SWTEST
PROBE TODAY, FOR TOMORROW
2025 CONFERENCE

Broadband Attenuators using Thin Film for Wafer Sort

FormFactor™

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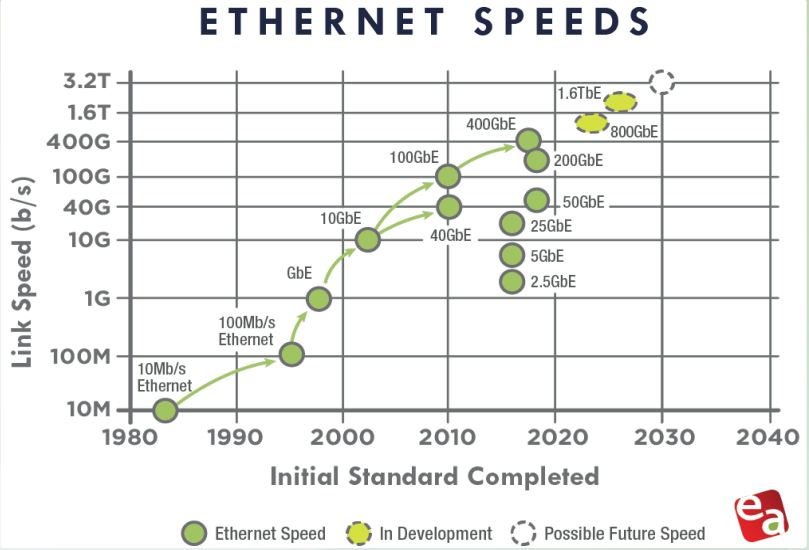
Agenda

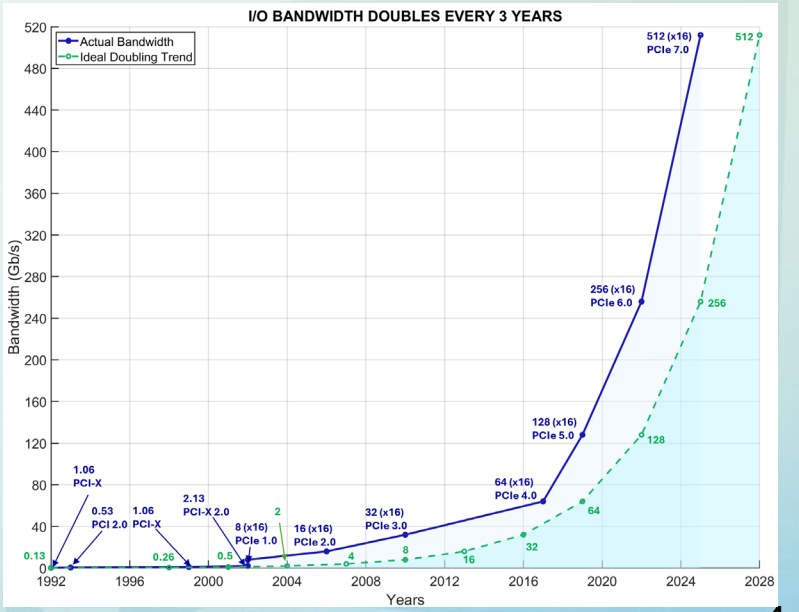
- Market Drivers
- Attenuators
- Design and Test Setup
- Results
- Future Work

