5G: How to Be Heard in a Crowded Room

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Form Factor

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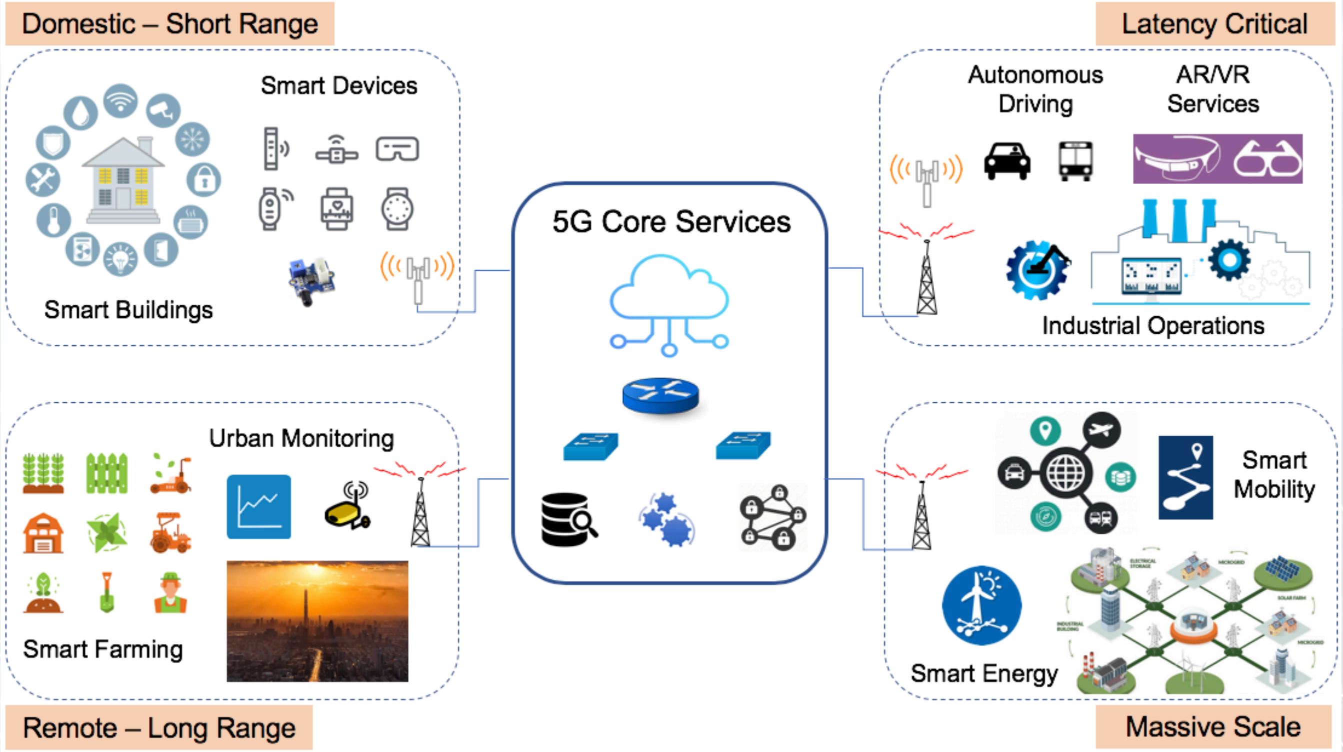
Overview

- **Discussion on the Market Drivers on 5G with Carrier Aggregation**
- **Discussion on different test requirements**
  - Extremely high isolation performance of a probe card for filter test
  - High power test at > 40 dBm
  - Harmonic test considerations in a probe card for IMD measurements

5G Core Services Breakdown

- **5G has been discussed and characterized over the past few years to include:**
  - Short range – Personal Smart Devices/Buildings
  - Long Range: Smart Farming/Urban Monitoring
  - Latency Critical: Autonomus Driving/AR and VR services/Industrial Monitoring
  - Massive Scale: Smart Energy/Smart Mobiility

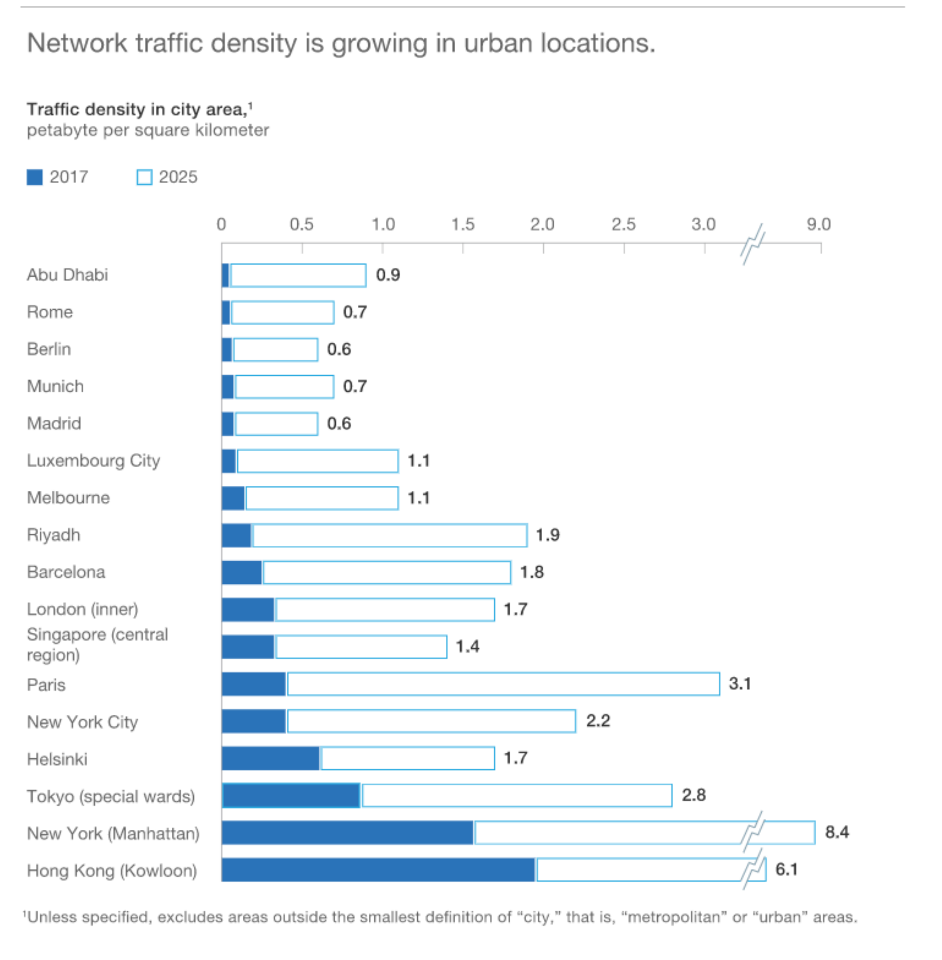


https://deepai.org/publication/5g-applications-requirements-challenges-and-outlook

Growth in Communication

- Due to the large urban capacity, there is expected to be a lot of growth in data transfer per square kilometer
  - In rural and suburban areas, operators can handle increased traffic simply by densifying existing networks with macro sites
  - In one European city, traffic density above 0.5 petabyte per square kilometer per year had a cell radius of less than 200 meters, necessitating small-cell solutions.
  - Many major cities will be at 1 or 2 (or more) petabytes per square kilometer by 2025!

