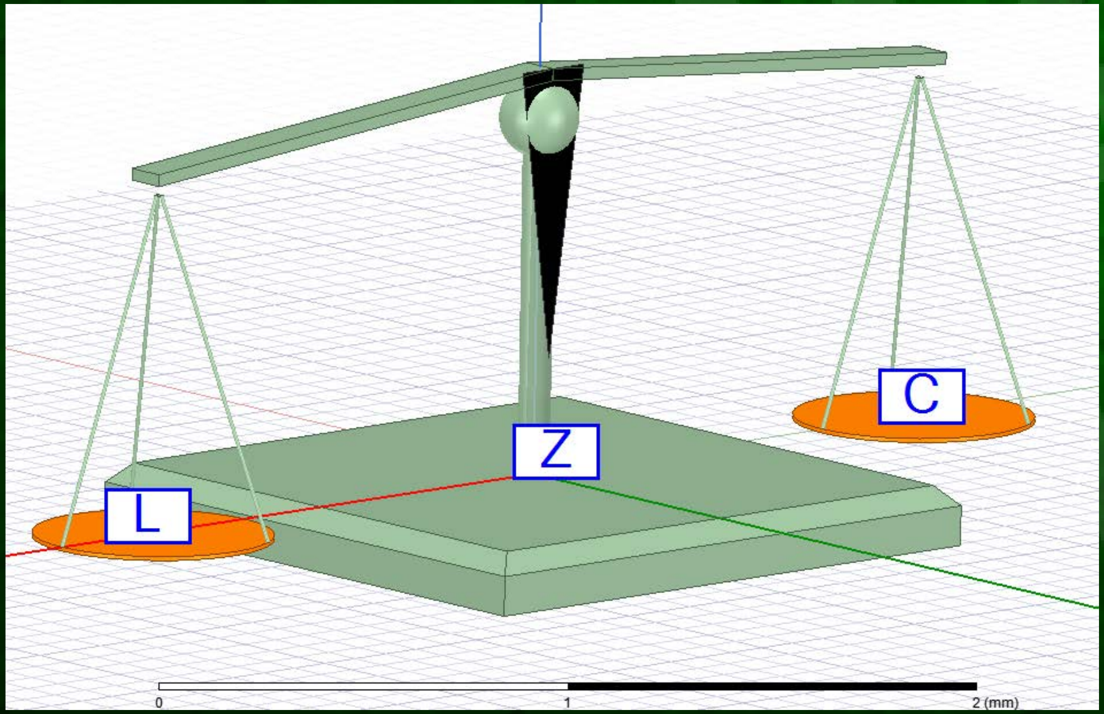
- **Inductance depends on length.**
- **The higher the frequency the shorter the wavelength. Lower than ~1/10th of a wavelength is distributed to lumped element transition.**
- **To get to higher frequency, make it smaller/shorter, but this has a cost (stiffer, less useful springs, pitch limitations)**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

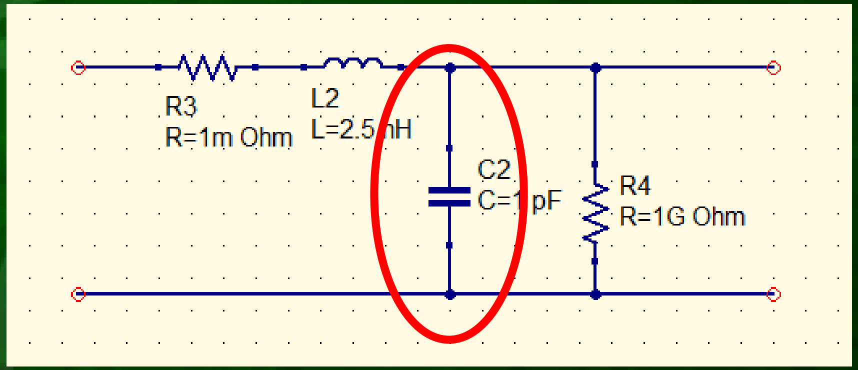


Pogo Pins:
often longer than 5 mm, much stiffer as they get shorter, unbalanced inductance