Market Drivers

AI Applications Driving High Data Rates

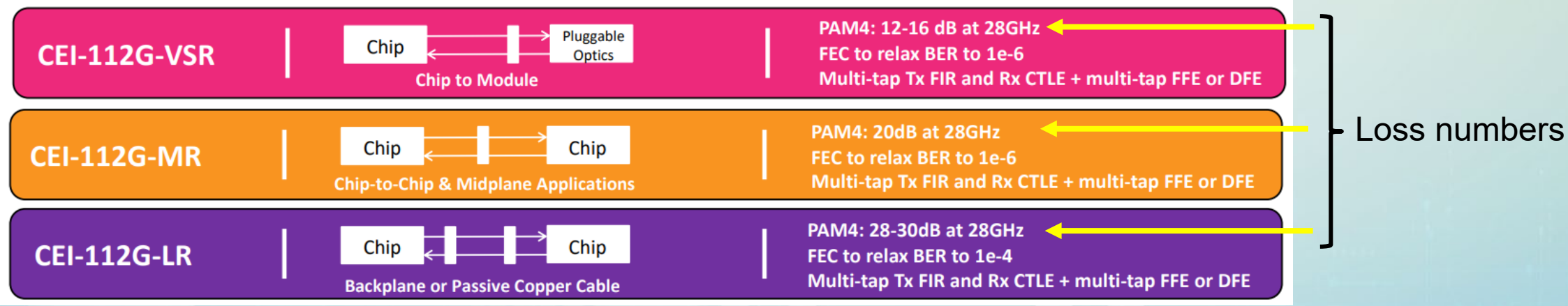
- The rise of cloud computing and AI has significantly increased the demand for high-speed SerDes (Serializer/Deserializer) chips utilizing PAM4 (Pulse Amplitude Modulation 4-level) signaling
- Real-time AI applications like autonomous driving, real time analytics, robotics etc. require sub-millisecond latency
- Data centers rely on high-speed digital communication systems, doubling bandwidth every 3 years to keep up with AI needs
- To meet these needs, development efforts are focused on moving to 448Gbps, where 224Gbps is now being deployed





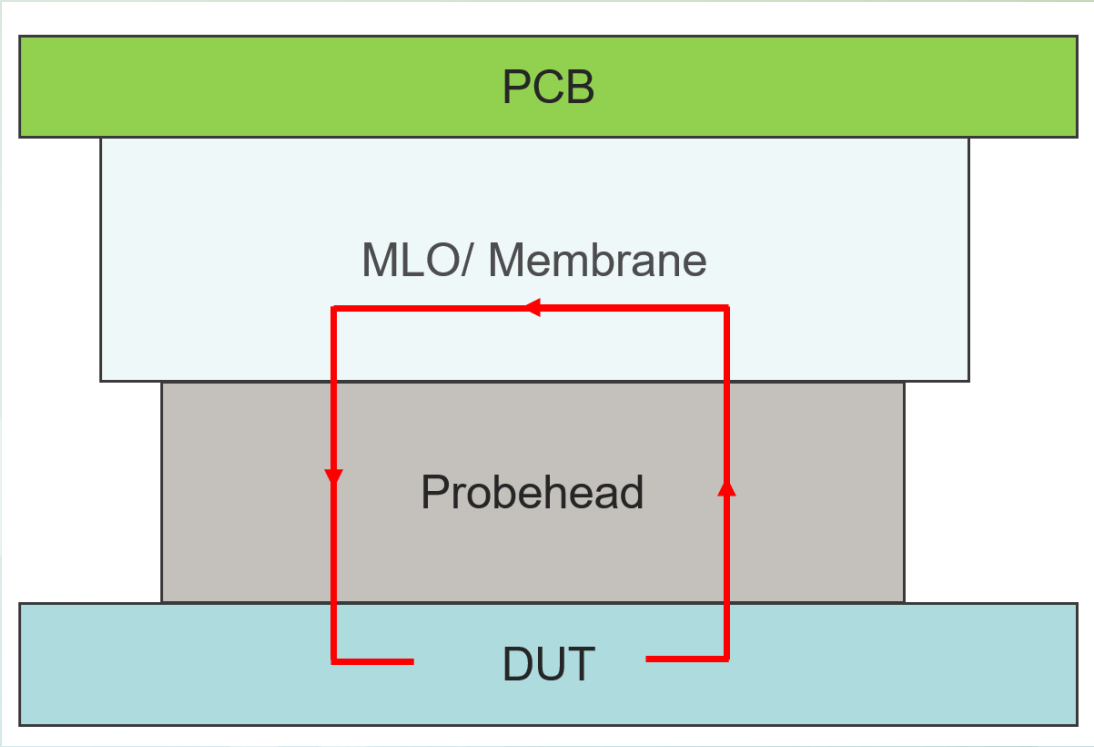
End Module Impacts Loss

- To enable next generation data rates, it is necessary to address the interoperability requirements as defined in the communication standards
- In particular, we need to emulate the loss numbers at wafer sort to get highest possible performance to ensure correctly identifying good and bad die
- Different applications have different module types leading to different loss numbers and require different equalization techniques