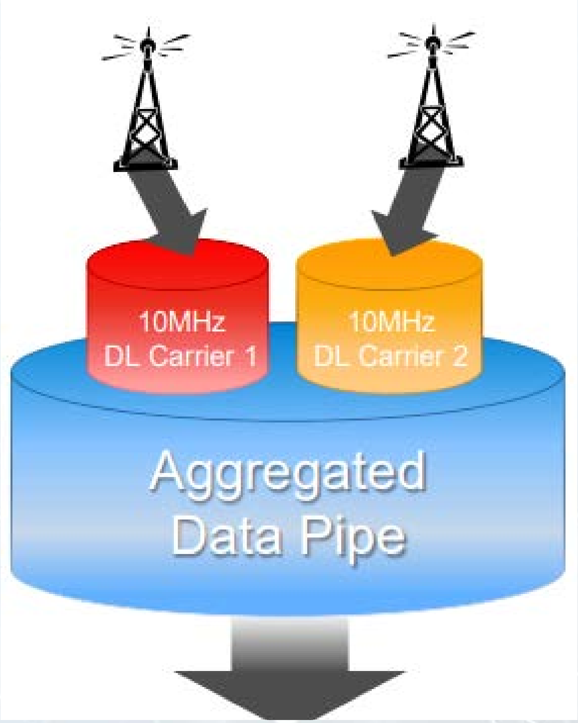
- **All of this will require a large investment in carrier aggregation with improved modulation methods**



https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-road-to-5g-the-inevitable-growth-of-infrastructure-cost

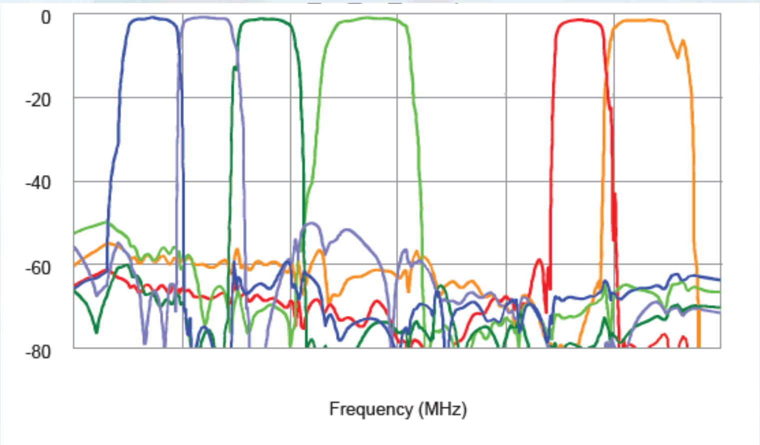
What is Carrier Aggregation?

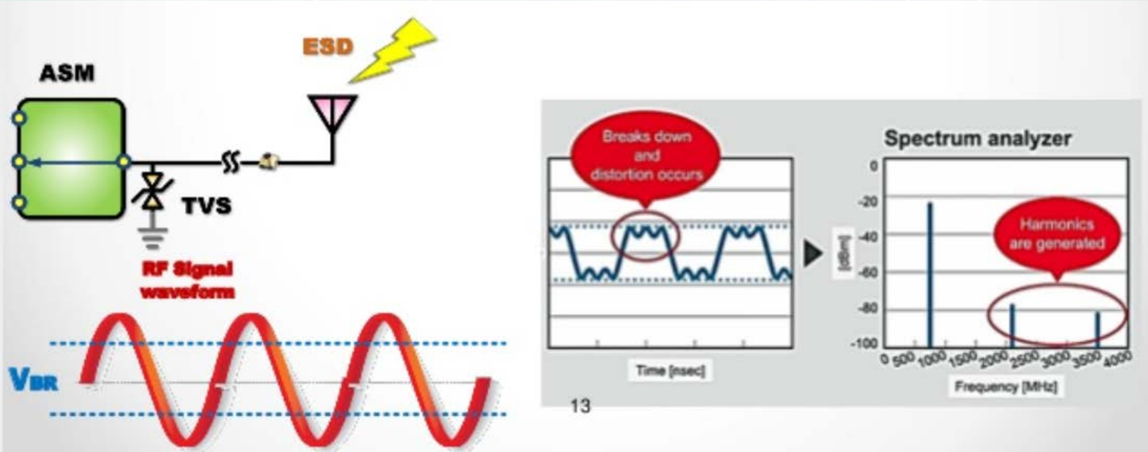
- **Carrier aggregation is one of the primary tools to increase bandwidth**
  - Current channels sizes for LTE is 20 MHz, so increasing spectral efficiency is not able to handle the required bandwidth
  - Bandwidth extension by aggregating (combining) multiple carriers channels into one data pipe is the best solution
  - 5G is also adding about 45% more <6 GHz bands, and 4 bands in the 25-30 GHz range
  - Provides:
    - Higher data rates
    - More efficient use of fragmented spectrum
    - Ability to handle more devices communicating simultaneously



5G Repercussions to Test

- **Due to the higher data rates, there are several repercussions that happen:**
  - Higher performance specifications due to the number of bands/filters
    - iPhones have > 30 RF filters today
  - High linearity performance metrics:
    - Intermodulation performance needs to be improved to prevent affecting the data
      - Amplitude and phase become an issue for bit error rate, especially if the device is nonlinear
    - Devices need to be able to handle more RF power with a higher Tx output IP3* point and higher RX input IP3
      - Be able to drive the device at the edges of RF power levels to measure





https://www.slideshare.net/criterion123/carrier-aggregation-discussion

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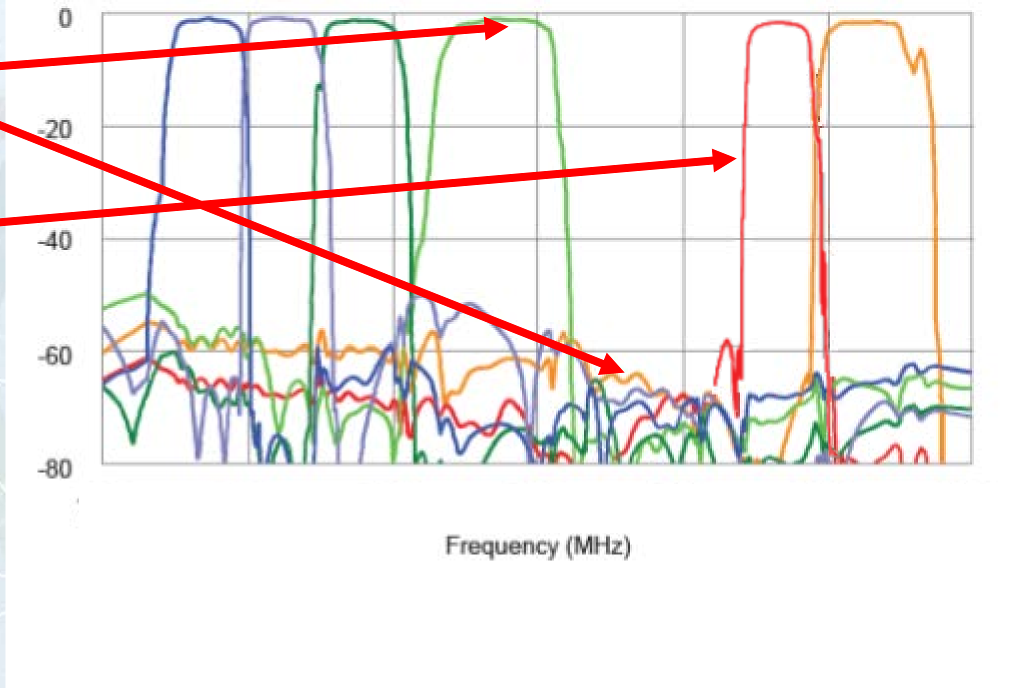
*intercept point is a measure of linearity

