SWTW 2018
SW Test Workshop
Semiconductor Wafer Test Workshop

Enabling High Parallelism in Production RF Test

Patrick Rhodes
Ryan Garrison
Ram Lakshmanan
FormFactor

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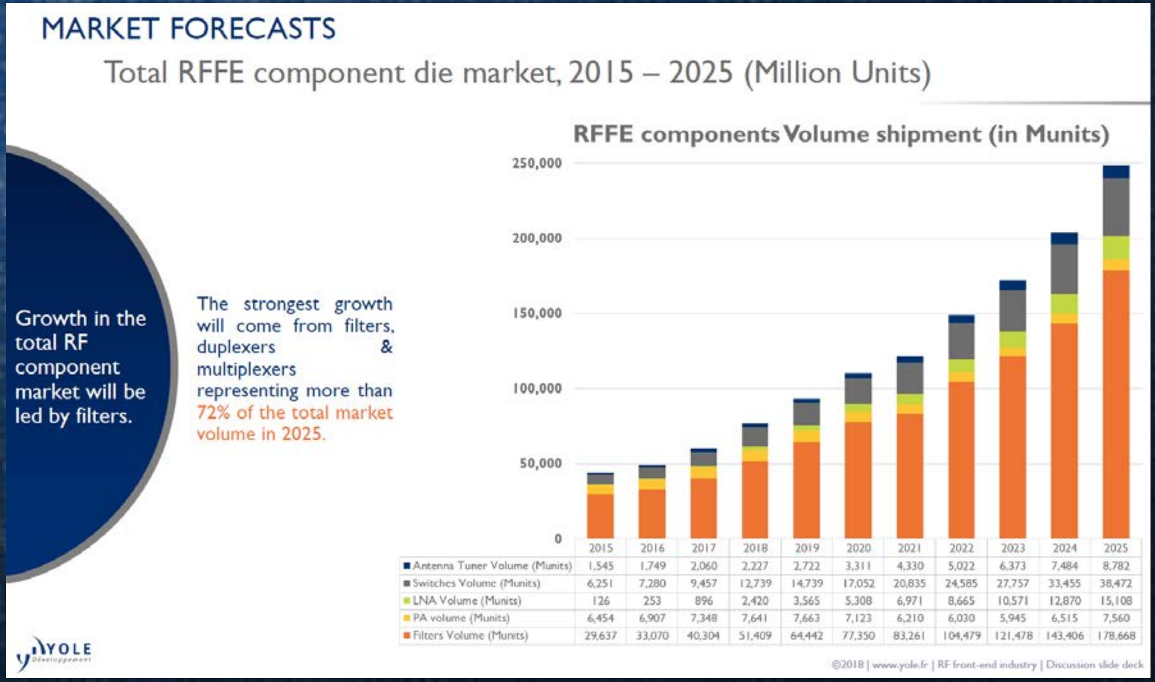
Connectivity is Driving Change

The connected world is driving the growth of RFICs in the market. These RFICs include – Filters, PAs, Switches for the front end and WiFi, BlueTooth, combo devices at the SoC level

Typically probing needs are:

- ❑ Operating frequency: <10GHz
- ❑ Loss Characteristics: -3dB IL/-10dB RL
- ❑ Ground Inductance: <0.8nH
- ❑ Higher Parallelism: larger volumes to test and increasing ATE capabilities



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Antenna Tuner Volume (Munits)	1,545	1,749	2,060	2,227	2,722	3,311	4,330	5,022	6,373	7,484	8,782
Switches Volume (Munits)	6,251	7,280	9,457	12,739	14,739	17,052	20,835	24,585	27,757	33,455	38,472
LNA Volume (Munits)	126	253	896	2,420	3,565	5,308	6,971	8,665	10,571	12,870	15,108
PA volume (Munits)	6,454	6,907	7,348	7,641	7,663	7,123	6,210	6,030	5,945	6,515	7,560
Filters Volume (Munits)	29,637	33,070	40,304	51,409	64,442	77,350	83,261	104,479	121,478	143,406	178,668

Credit: Yole, 2017

Example of Test Challenges

- **Combo devices:**
  - High RF channel count
  - Large general I/O count
  - High power requirements
  - Long test times
  - Delicate solder structures
- **High Speed Digital**
  - Large high speed channel count
  - Large dies
  - Stringent pad damage requirements

…all in a volume mfg. environment

X8 Array with >3000 Contacts and 6 GHz signals
Limited options for probe technology, all with trade-offs