Adding Loss at Wafer Sort

- Receivers for high-speed digital applications like SERDES and PCIe Gen 7 receive highly attenuated signals due to long transmission paths
- In wafer sort loopback testing, signal paths are short and have minimum attenuation (signal loss), as compared to a real communication channel
- Adding attenuators in the probe card is essential to prevent signal clipping and non-linear distortion

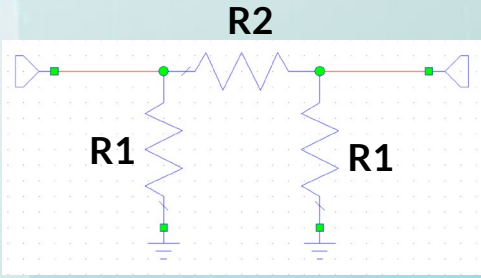


Matching Module Loss

- How can loss be added at wafer sort?
  - Connectorized attenuators ✘
    - Only matched to 50 ohms
    - Too large to fit more than a few on the PCB
    - Requires complex routing to get signals out of the PCB/MLO
  - SMT Attenuators ✘
    - Only matched to 50 ohms
    - Single-Ended format only
    - Long lead times
  - Custom Attenuation Network ✓
    - Can match any impedance
    - Can be design for single and differential mode
    - Short lead times for off-the-shelf components