Requirements for RF Filter Probing

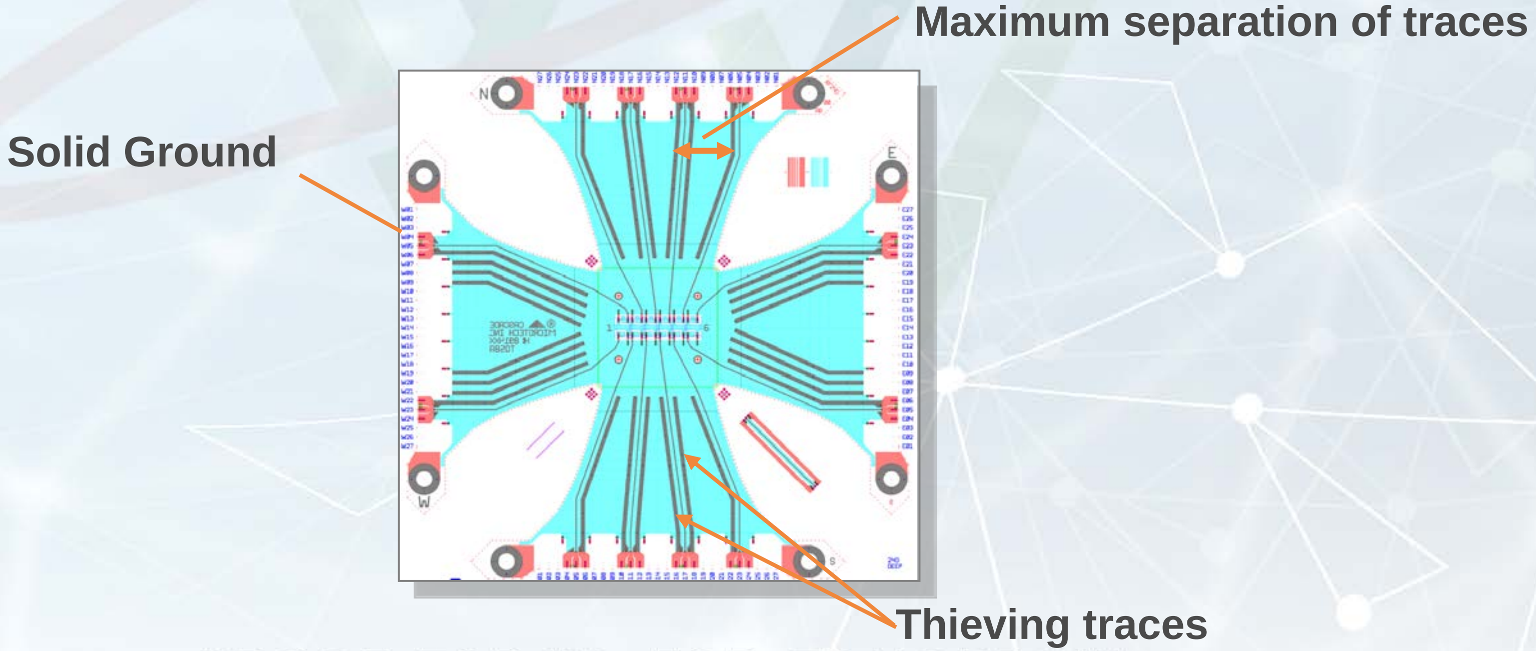
- Isolation of the probe card needs to be better than the filter
  - >50dB @ 2GHz
  - Moving to > 70 dB in some cases
- Ability to calibrate to the probe tips
- Low insertion loss
- Accurate package correlation to take into account parasitic as well as tuning elements for the filters
  - Includes in probe card inductors



*Representative example

Pyramid Probe: Isolation Techniques

- **Isolation:**
  - Essential for accurate filter response measurements and is perhaps the most difficult specification
  - Design layout done to ensure maximum trace separation
  - Custom ground structures
    - Low ground inductance paths with a customer requested solid ground in the entire membrane



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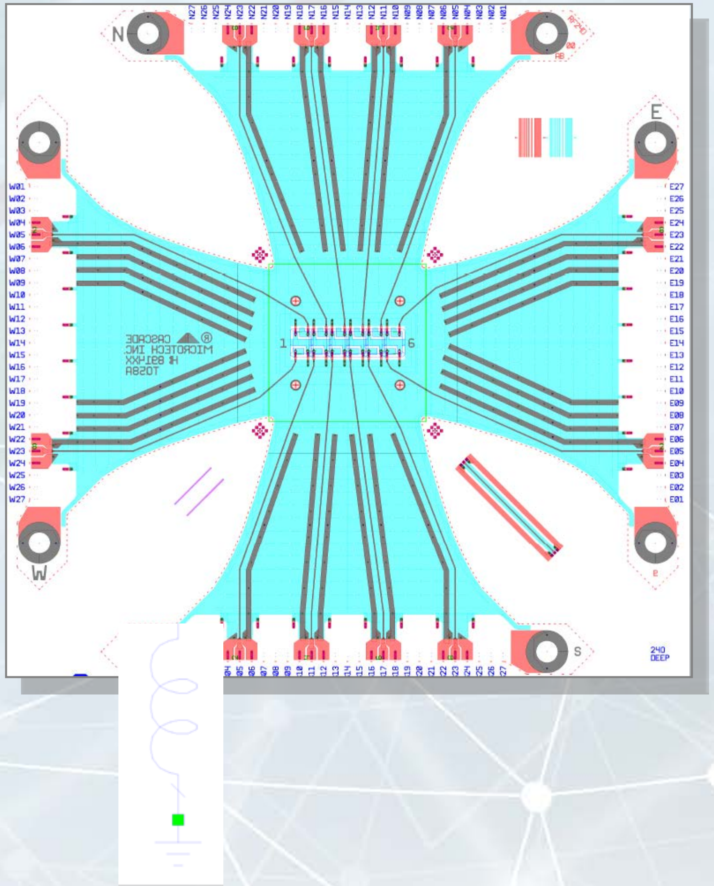
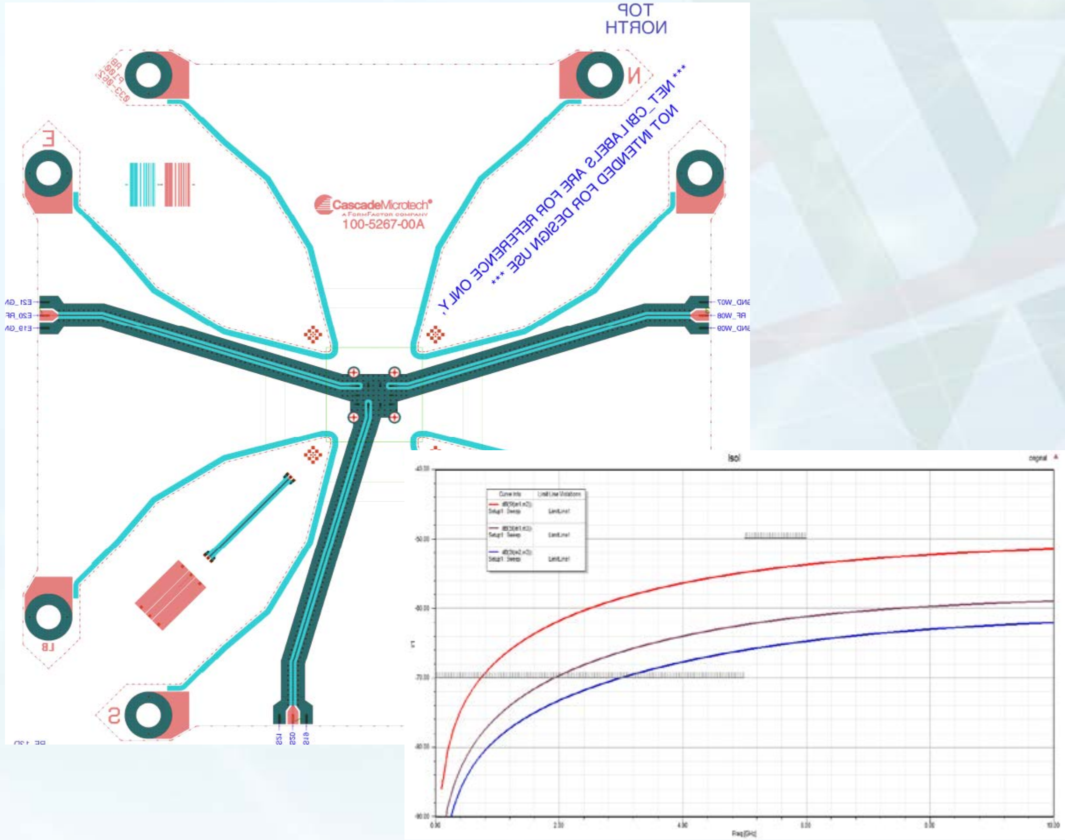
Ground Inductance Description

