Complex Impedance Matching Structures for Advanced On–Wafer AiP Testing

Pratik Ghate, Ph.D.
FormFactor, Inc.

4th Annual SWTest Asia | Hsinchu, Taiwan, November 2-3, 2023

Overview

- Market Drivers
- What is Antenna in Package (AiP)?
- Impedance Matching
- Challenges with Complex Impedance Matching
- Probehead Design
- Test Setup and Measurement Results
- Conclusion

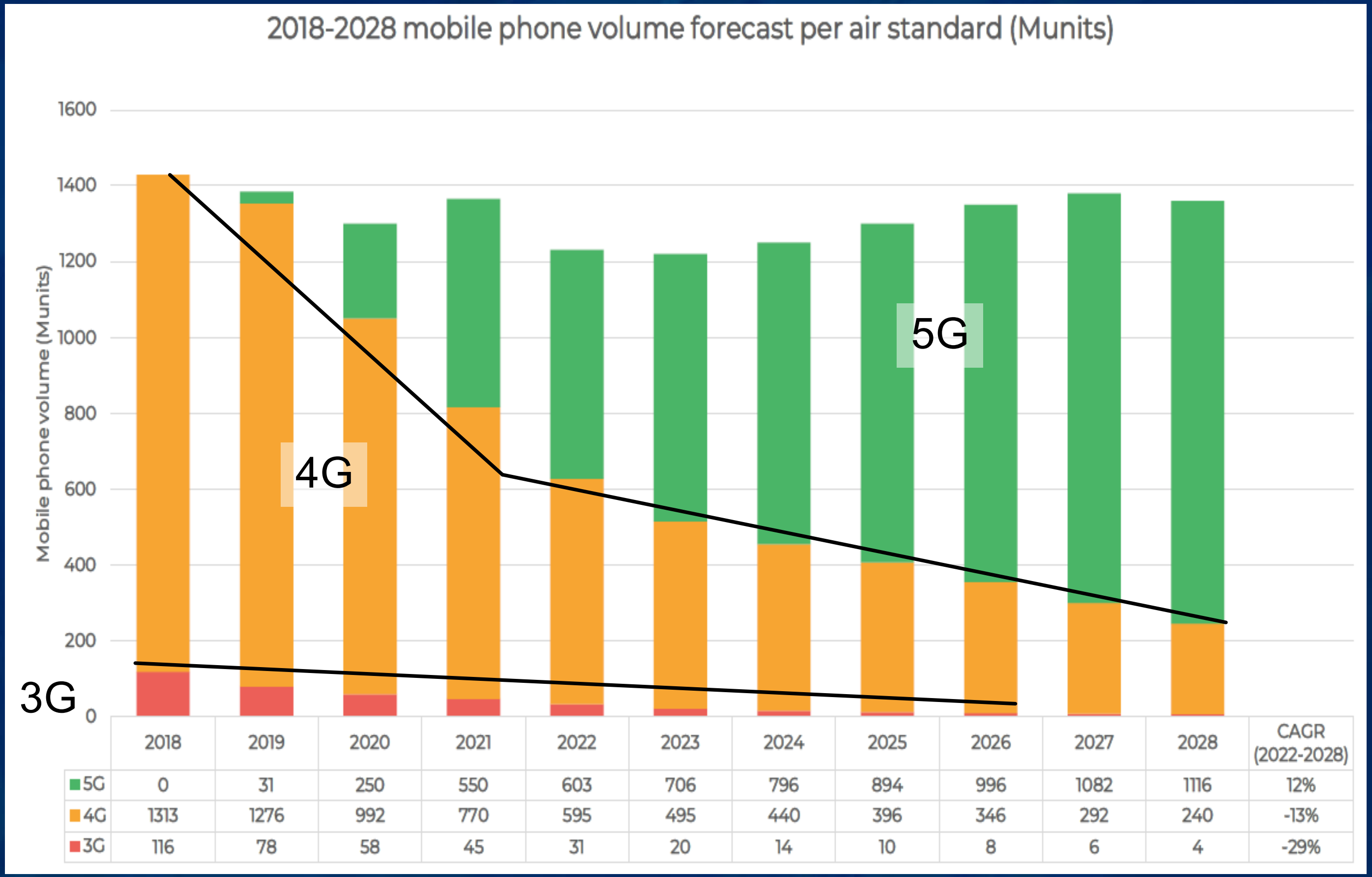
Market Drivers

5G: Smaller Better Faster

- The world's leading economies are actively deploying 5G coverage
- Demand ramp is soaring and will continue

Advantages of 5G

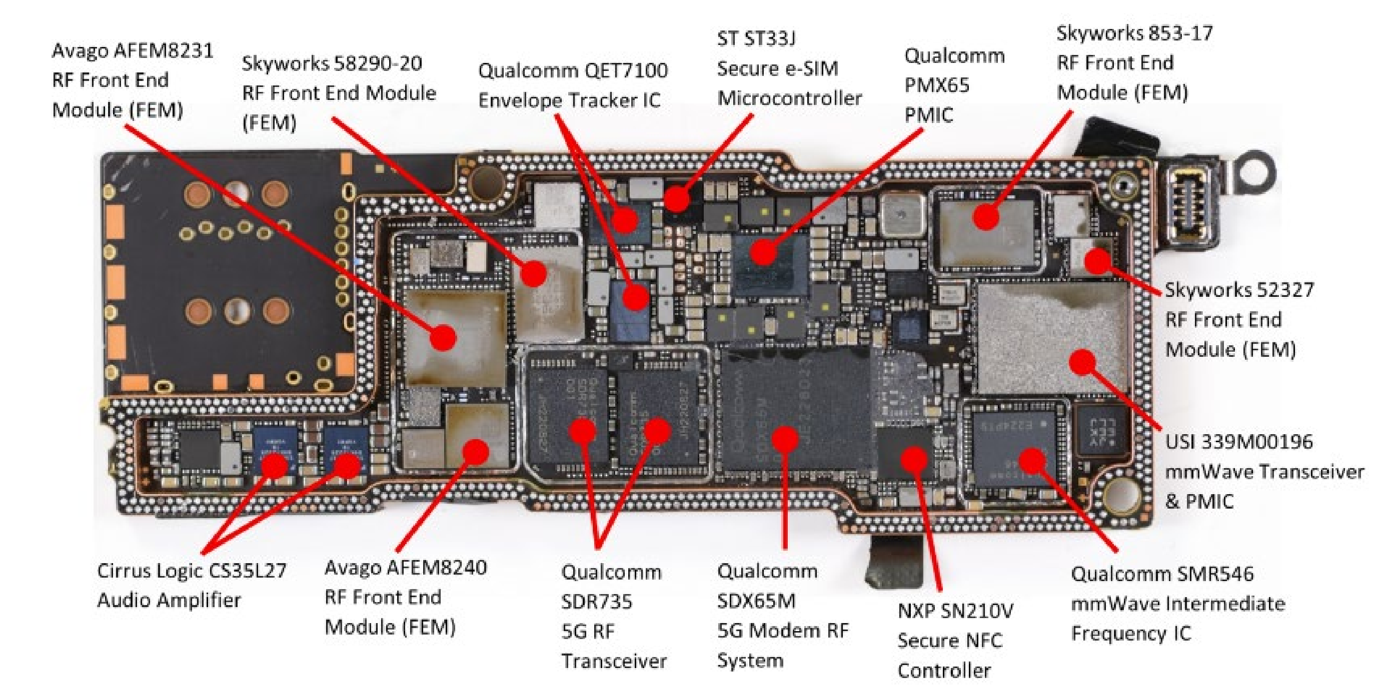
- High Speed
- Large Capacity
- Wide Spectrum
- Low Latency
- More Security