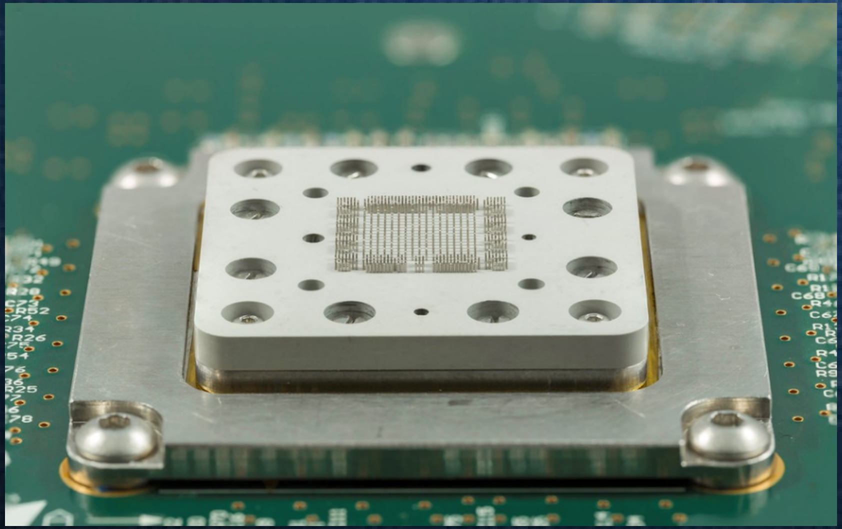
Limitations with Existing Solutions

- Traditionally, device manufacturers have deployed probe cards that support high frequency signals (>3 GHz) OR mechanically robust multi-site probe cards, but not both
- Many of the ingredients needed to get to a mechanically robust, frequency capable, multi-site probe card have been around for years, but gaps remained

Pogo Pin Limitations

The GOOD:

- Readily available
- Low cost
- High CCC



The LACKING:

- Pitch and frequency limited
- High inductance
- Maintenance-intensive
- High force

Getting to Higher Parallelism in RF Test

- We'll explore a new combination of the existing ingredients, as well as a technological sweetener that completes the picture, for a robust, multi-site probe card for production RF test

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A New Ingredient!

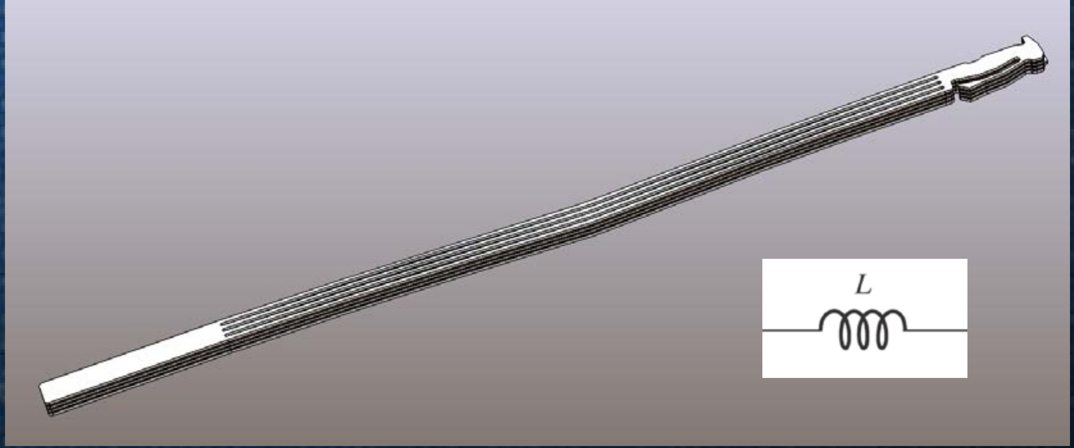
Ingredient 1 – Vertical MEMS

The GOOD:

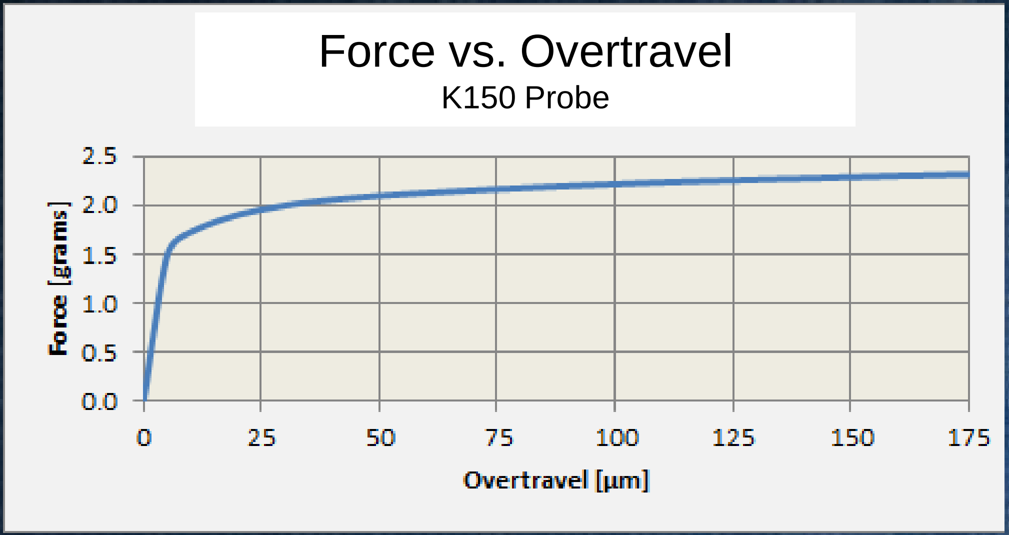
- ***Lots of people make these now, but only some are reasonably short***
- **Low Force (~2 grams at maxOT)**
- **Long Lifetime**
  - Mechanically these will exceed 1M touchdowns, considering both fatigue and wear
- **High CCC (~1A, depending on type)**
- **Easily Replaceable**
- **Scalable to large arrays and many sites**