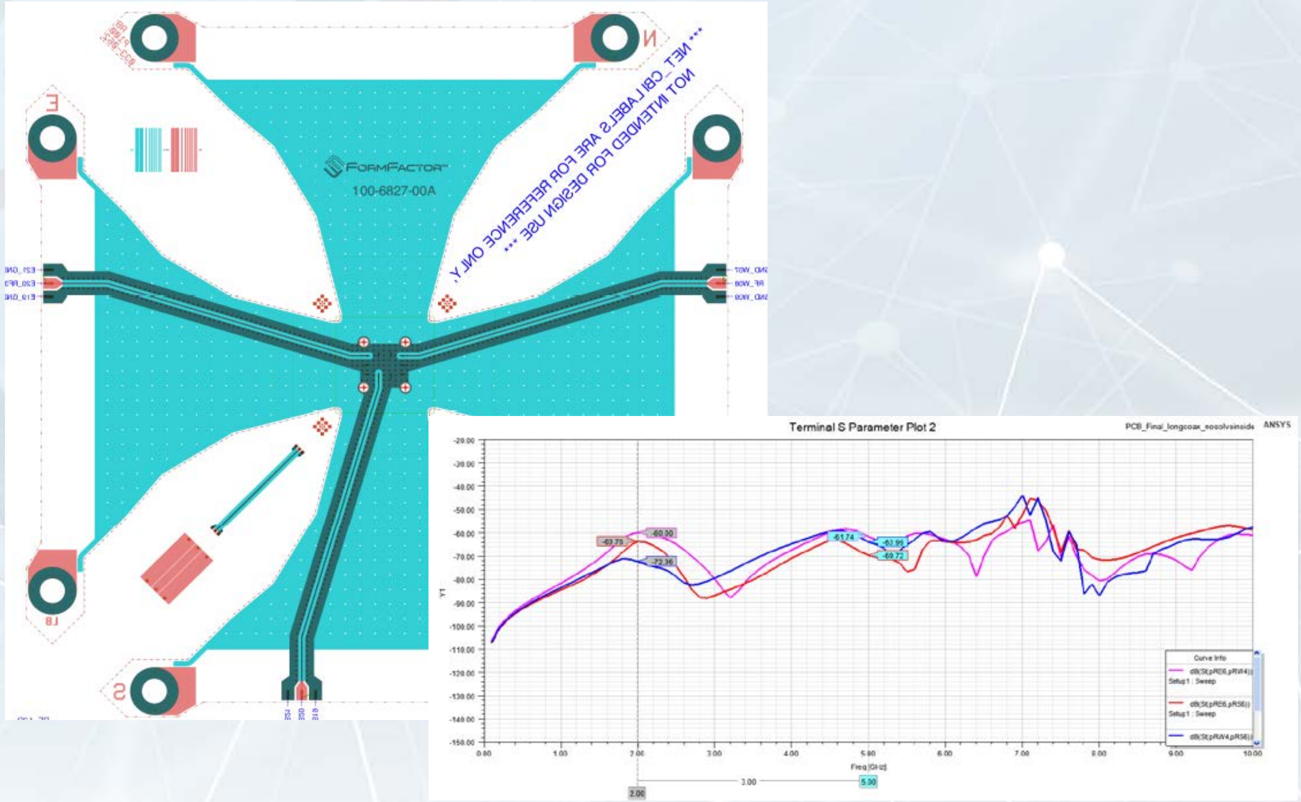
- **Ground inductance is a way to represent a ground return that is not a perfect ground, with some amount of reactance**
  - That can affect isolation in designs dramatically, limiting the isolation level from a DUT
  - Using traditional Pyramid Probe rules, we can hit isolation of ~-60 dB around 2 GHz
    - That corresponds to a ground inductance of ~4.0 pH
  - Future designs are looking for isolation of ~-70 dB around 2 GHz
    - Ground inductance of < 1.3 pH



Design Comparisons for Isolation

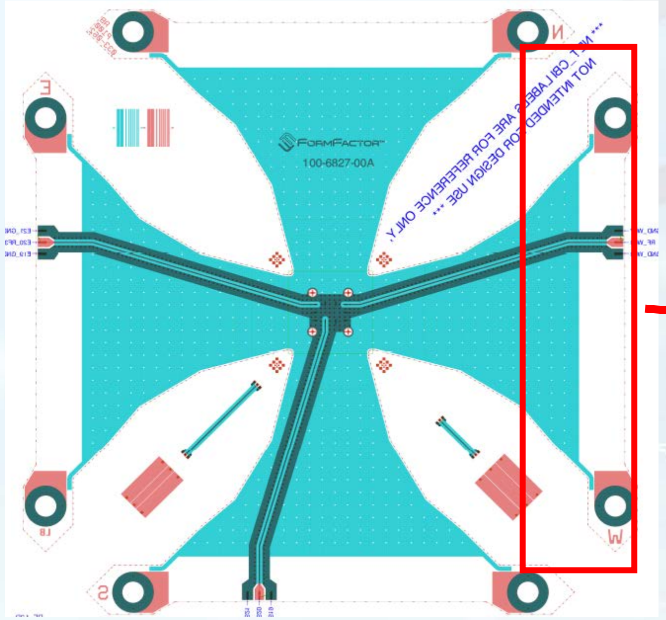
- Filter design 1 has isolation at 2 GHz of 62 dB, Lgnd = 3.2 pH
- Solid ground on wings has isolation of about 65 dB, Lgnd = 2.2 pH