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	CAGR (2022-2028)
5G	0	31	250	550	603	706	796	894	996	1082	1116	12%
4G	1313	1276	992	770	595	495	440	396	346	292	240	-13%
3G	116	78	58	45	31	20	14	10	8	6	4	-29%

RF Front-End for Mobile 2023 | Report | www.yolegroup.com

5G mmWave in the Handset



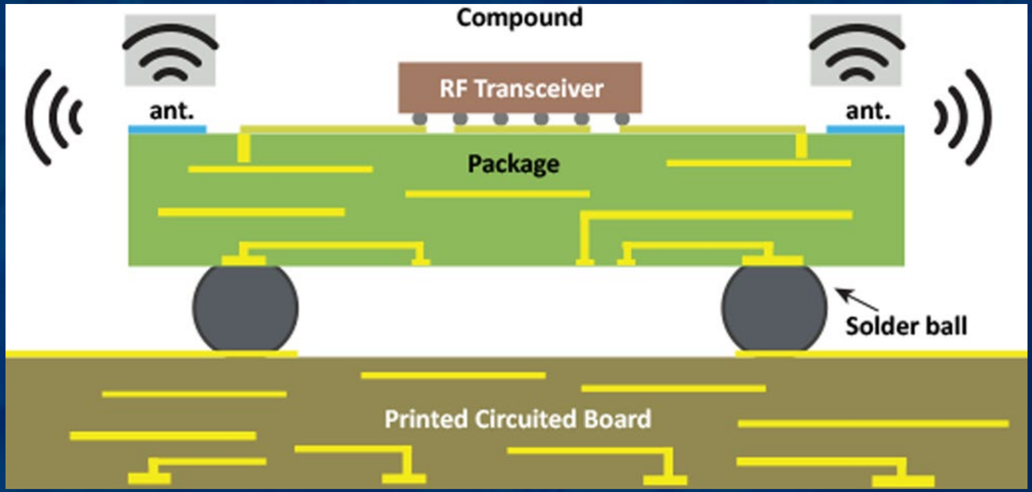
https://unitedlex.com/insights/apple-iphone-14-pro-teardown-report/

What is AiP?

- AiP (Antenna in Package) is an antenna packaging approach that implements an antenna or antennas in an IC-like package that also houses the bare RF chip transceiver.
- The AiP combination can be further integrated with front-end components such as power amplifiers (PA) or low-noise amplifiers (LNA), switches, etc.

Advantages of AiP

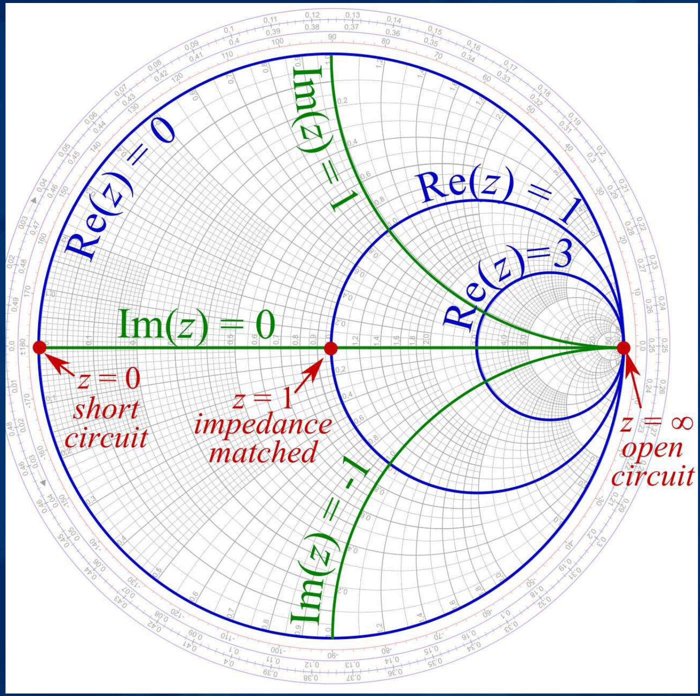
- Miniaturization of the system
- High density interconnects
- Reduction of parasitic effects
- Improved electromagnetic performance
- Design flexibility
- Applications up to 100 GHz