The LACKING:

- **Vertical MEMS probes are essentially series inductors in traditional implementations**



Ingredient 1 Details



Probe Type	K400 (7-leaf)	K150 (4-leaf)	K80* (3-leaf)
Probe Technology	Vertical MEMS	Vertical MEMS	Vertical MEMS
Available Probe Tip Shape	Flat	Flat, Pointed	Flat, Pointed
Minimum Pitch [µm]	130 Inline Single Row (→105)	112 Inline Single Row (→87)	112 Inline Single Row (→87)
	200 Square Grid	150 Square Grid	130 Square Grid
	300 anywhere	175 anywhere	150 anywhere
Flat Tip Size (um)	80 x 200	51 x 76	51 x 55
Pointed Tip Size (um)	-	16 x 16	16 x 16
Probe Force at Production OT(g)	5~6	2.1~2.3	1.9~2.1
Max OT [um]	350	175	125
CCC [A]	1.5	1.1	0.8
Probe Length [mm]	2.95/3.75	2.79	2.79
Operating Temperature	-40~160C	-40~160C	-40~140C
Loop Inductance	0.6-1.2 nH GSG	0.4 nH GSG	0.4 nH GSG
@ Assembly Minimum Pitch	1.0-1.8 nH GS	0.75 nH GS	0.75 nH GS
Repairability	Single Probe Replaceable		

Buckling action of these probes makes good contact quickly, and leaves plenty of usable overtravel

Ingredient 2 – Membrane Space Transformer

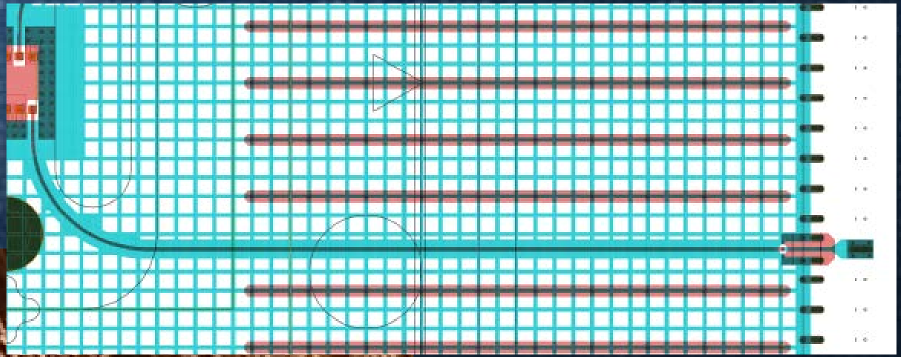
(now with only 1 job – space transformation)

The GOOD:

- ***These have been around for a long, long time***
- **Straightforward transmission line routing from one end to the other**
- **Short lead times**
- **More cost effective than typical MLO space transformers**

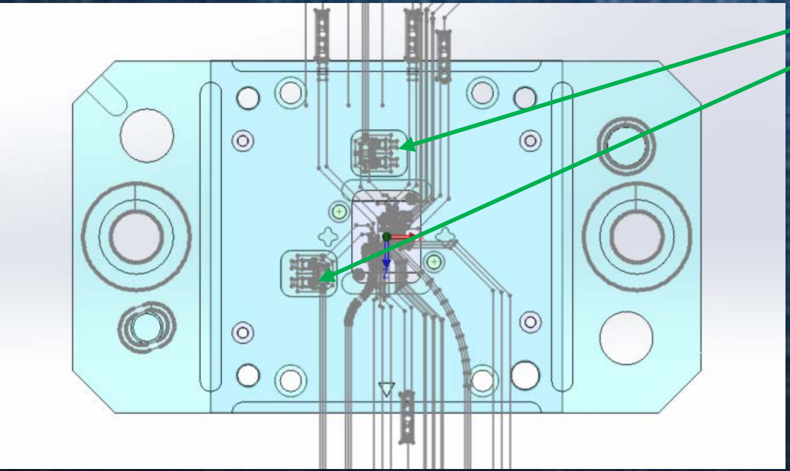
The LACKING:

- **Traditional use of these as a space transformer AND a contactor has limitations**
  - Large arrays can be mechanically unwieldy
  - Repairs often not possible



Benefits of Ingredient 2

- Use of the membrane as a space transformer only is far simpler than using it as a space transformer AND contactor
- It frees the membrane up for some *fringe benefits*



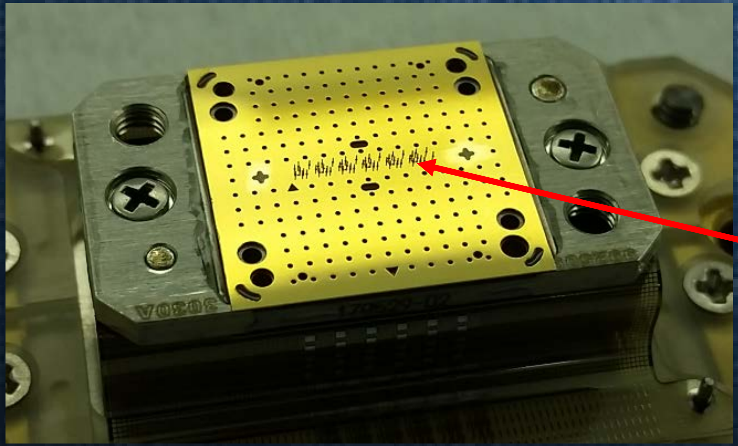
1. Additional space in general – landing pads for vertical probe distal ends take up less space
2. Loopbacks – see also: extra space
3. Component placement – right on the membrane face, underneath the spring head and very close to the die

Ingredient 3 – The New One!

So now we have vertical MEMS probes and a membrane space transformer. This is great for DC applications, *but that's not the endgame*. The combination is part way there, but now we're dangling an inductor off the end of a nice transmission line.

Bringing Balance to the Force:

- Add a metal layer to the guide plates
- Connect these metal layers to GND
- Connect all the GND probes to this metal layer
- Isolate all other probes from this metal layer



All GND probes are always in contact with the metal guide plate, all non-GND probes are isolated from the metal guide plate

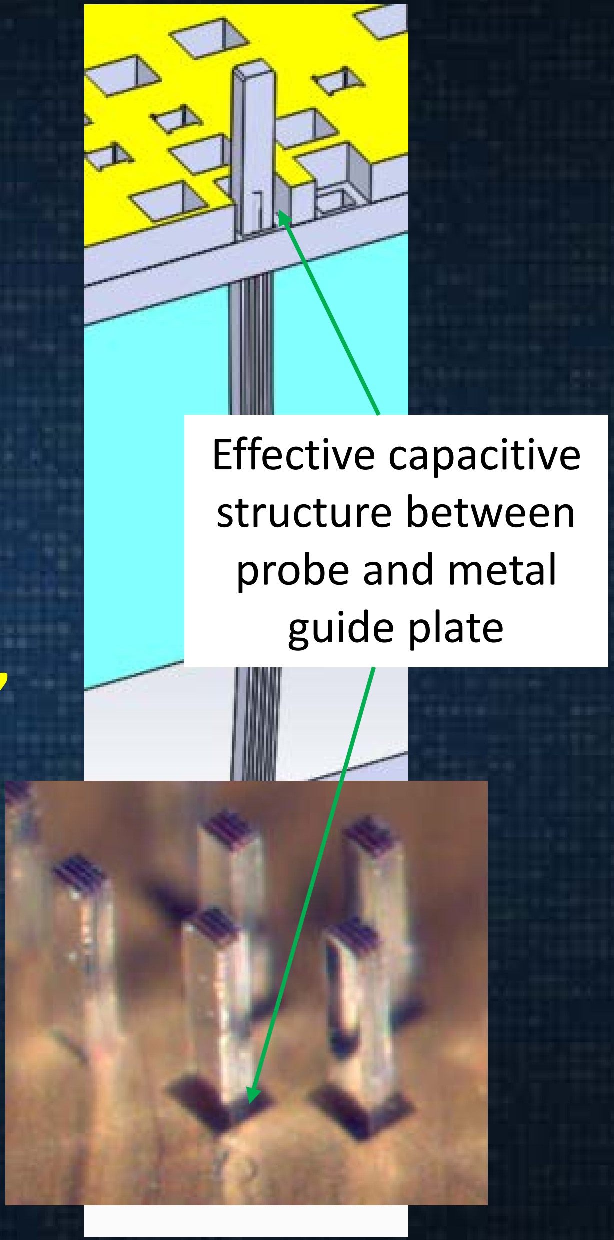
Benefits of Ingredient 3

So now we have metal+ceramic guide plates:

- **Enjoy the capacitance that the metal layer adds…and the balancing effect to the typically inductive vertical MEMS probe**
- **Further enjoy the ground plane between the die and space transformer**
- **Continue to enjoy the robust mechanical characteristics of ceramic guide plates (long lifetime, accurately feature placement, etc)**