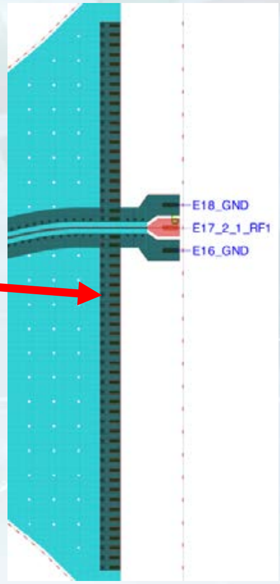


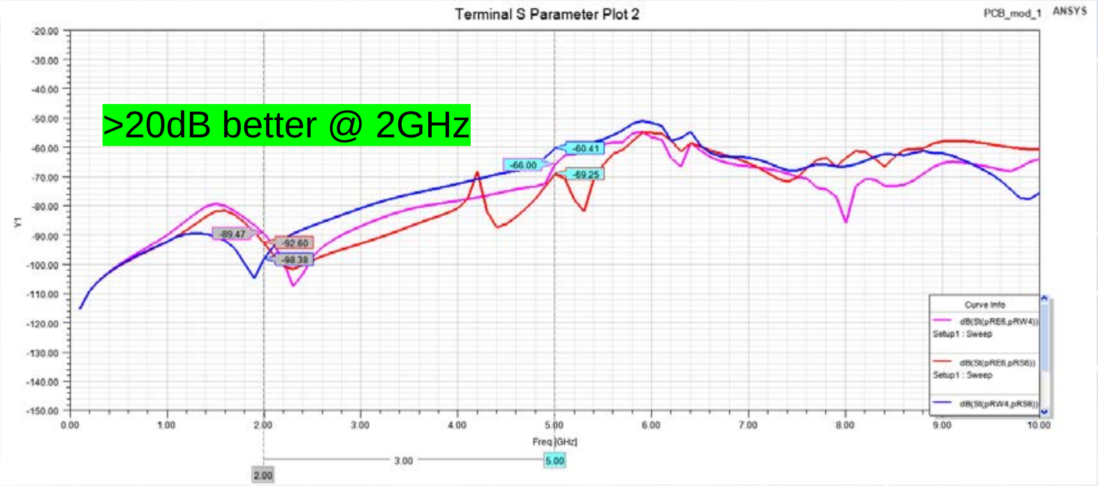


Change in Membrane CBI

- **By then increasing the number of ground connections from the membrane to the PCB, the ground inductance is further improved**
  - The ground inductance is < 0.5 pH







How much power can you deliver?

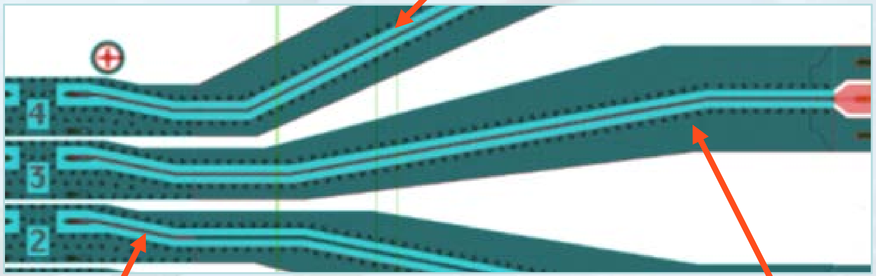
- **In order to measure the IP3, IMD, and other nonlinear device characteristics, test must be able to send in large RF powers in order to push the components to the edge of performance**

- **In order to provide the RF power, large transmission lines need to be used**
  - DC resistance is just part of what causes loss
  - At high frequencies, loss from skin effects and dielectric loss dominate, increasing loss vs frequency

Standard RF Transmission lines

- **50 Ω Microstrip**
  - Standard option for filters today
  - Allows higher routing density
  - Only up to 36 dBm

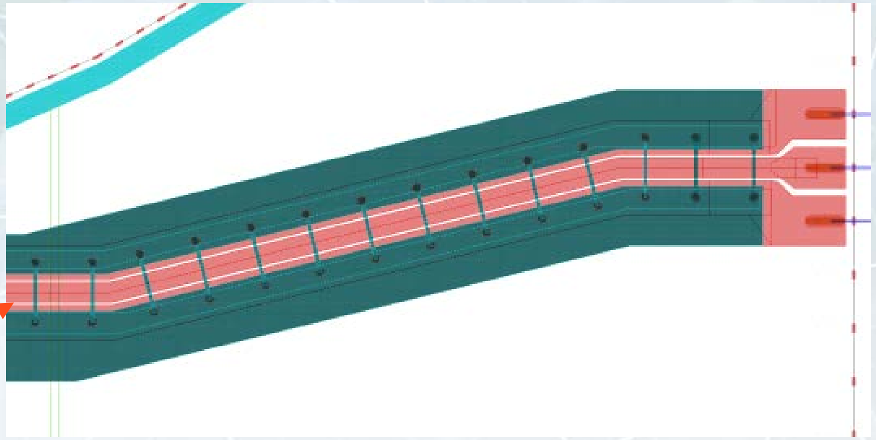
Solid Ground Plane (shown in blue)



50 Ω Microstrip

Signal Layer Ground with Vias for High Isolation

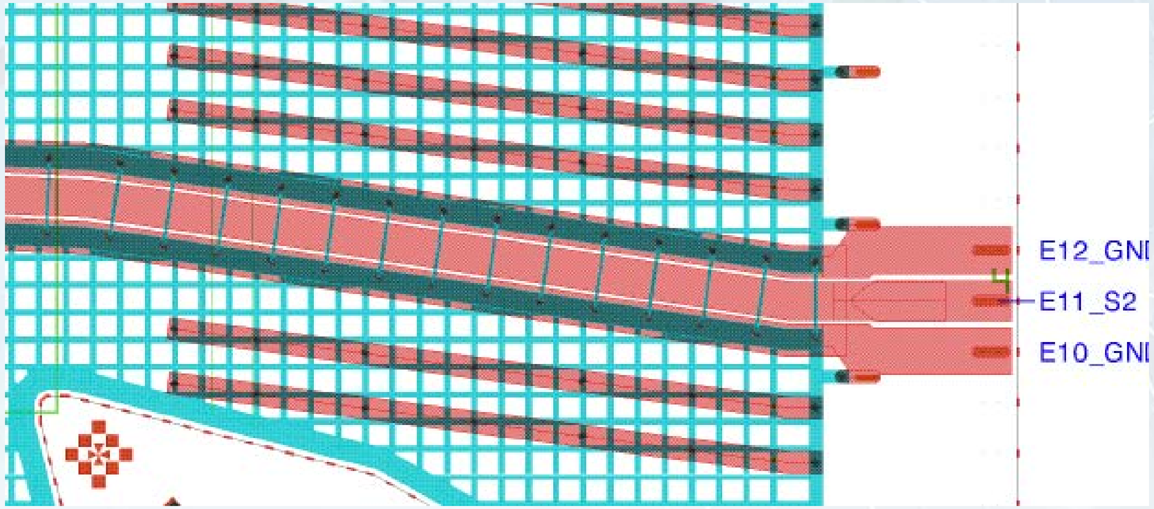
- **50 Ω Coplanar Waveguide**
  - GSG in the signal layer
  - Larger structure reduces available routing area, but can handle more RF power
  - Up to 39 dBm