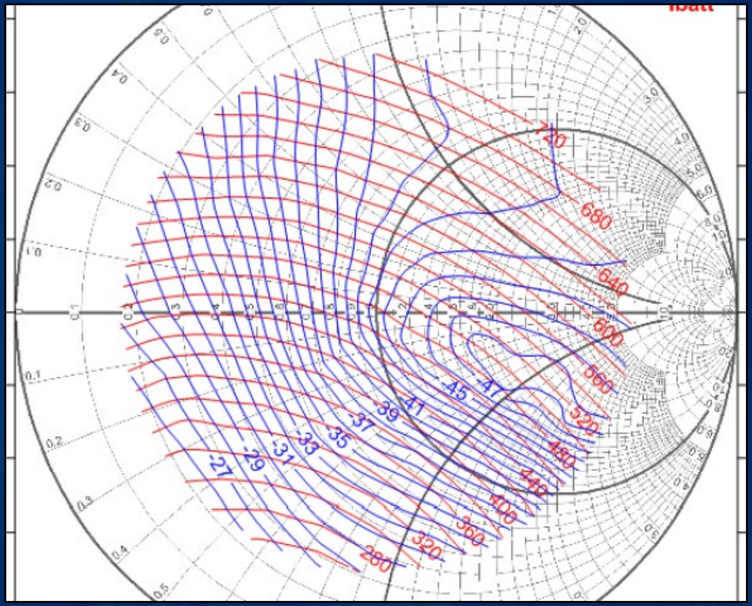
https://ase.aseglobal.com/antenna-in-package/

Challenges in Testing Antenna Drivers

- **Antenna input impedance is rarely 50Ω in the target band**
  - More optimal performance can be achieved using non 50Ω impedances
  - Varying input parameters can result in contour lines on the Smith chart
  - Matching PA (Power Amplifier) output impedance to antenna impedance minimizes reflections back into the device



Smith Chart



Typical Antenna input impedance optimization plot

Why We Need a New Test Methodology

- **Currently external circuitry is used to enable wafer-level die testing.**
  - Interfacing external circuitry to the die follows a circuitous path through multiple distinct materials
  - Transitioning between these multiple materials directly results in loss of dynamic range. This has the following detrimental consequences:
    - Increased impedance mismatch
    - Additional parasitic effects
    - Worse insertion loss
    - Reduced signal integrity
    - …
- **Takeaway: Existing methods are sub-optimal. They are:**
  - High cost (due to the need for external circuitry)
  - Have observable performance impacts resulting in loss of test precision.

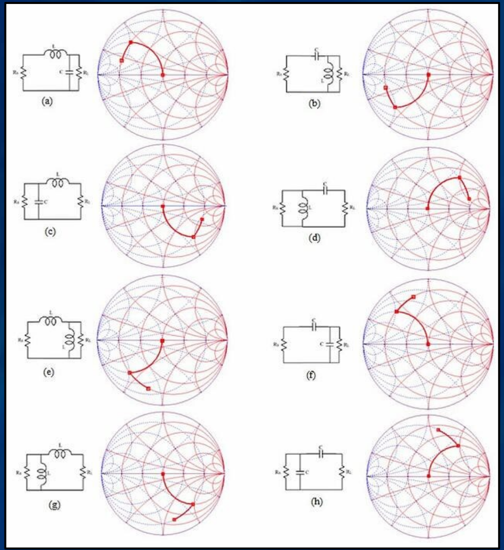
Impedance Matching

Why is Impedance Matching Important?

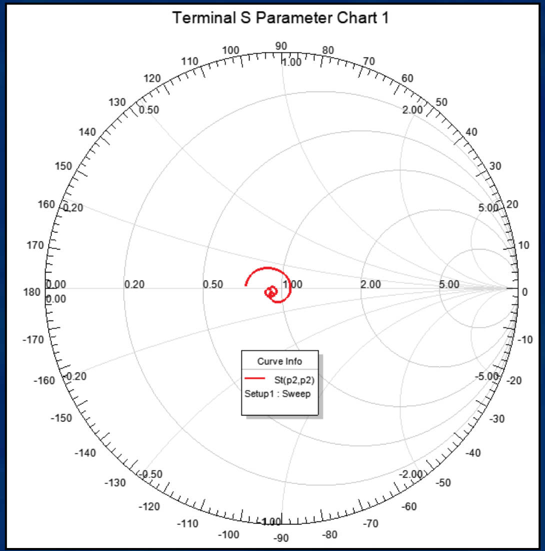
- **Impedance matching is essential to maximize the transfer of RF power or signal from the source to the load.**
- **An RF trace can be used to match two impedances between source and the load.**
- **Impedance matching can be defined in two types:**
  - Net Impedance – ($R \pm 0jX$)
  - Complex Impedance – ($R \pm jX$)
  - Where R is the resistance and X is the reactance (reactance can be capacitive or inductive).

Toward a Solution – Pyramid Probes

- **Pyramid Probe transmission lines can be matched to customer requested input impedances**
- **pProbe Unique Capabilities:**
  - Non-50Ω transmission lines
  - Complex impedance matching through discrete component networks
  - Impedance transitions in transmission lines
  - Transitions can occur very close to DUT



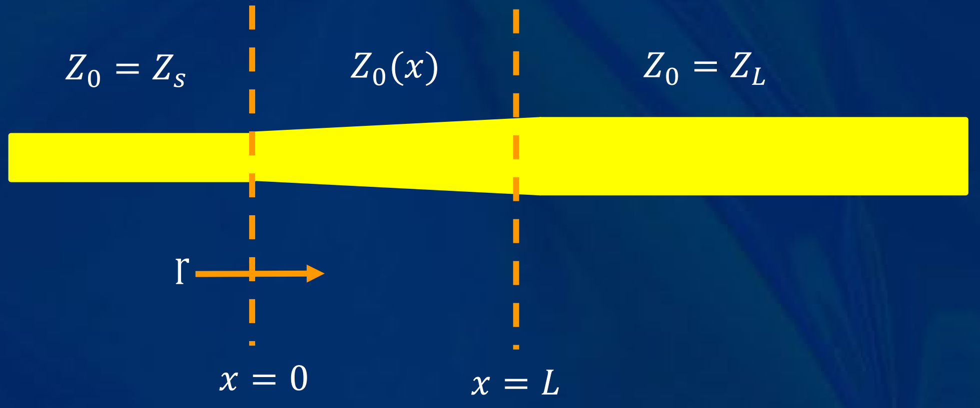
Complex impedance matching with discrete components