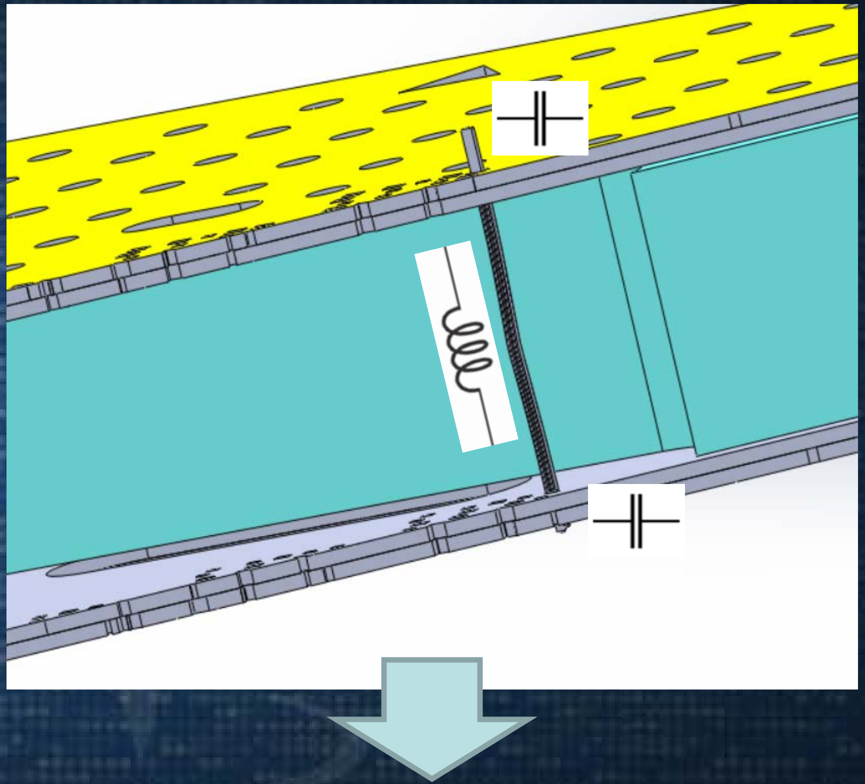
→Loss characteristics are improved over typical vertical MEMS probe cards

→The die and space transformer are nicely shielded from one another



Putting it Together (Pyramid + Katana = Pyrana)

- **Frequency performance – to about 10 GHz considering insertion and return loss**
  - Dependent on die layout and other factors
- **Isolation – die and space transformer aren't talking to one another**
- **[Standard benefits of vertical MEMS]**
- **[All the pluses of a thin-film space transformer]**



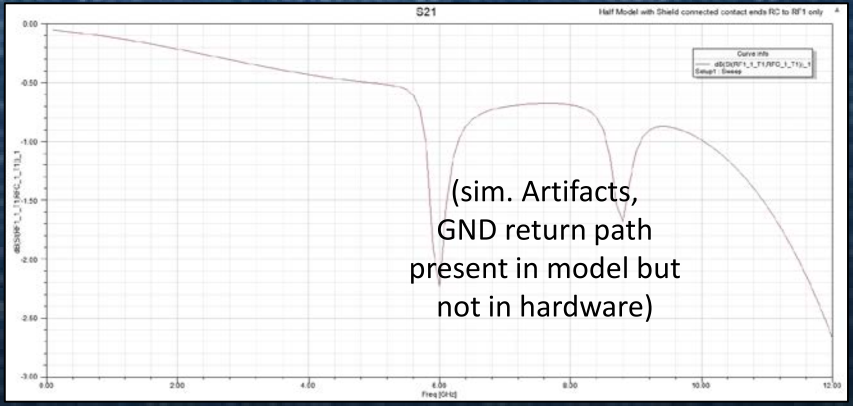
It's imperfect, but it moves the probe head back towards a 50 ohm environment; the space transformer is already there

How We Got Here: Simulations

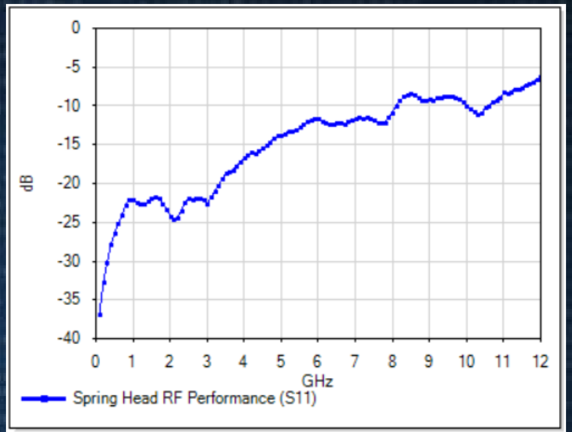
(spring head only)