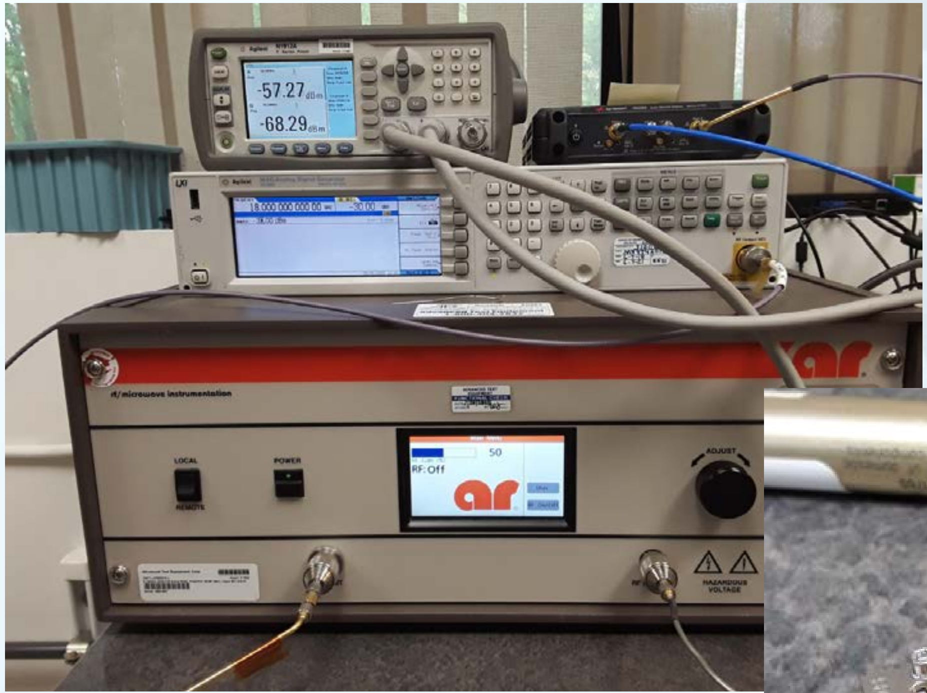
50 Ω CPW

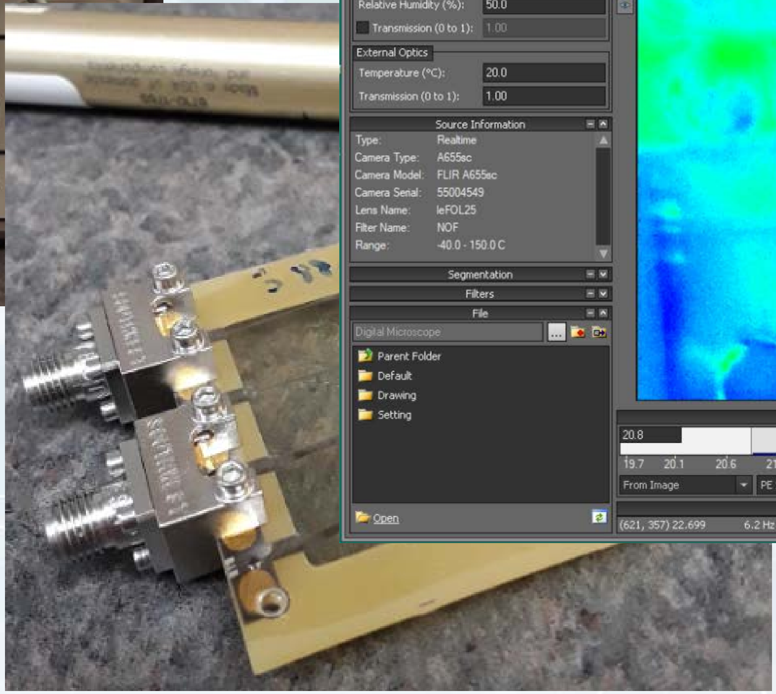
50 Ω Transmission Line for Higher Power

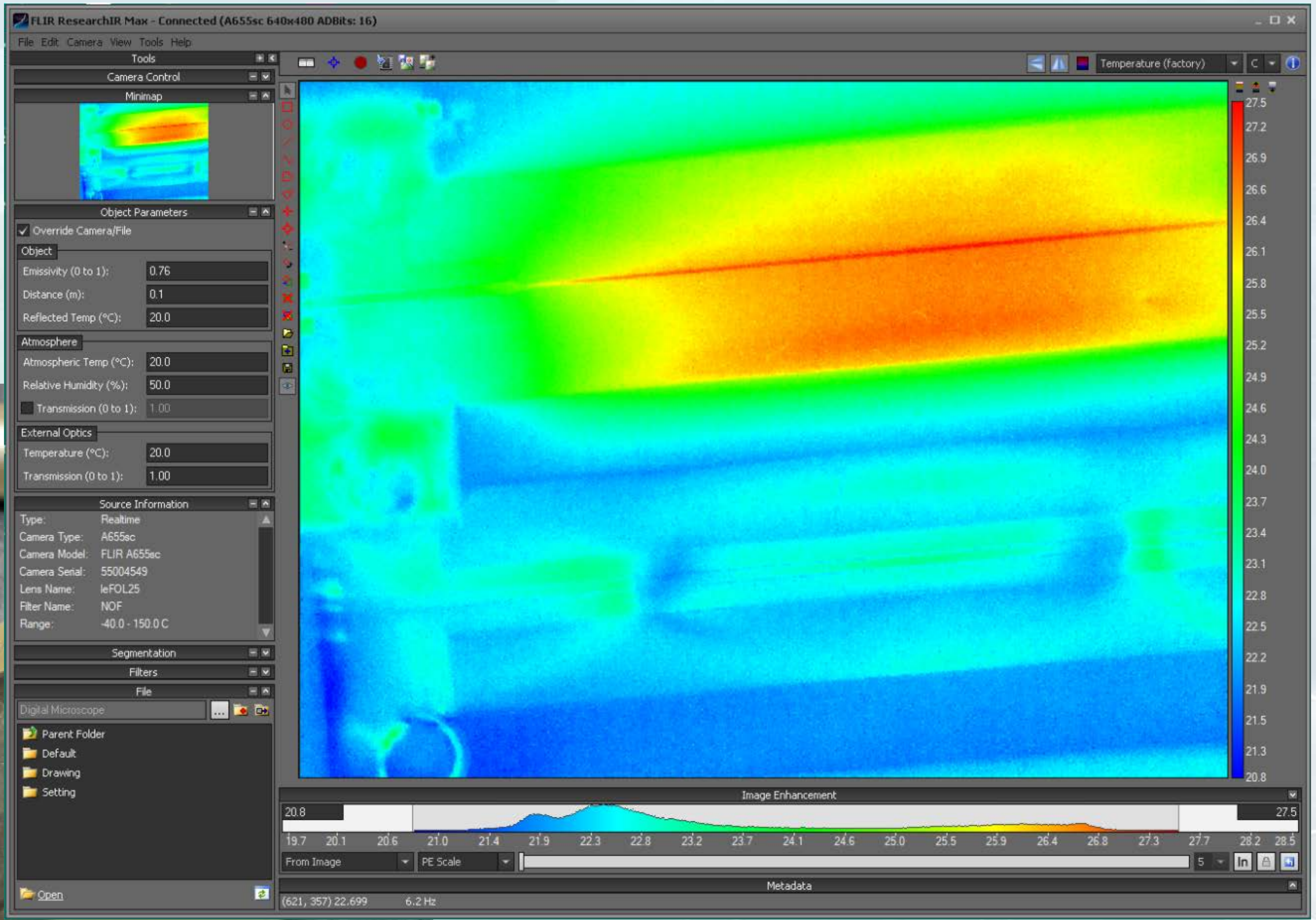
- **Ultra-wide 50 Ω CPW**
  - We can use an even wider CPW to handle more RF power
    - Nominal width is ~180 μm for our normal CPW
    - We enlarged it to ~350 μm to increase the power handling capability