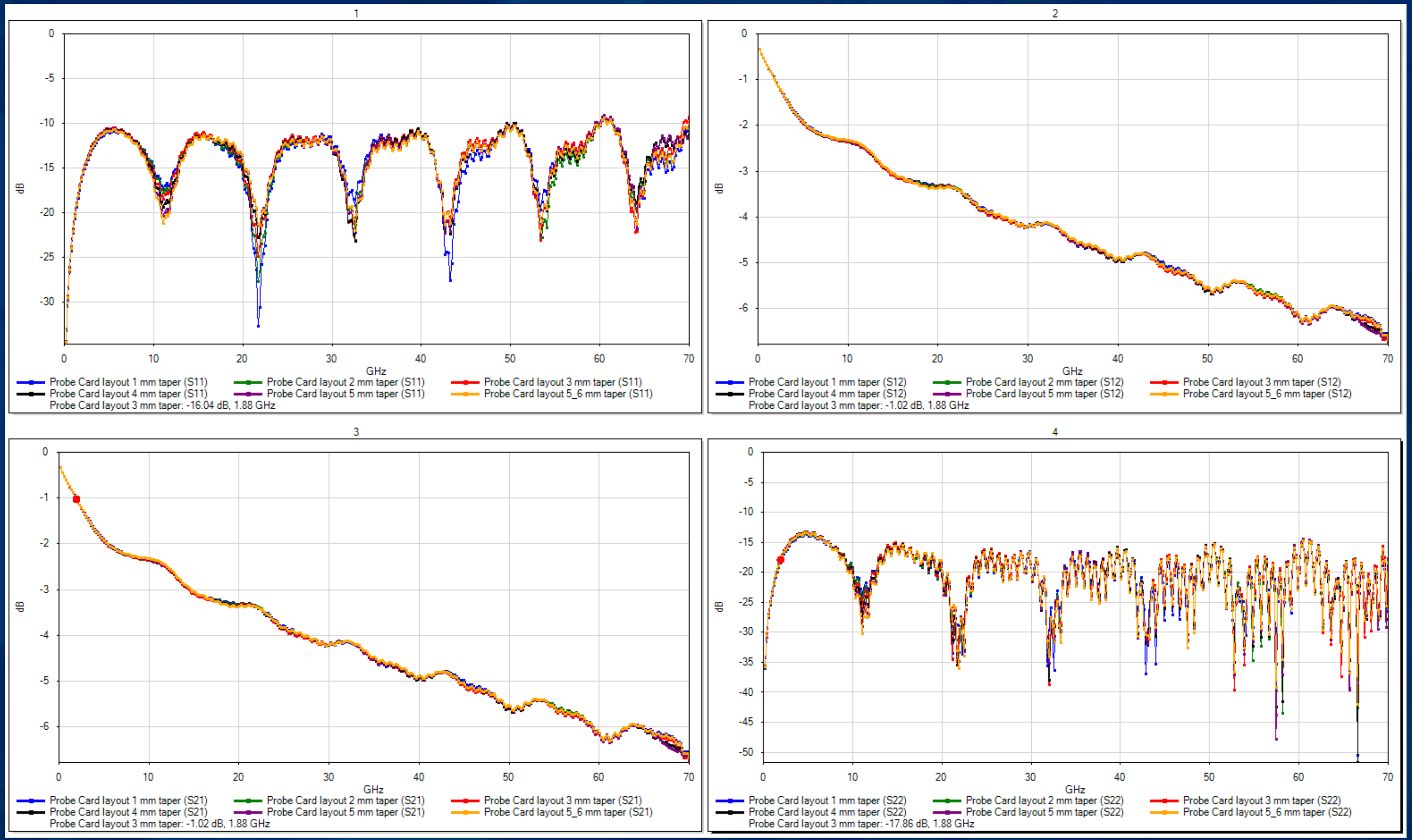
Transmission line impedance matching

Impedance Matching – Taper Approach

- **Impedance matching using a taper approach is often used for wide frequency bandwidth (0-81 GHz).**



Tapered Impedance Match



Experimental Data Results

Complex Impedance Matching

- Complex impedance (R ± jX) consists of resistance (the real part), and reactance (the imaginary part) and is responsible for the reactive power of the circuit.
- Reactance can be inductive, capacitive, or both, and is a frequency dependent parameter.

Challenges with Complex Impedance Matching

- Achieving wide bandwidth (E.g., 35-50 GHz)
- Long transmission line effects
- Challenges with passive components – Introduces parasitic effects