Offsetting Inductance – Parasitic Capacitance

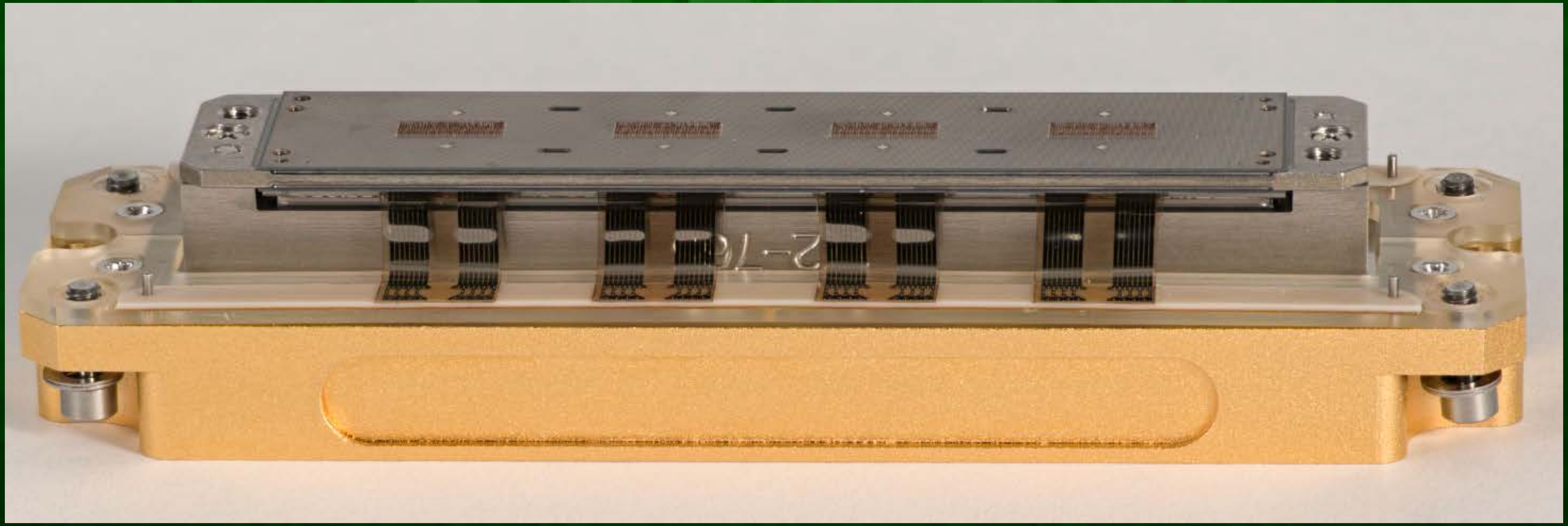
- **The length of <u>residual</u> inductance is what really matters.**
- **The inductance of a coax cable center conductor is not relevant because the capacitance to the shield compensates.**