Connectorized Attenuator

SMT Attenuator

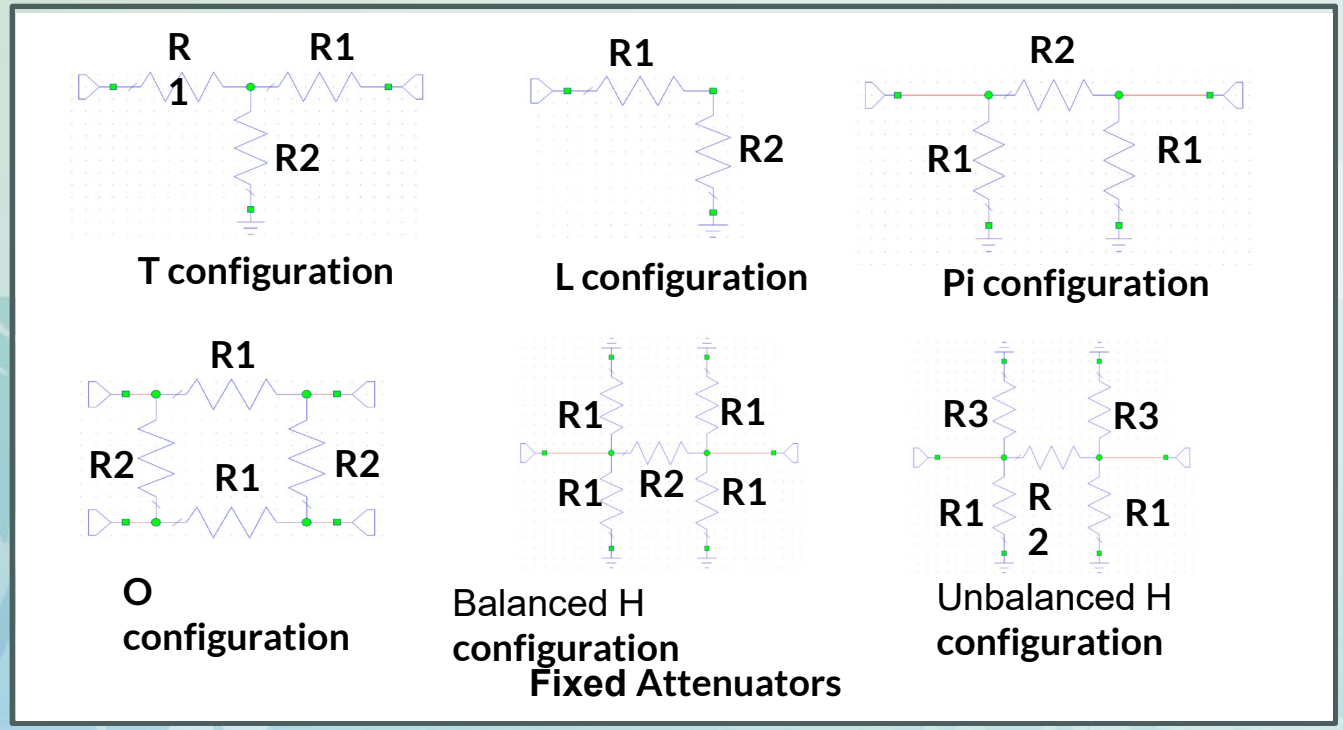


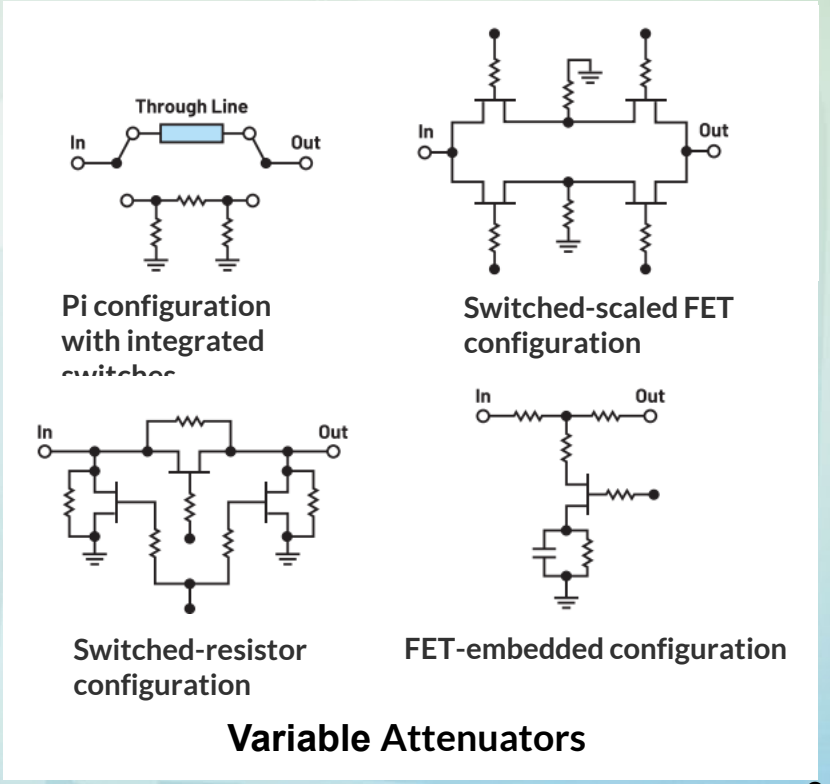
Pi-Attenuator

Attenuators

Attenuators

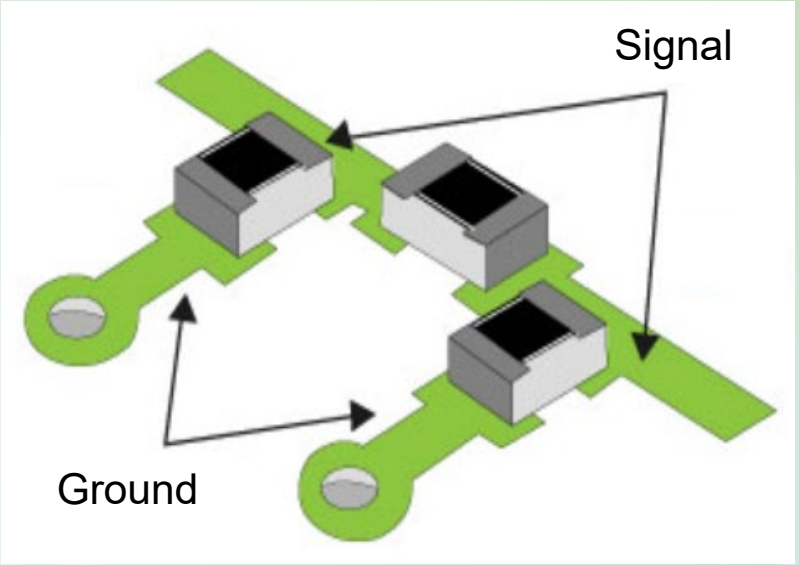
- What are Attenuators?
  - Passive components that reduce signal power without distorting waveform
  - Available in fixed or variable types
  - Characterized by attenuation value (e.g., 10 dB, 12 dB, 15 dB)