Complex Impedance Matching Structures

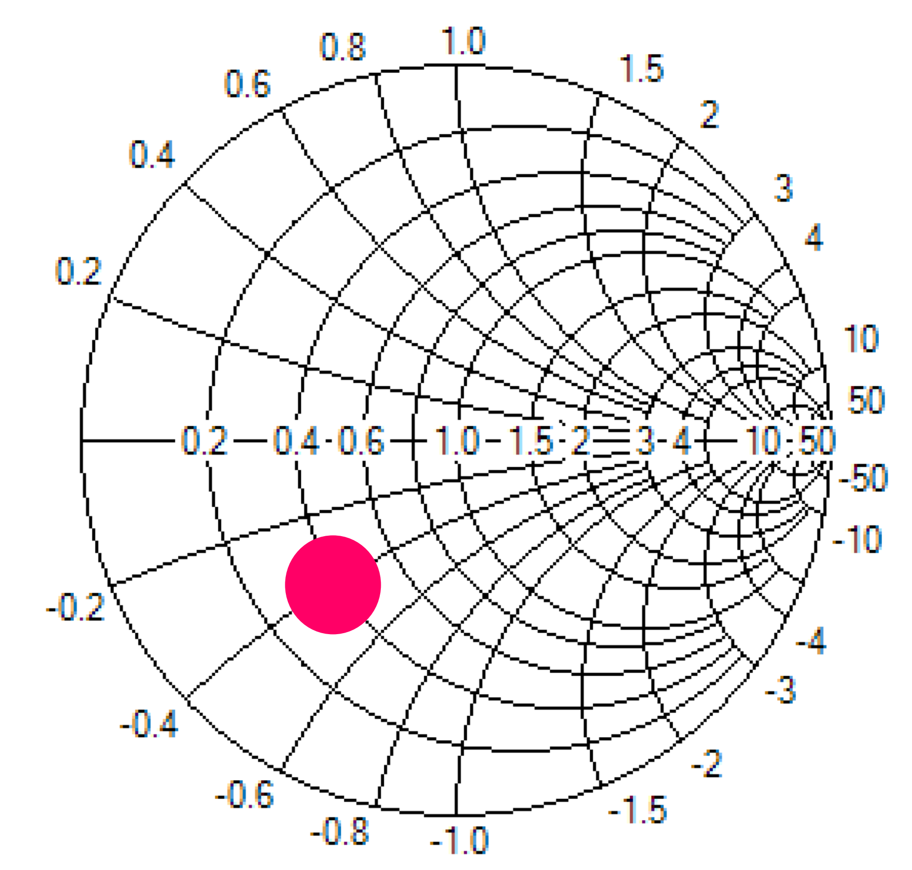
Square Capacitive Section

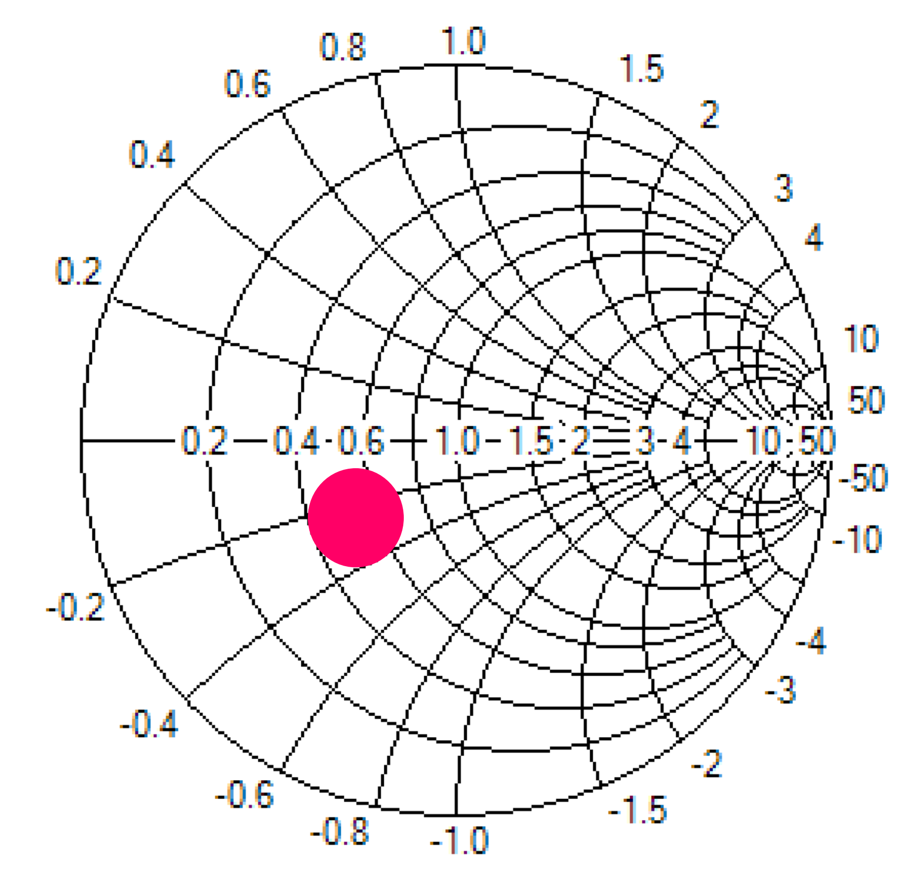
Circular Capacitive Section

Multiple Capacitive Section

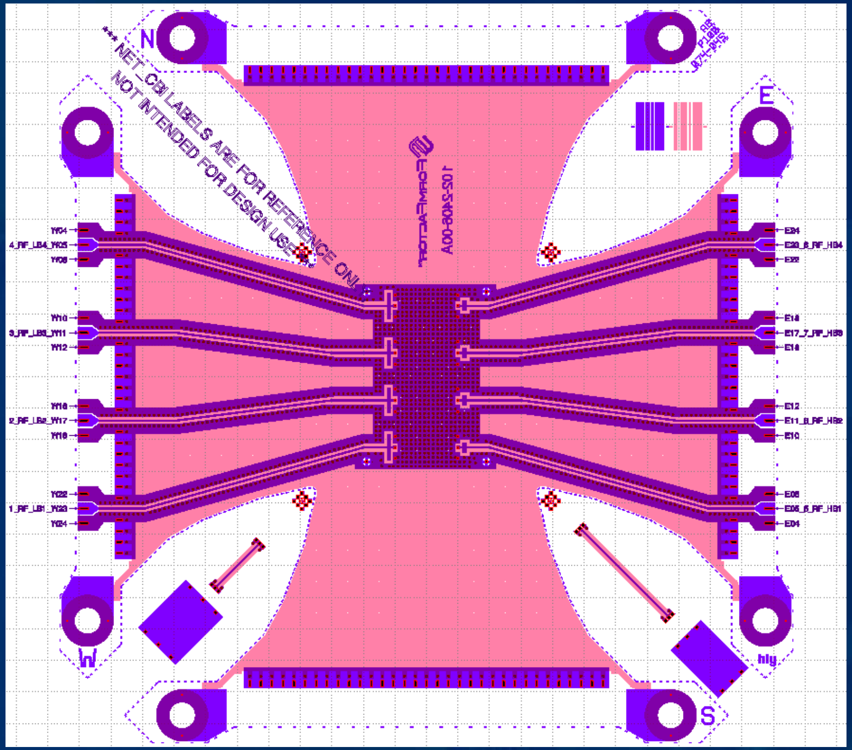