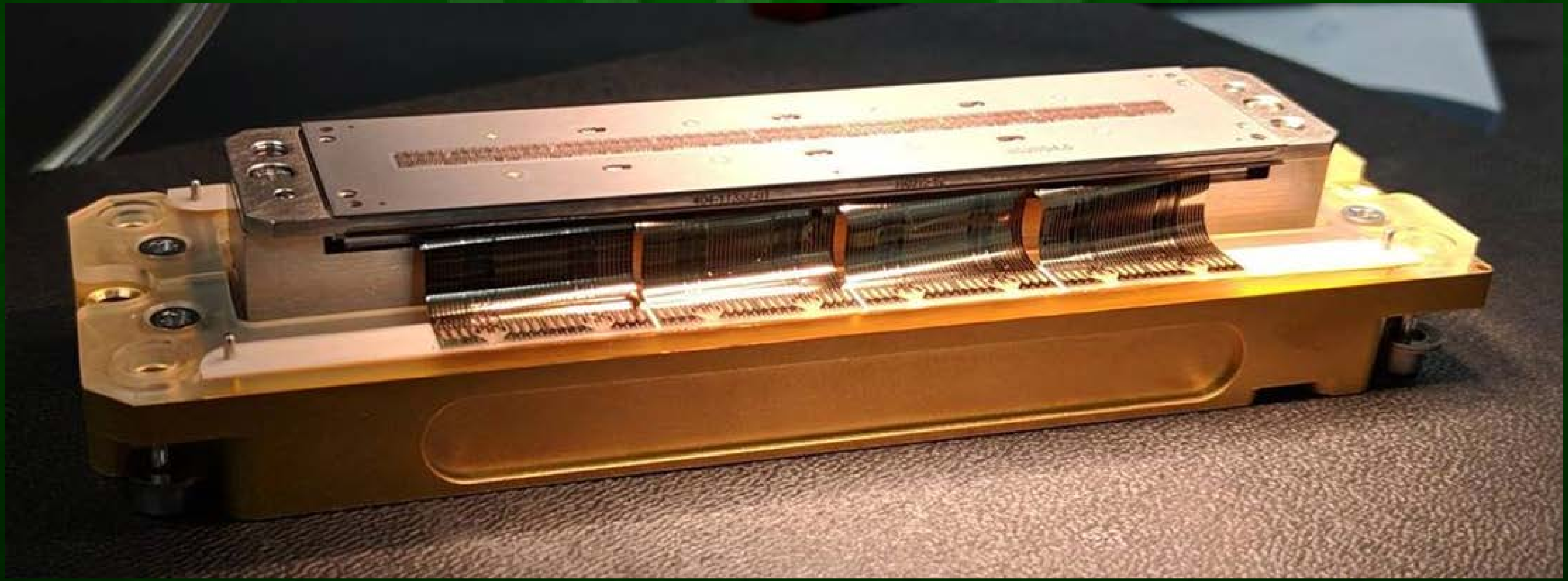
Offsetting Inductance

- **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



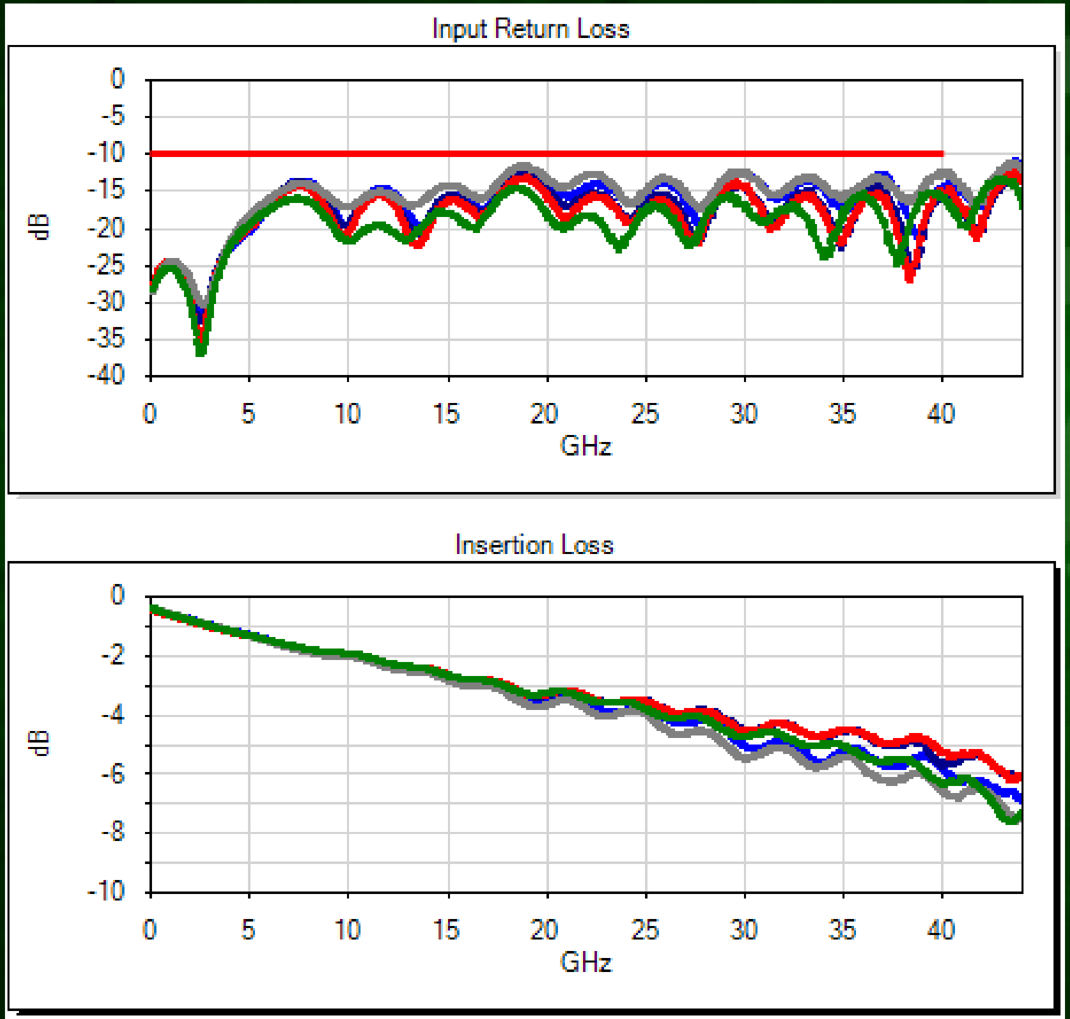
Results

- 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!*