Disadvantages of Existing Methodology

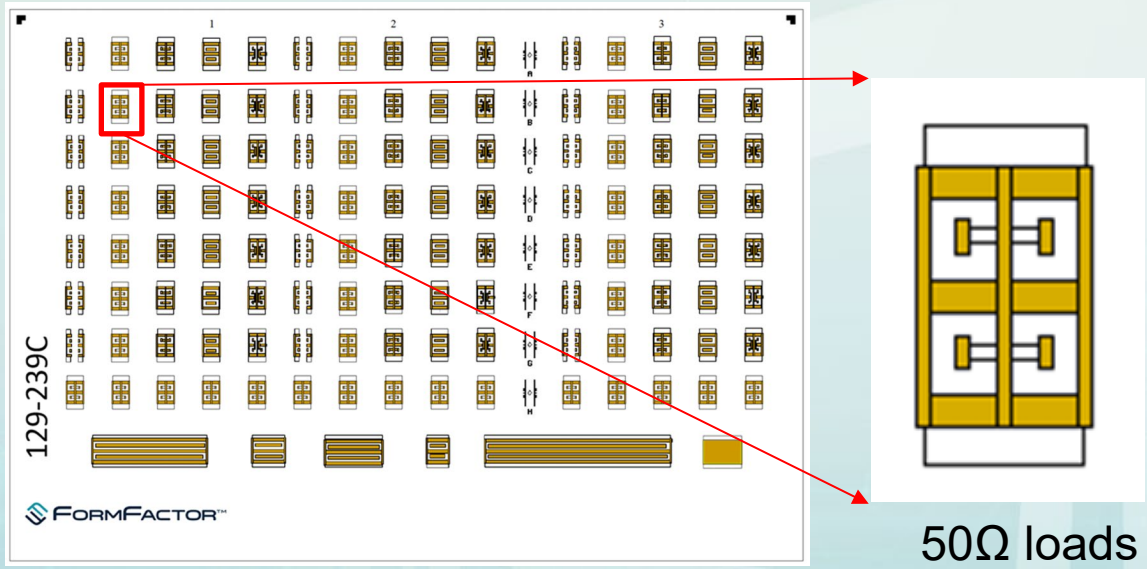
- Limited to narrowband
  - Not a compact footprint
  - Poor control on EM parasitics
- Harder to replace individual components
- Attenuation depends on available value of surface mount resistors
- Active circuits require tuning to achieve broadband attenuation resulting
  - Complex circuitry
  - Manufacturing challenges
  - Yield loss
  - High cost



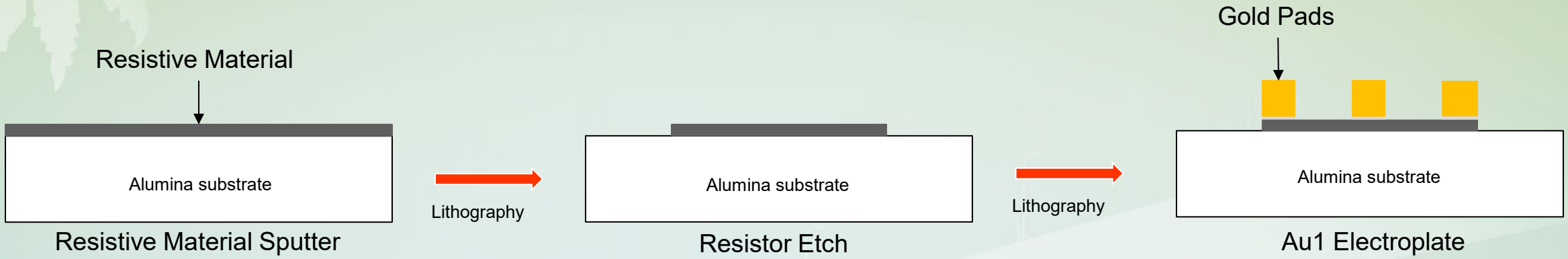
SMT components

Why Thin Films?