Results

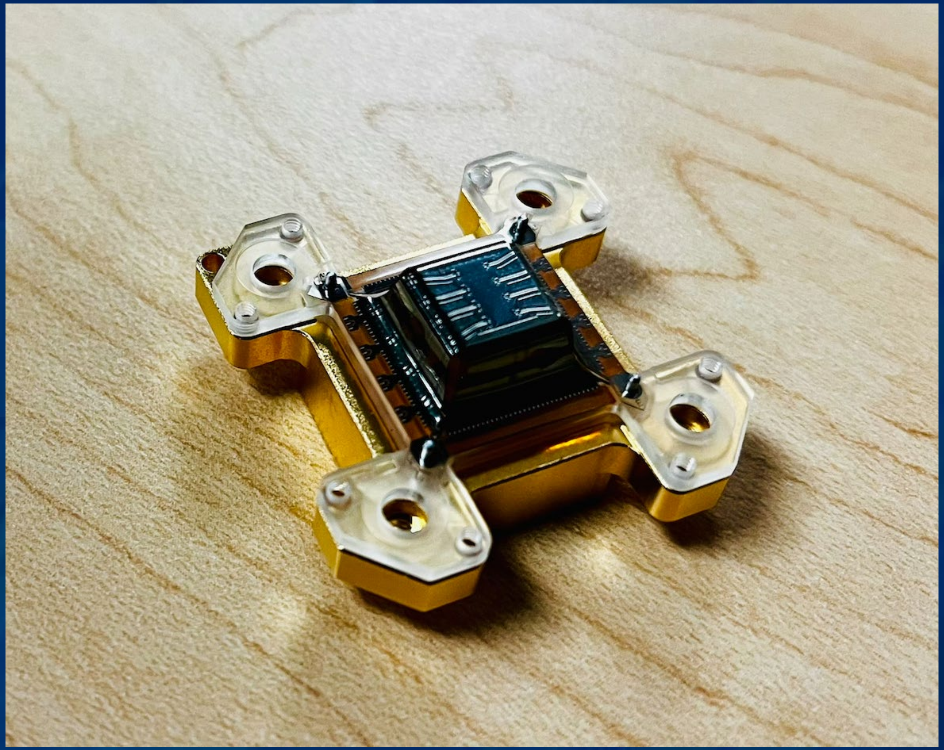
Target


0.2
0.4
0.6
0.8
1.0
1.5
2
3
4
10
50
-50
-10
-4
-3
-2
-1.5
-1.0
-0.8
-0.6
-0.4
-0.2


0.2
0.4
0.6
0.8
1.0
1.5
2
3
4
10
50
-50
-10
-4
-3
-2
-1.5
-1.0
-0.8
-0.6
-0.4
-0.2