- **The spring head remains the least ideal portion of the signal path**
- **Simulations for RL/IL suggest loss contributions, and measurements largely agree**

Simulated



Measured/De-embedded



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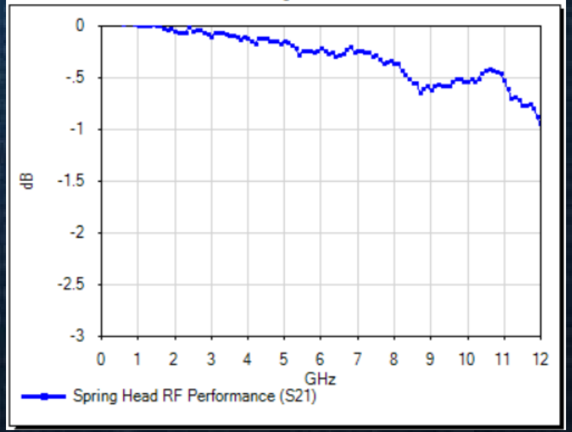
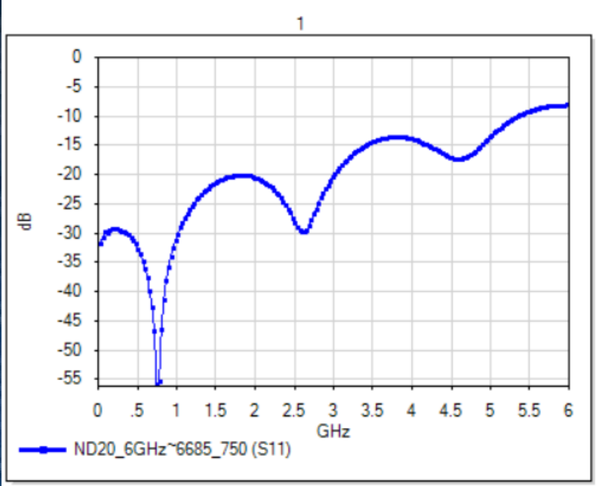
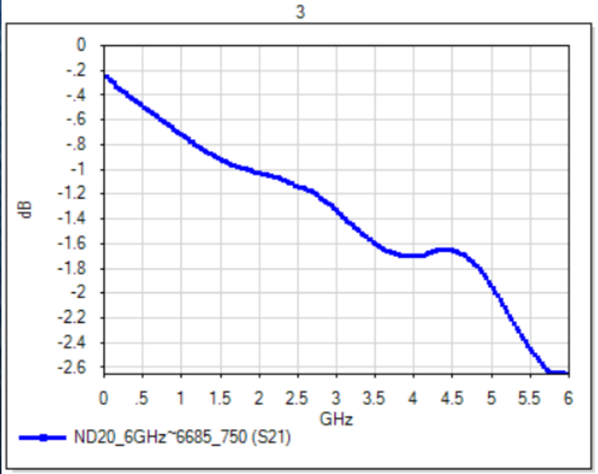
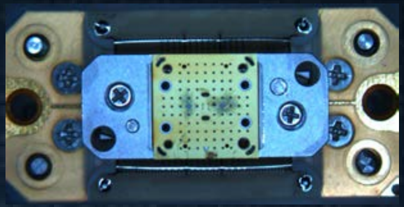


Case 1: Testing a Filter

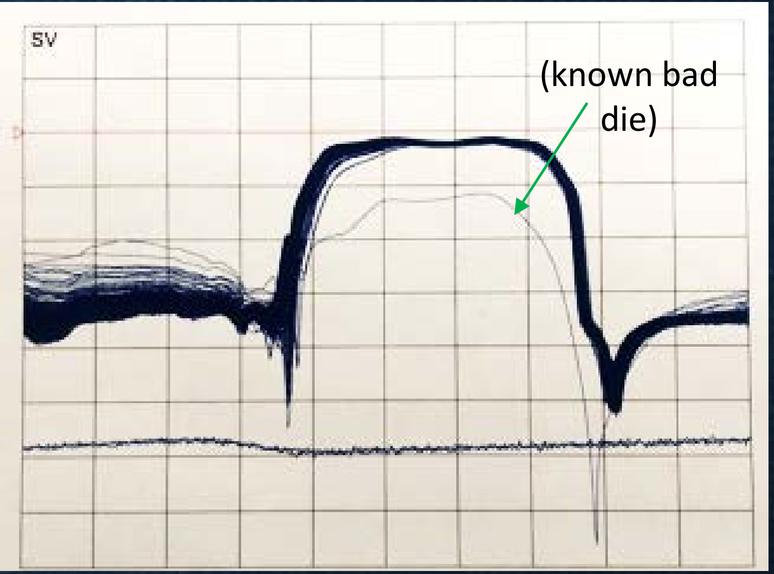
- ***Need***: mechanically robust probe technology with low loss (able to see defined passband), DC to 6 GHz
- **Entire signal path shown in S-parameters at center (connector to probe tip)**
- **Defined passband as seen through the probe card at right**