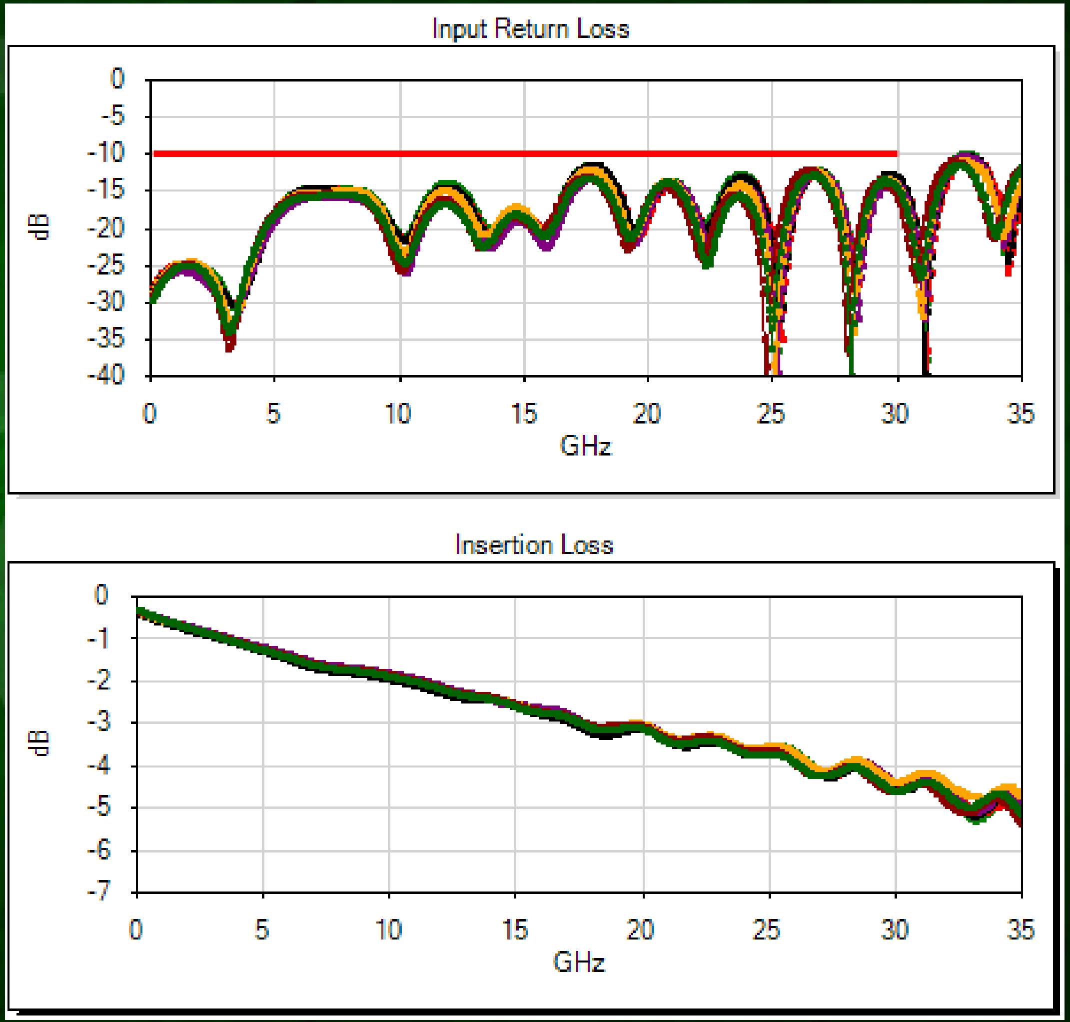


S-Parameters – Probe Head and Start of PCB

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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