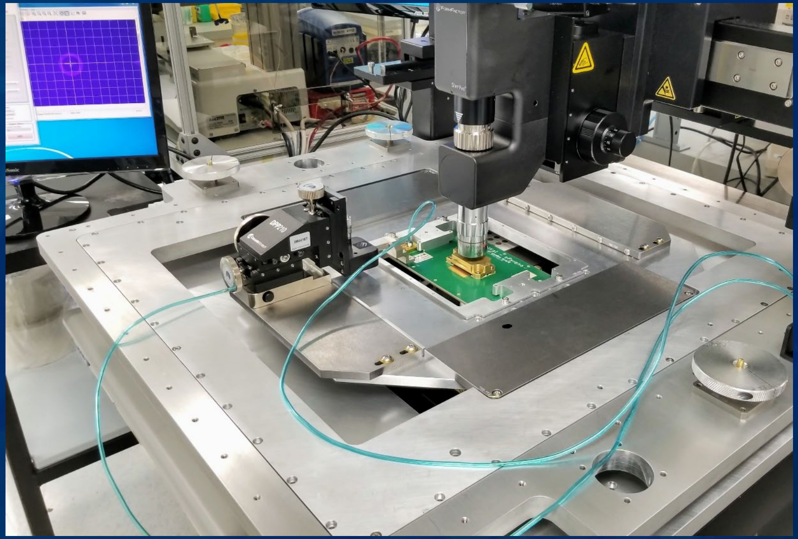
Design

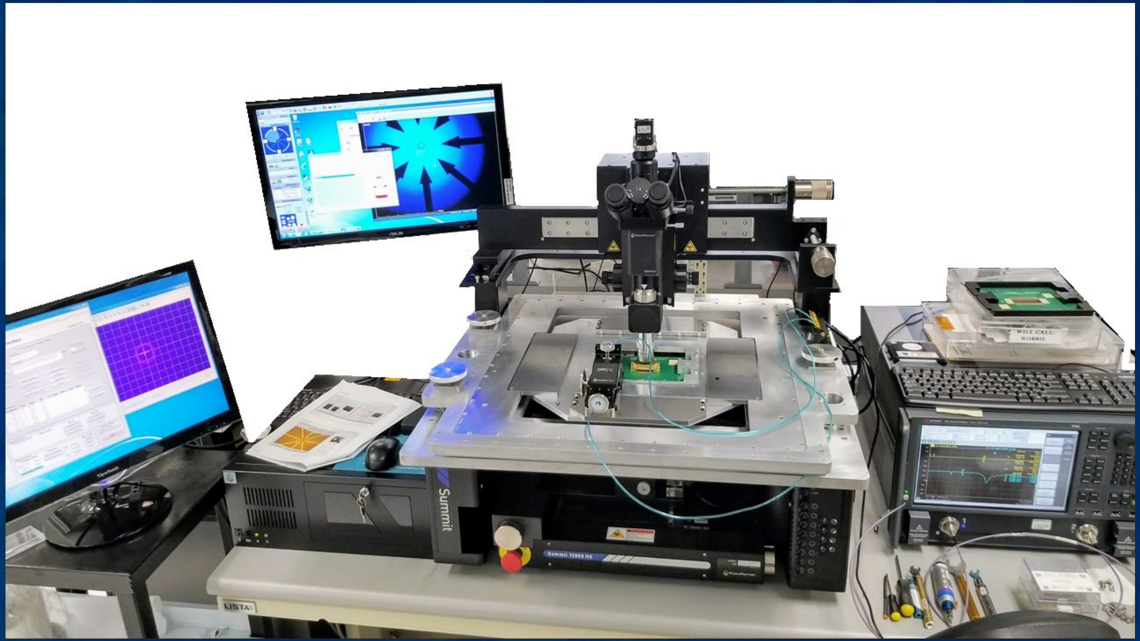

N
E
S
NET_CB LABELS ARE FOR REFERENCE ONLY
NOT INTENDED FOR DESIGN USE



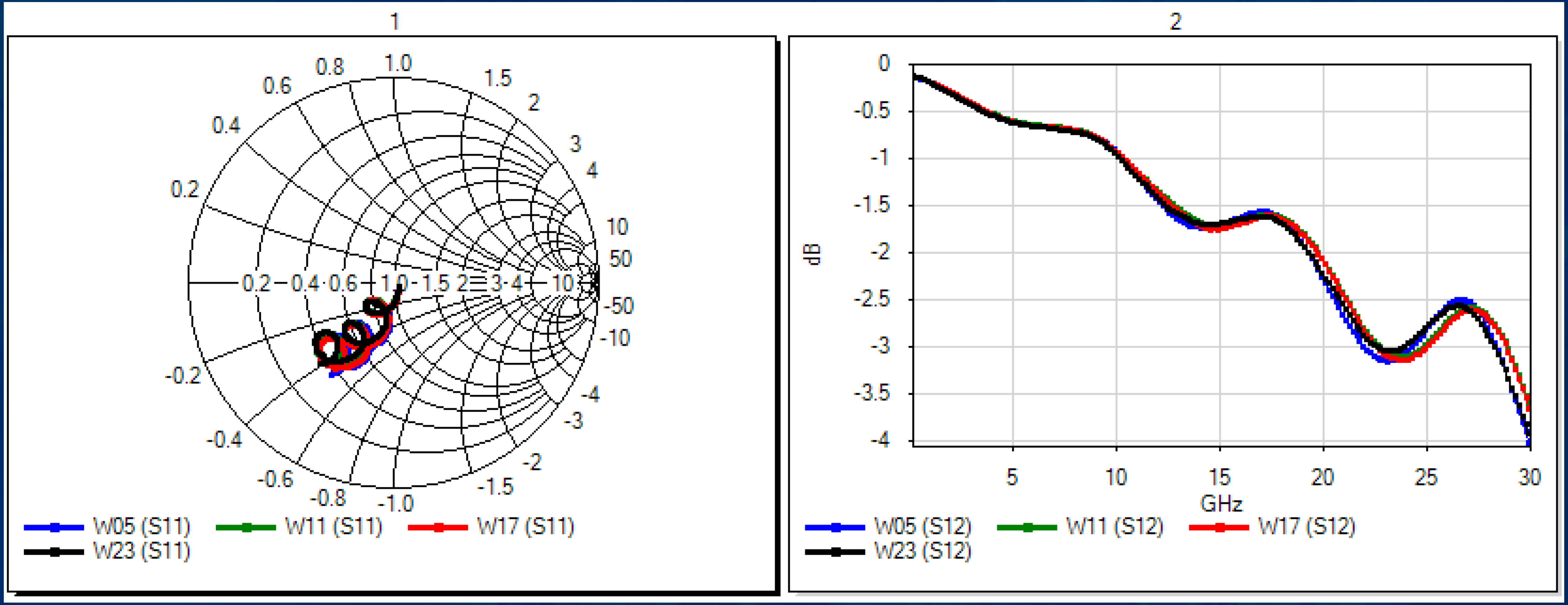
Test Setup

- **FFI Summit 12000 semi-auto station**
- **Keysight PNA with 4-port capability**
  - 50 MHz – 67 GHz
  - 201 points
- **Use the Keysight eCal for cable calibration**
- **Use eLRRM for Probe Calibration**
- **ISS: 106-682-00**
- **Core: RFC**