PV6: Smallest Pyrana Probe Head



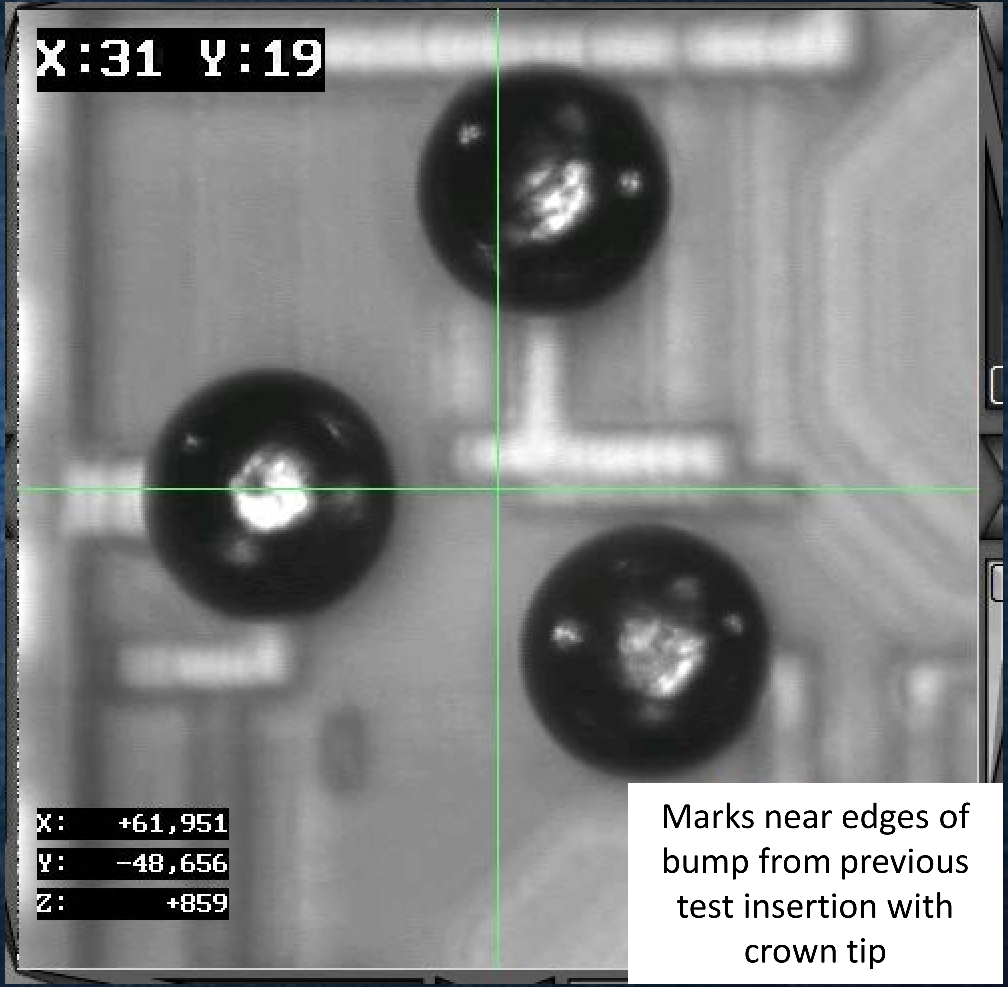
Case 2: Testing a Large Die, Lots of RF lines

- **A device with 32 RF lines for multiple radios shows yield loss due to insertion/return loss and crosstalk with more traditional probe technology**
- **Using a vertical head with a metal guide plate maintains yield >90% over the course of a full wafer**
  - Uncalibrated, but with repeatable results
  - RF power levels as seen by tester better than expected
- **Isolation and attenuation issues attributable to the contacts are largely addressed**
- **Heads used in a non-cleanroom engineering environment suffered damage due to overcurrent events, handling, etc, *<u>but repairs were generally straightforward</u>***

Test Data, about as sanitized as it gets!