High Power RF Test Setup







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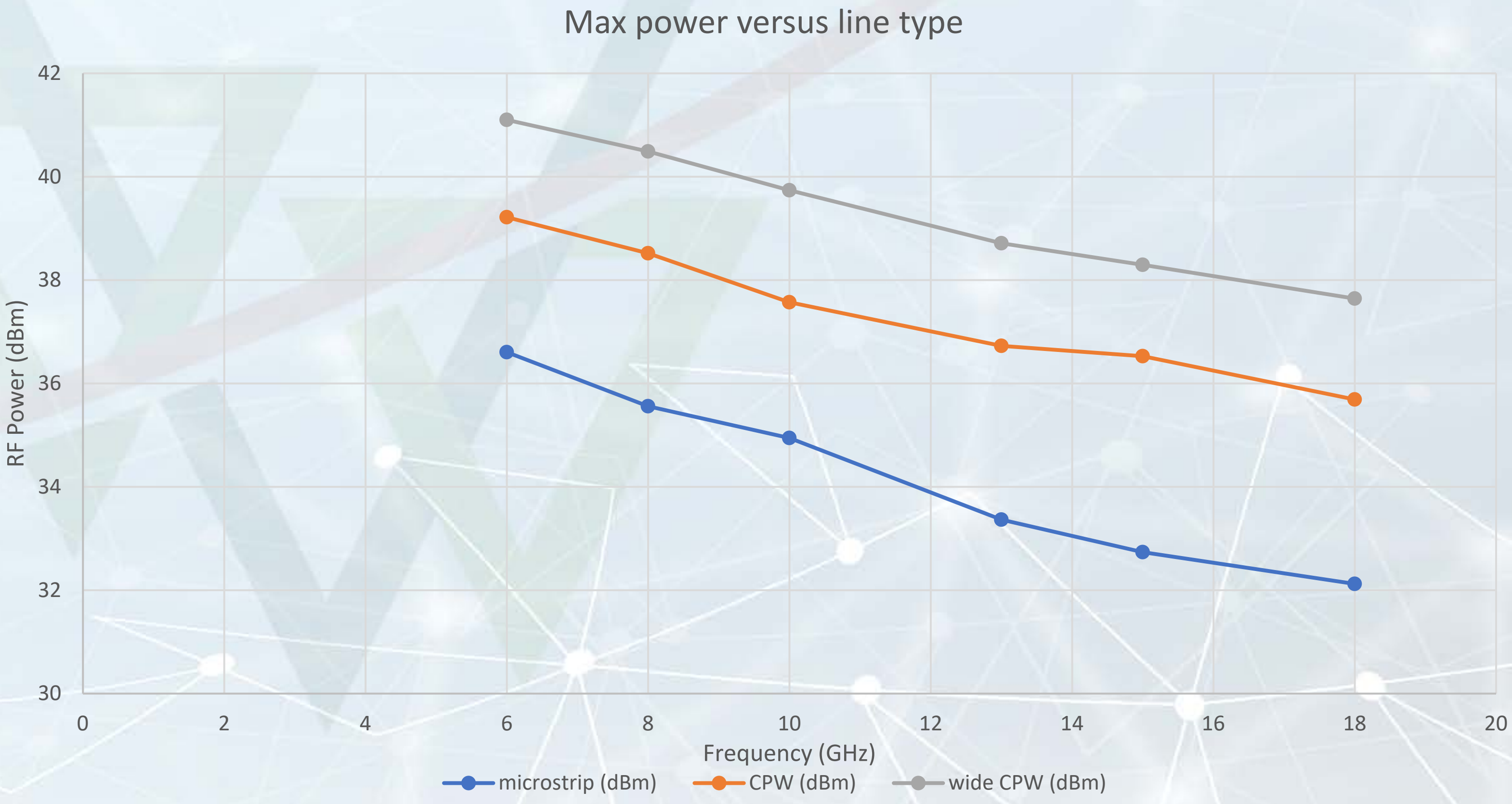
Power Handling Comparison for Different Types of Transmission Lines

- **The maximum power handling was set by what RF power would the membrane reach a steady state temperature of 225 C**
  - This provides good margin before the membrane would degrade



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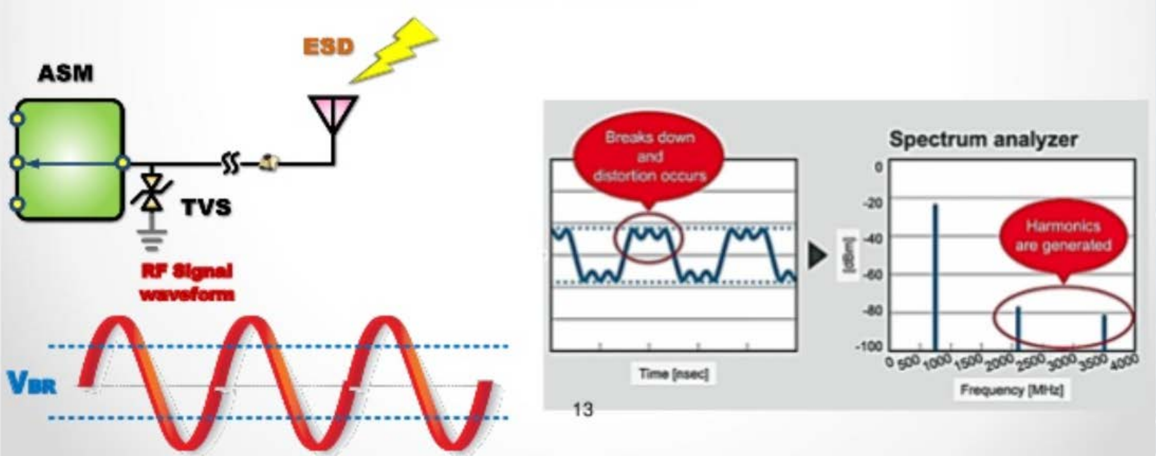
Harmonic Test With Pyramid Probe