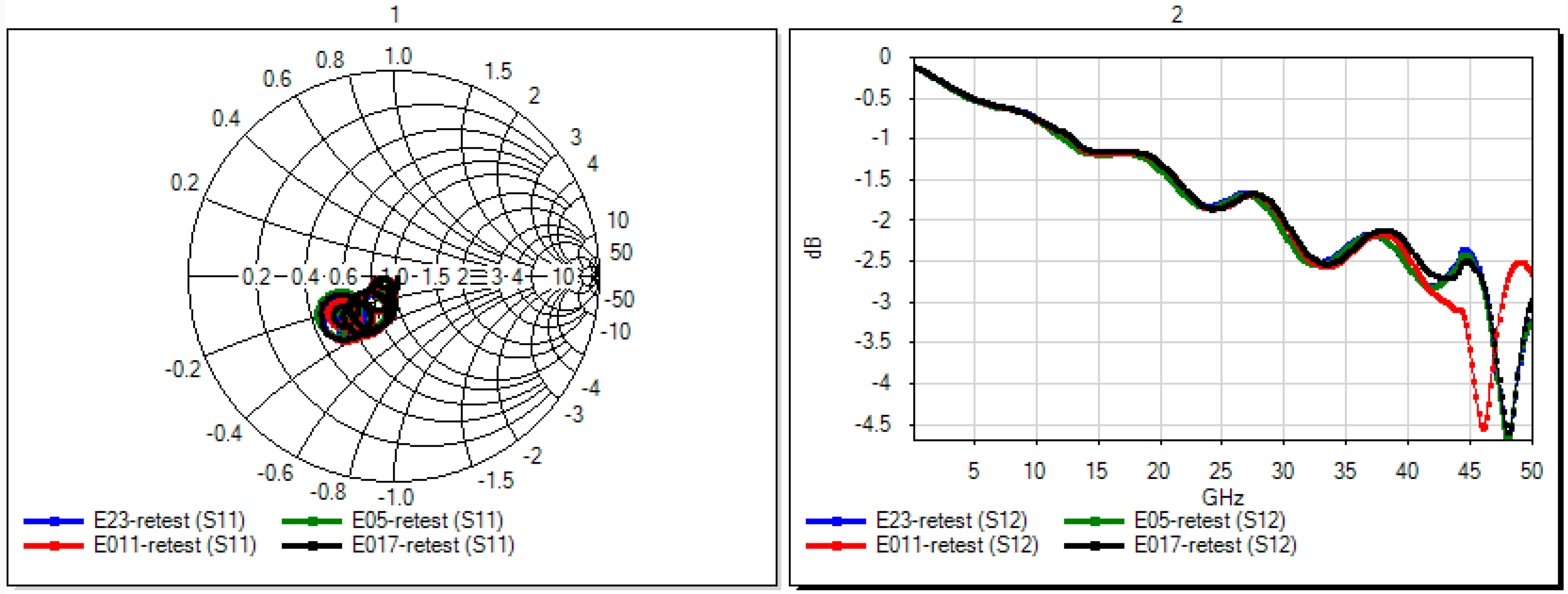


Measurement Results – Low Band



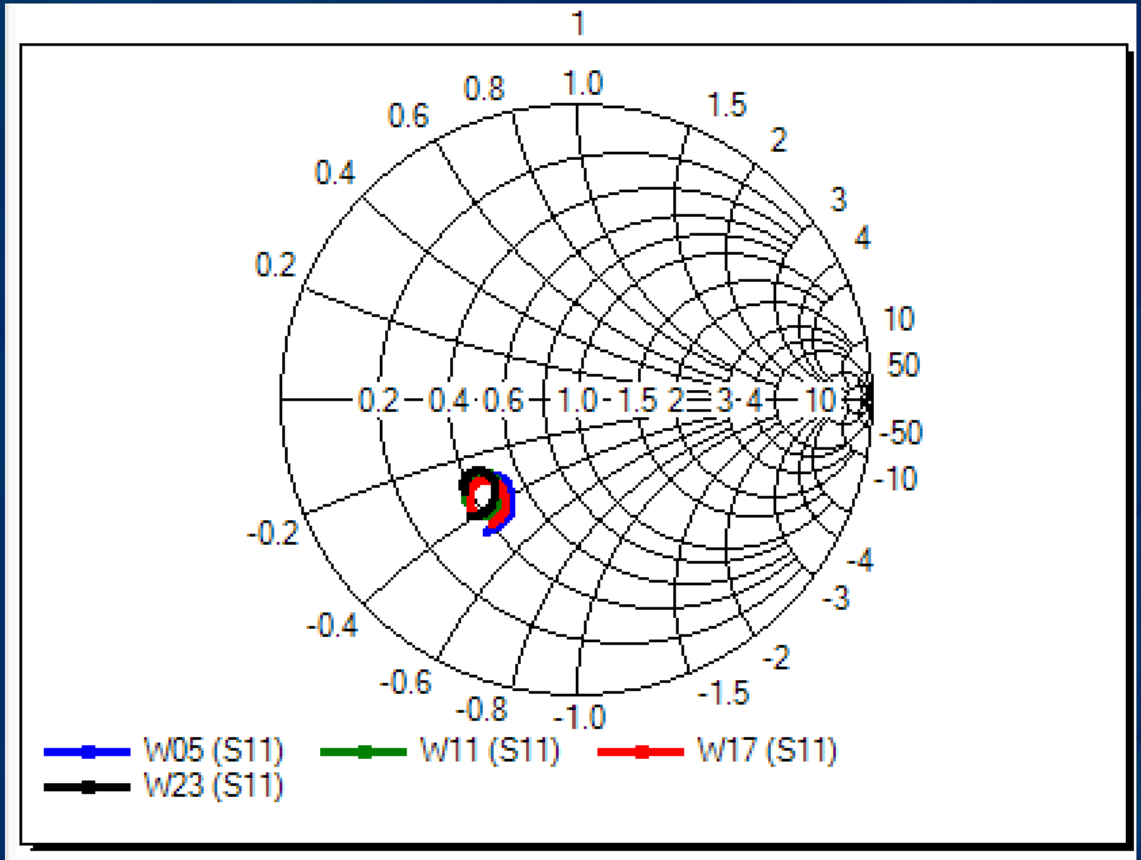
0.167 GHz to 30 GHz

Measurement Results – High Band

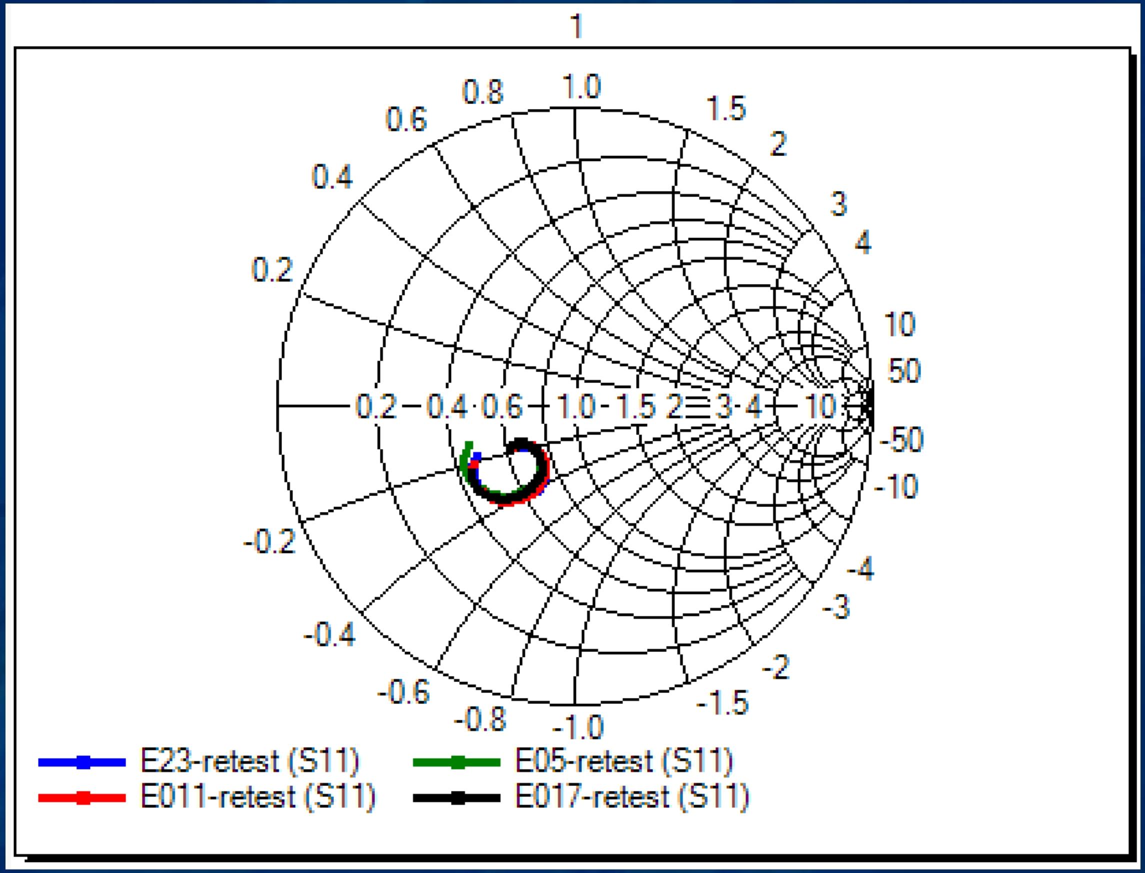


0.167 GHz to 50 GHz

Post-Processing



LB (24 – 30 GHz)



HB (36 – 44 GHz)

Conclusion

- **We have proven that with Pyramid probes complex impedance matching is possible.**
- **This offers significant benefits including:**
  - Eliminating the use of external circuitry
  - High-performance efficiency
  - Cost reductions

Questions?