Case 2: Probe Marks

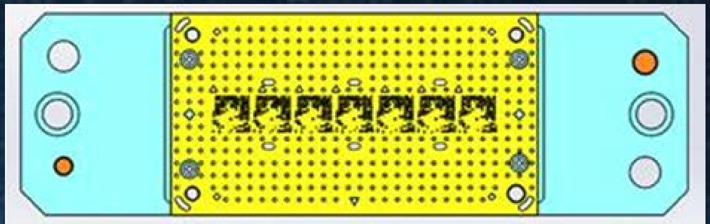
- **Low force and modest but non-zero scrub minimizes bump damage while maintaining good contacts**
- **Bumps at right are 90 um tall, 120 um diameter**
- **Top ~1/3 of hemisphere is *coined* but otherwise undisturbed**

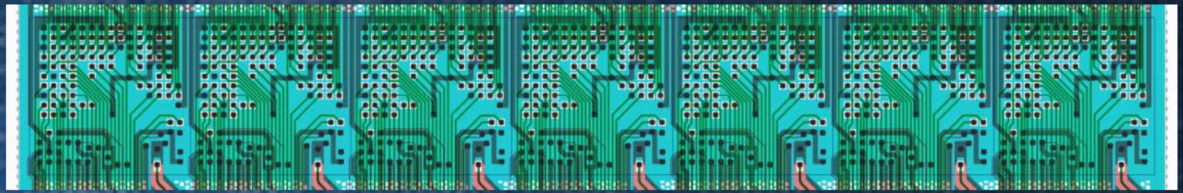


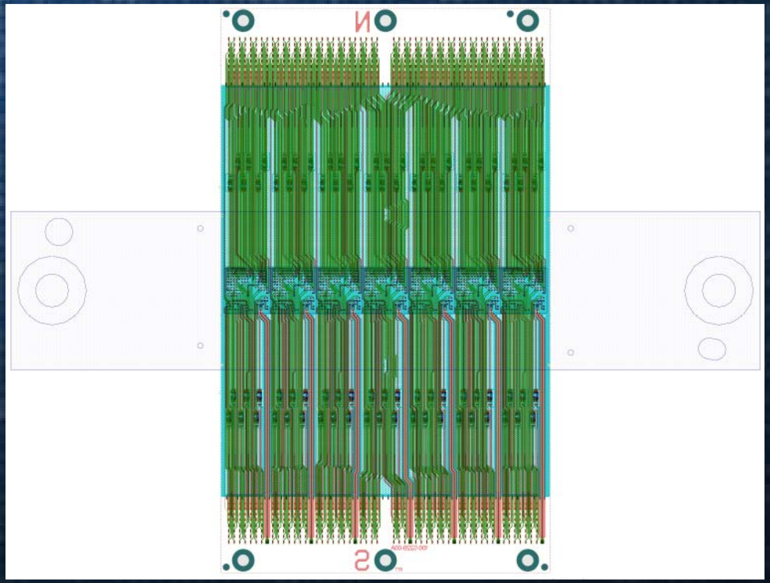
Marks near edges of bump from previous test insertion with crown tip

Case 3: Scaling Up

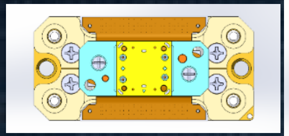
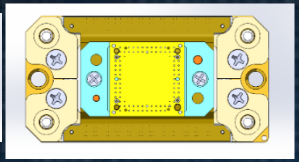
- **7-site testing of a Bluetooth device on a Teradyne UltraFlex tester**
- **Array size approximately 24 mm in the long dimension**
- ***Need*: probe technology that takes advantage of 7-site tester capability, without mechanical shortcomings**
- ***This design is complete, parts are in manufacturing, and will be evaluated over the second half of 2018***
- ***Additional multi-site designs now in process***



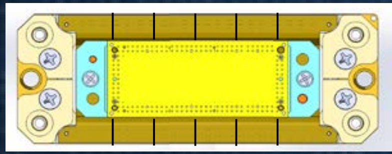




Pyrana – Additional Details

PV6	PV10
6mm x 6mm	10mm x 10mm




PV35	PV75
35mm x 10mm	75mm x 12mm

- **4 standard sizes for probe heads, with active areas shown**
- **Coverage for a wide range of devices, site counts, pin counts**
  - Filters to RF-SoCs
  - Inductance-sensitive devices, including MEMS sensors and power amplifiers
  - Tens of sites
  - Tens to thousands of probes
  - *Pin count is typically not the limiting factor*
- **Standard probe head footprints make generic, low-cost PCBs a real possibility**

Additional Product Data: www.formfactor.com/product/probe-cards/rf-mmw-radar/pyrana/

Pyrana Future

- **New vertical probe card architecture is opening new doors right now, but there's more to come:**
  - Drive to higher frequencies to support expanded applications
  - Improved pitch capability
  - Lead time reduction
- **Actively pursuing improvements to the Pyrana architecture to address all of these**

Wrap Up

- **Pyrana is an effective combination of a couple of existing, proven technologies plus a new ingredient**
- **It offers the possibility of much higher parallelism for all kinds of devices with signals up to 10 GHz**
  - Today's 10 GHz limit represents a trade – a lower frequency limit for a number of mechanical advantages
  - This limit is a soft one, as we're already driving toward improved bandwidth capability

Thank You!

- **Patrick Rhodes – Product Engineer, Patrick.Rhodes@formfactor.com**
- **Ram Lakshmanan – Marketing Manager, Ram.Lakshmanan@formfactor.com**
- **Please question away!**