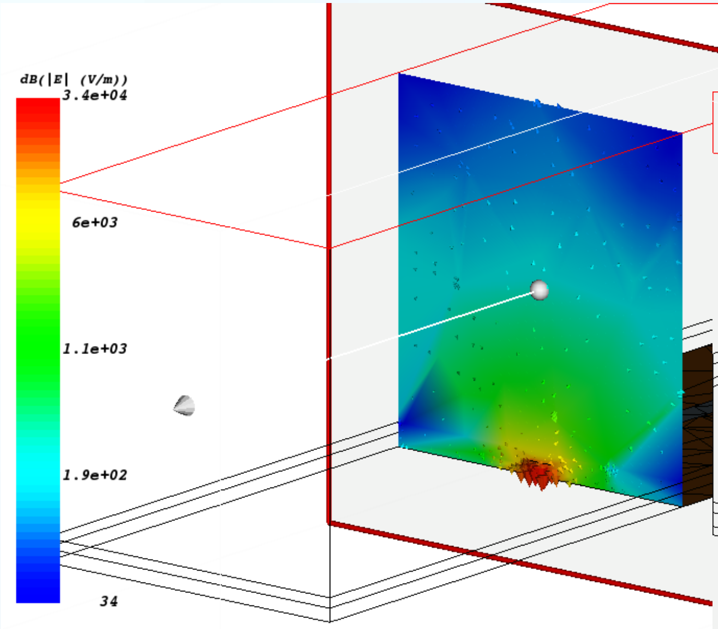
- **When doing harmonic test, the nonlinearities in material properties can be seen at high power test and can affect the ability to measure intermodulation with sensitive devices**
  - These effects are called Passive InterModulation (PIM) in probe cards since there are no active components



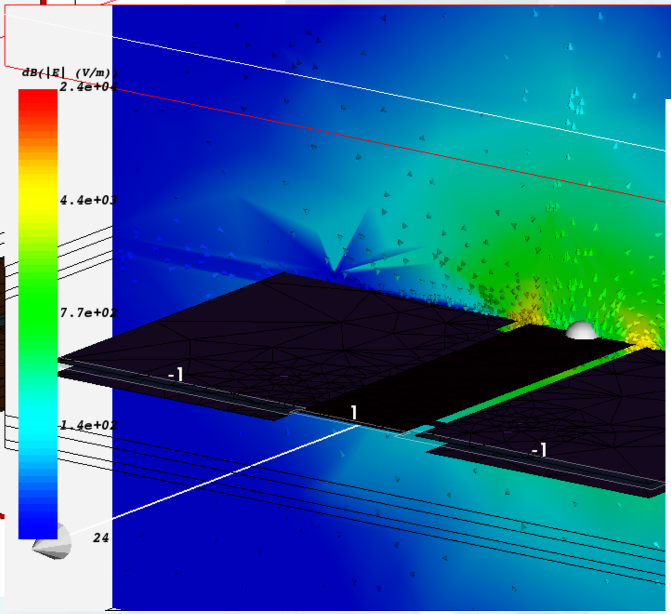
- **PIM is due to various factors**
  - Metal surface roughness
  - Type of conductor
  - Dielectric properties and water absorption
  - Metal to metal interfaces

How to Reduce PIM In Pyramid

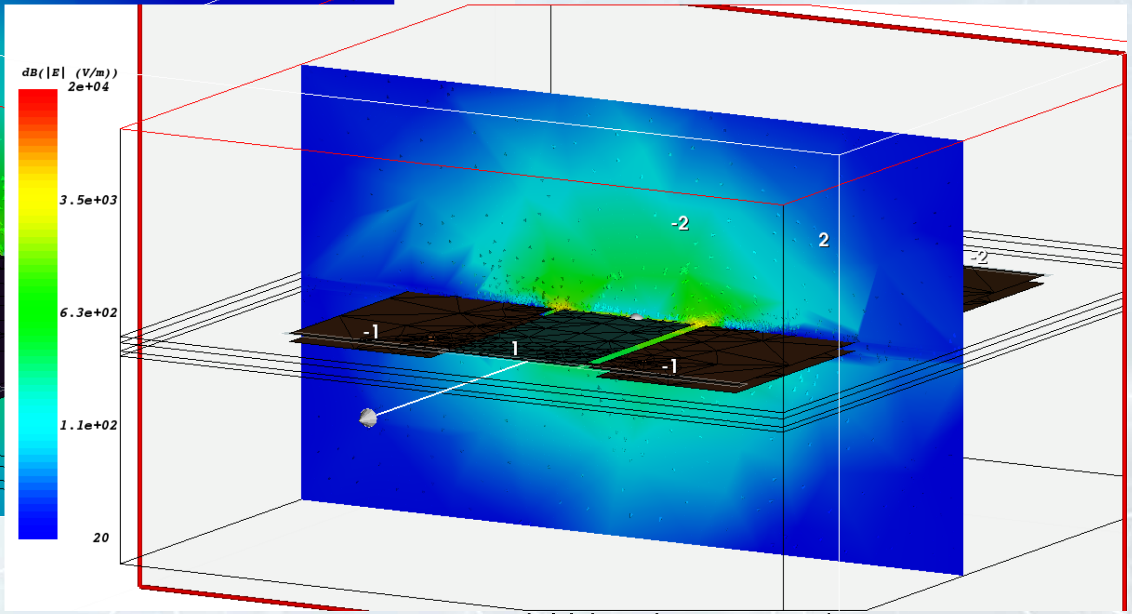
- **The level of nonlinearity in the membrane goes as the field strength (V/m)**
  - To minimize the field strength, you want the fields distributed over the largest area



Microstrip Field (max) = 3.4 e4 V/m



CPW Field (max) = 2.4 e4 V/m



Large CPW Field (max) = 2.0 e4 V/m

Microstrip has the largest field strength between our three transmission lines. This is because the fields are concentrated over the smallest area with microstrips

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How to Evaluate PIM

- **In 2007, Ref 2 proposed that the resistance of the device can be modeled having some nonlinear terms, where the voltage goes as:**

$$V(t) = R_o I(t) + R_2 I(t)^3$$

- **Where Ro is the normal 'resistance' of a transmission line, and R_2 is the nonlinear term**

What are the R_2 for each transmission line?

- **Based on measurements, we know that the PIM measured in an appropriate environment is:**
  - The PIM for CPW is: < -83 dBm
  - The PIM for microstrip is: ~-43 dBm
  - Both were excited with a signal at 27 dBm

Nonlinear term for:	R_2	
microstrip	4.00E-06	Ω/A^2
CPW	5.00E-09	Ω/A^2

Summary

- **In order to meet the technical challenges for RF test for the newest developments in 5G, we have evaluated:**
  - High isolation requirements and methods
  - RF power levels above 40 dBm
  - How to control PIM for the cleanest measurement of active devices possible

Any Questions?