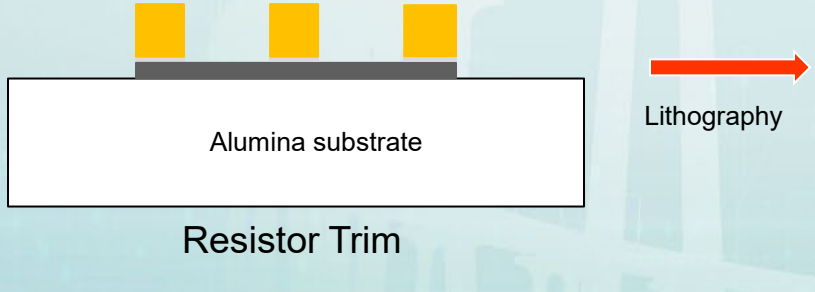
- FFI make resistors on calibrations substrates, with bandwidths capable >110GHz
- Process is tightly controlled to achieve desired resistance values
- We decided to use the same process to make attenuators
- We can design for non 50Ω load values, for single and differential configuration

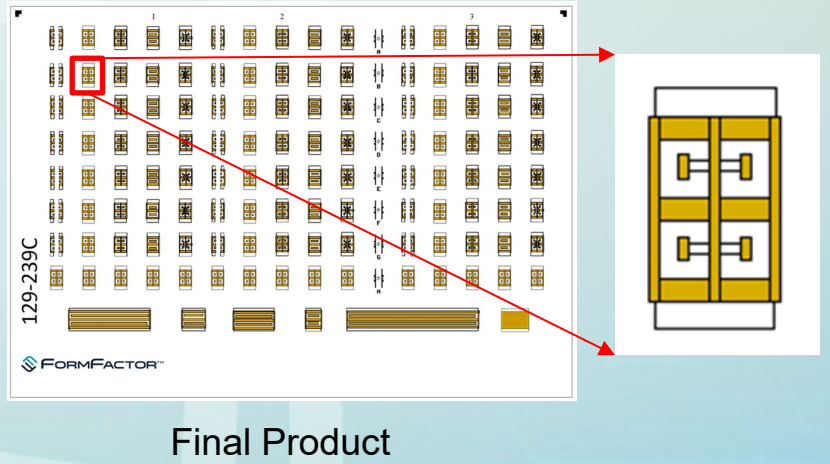


Thin Film Resistors



$$R_{Load} = R_S * (Length/Width)$$





Design and Test Setup

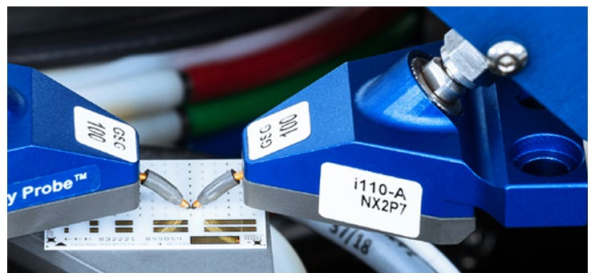
Calibration Strategy

VNA

Coaxial Cable

Coax Calibration

E-Probe

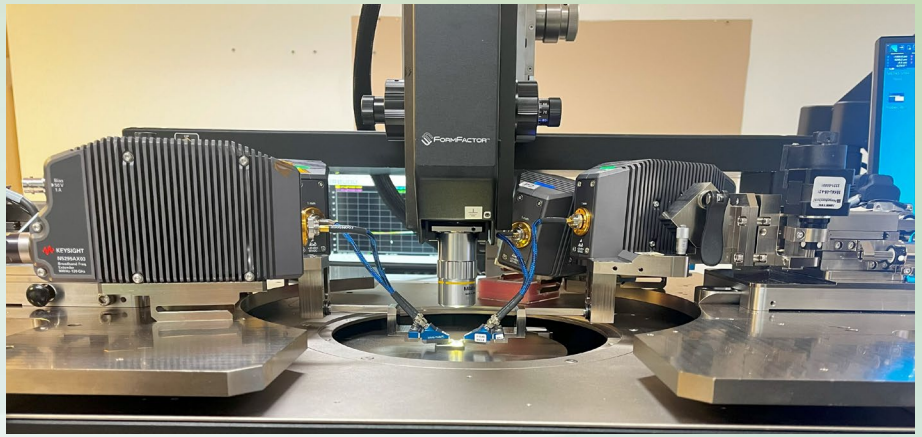


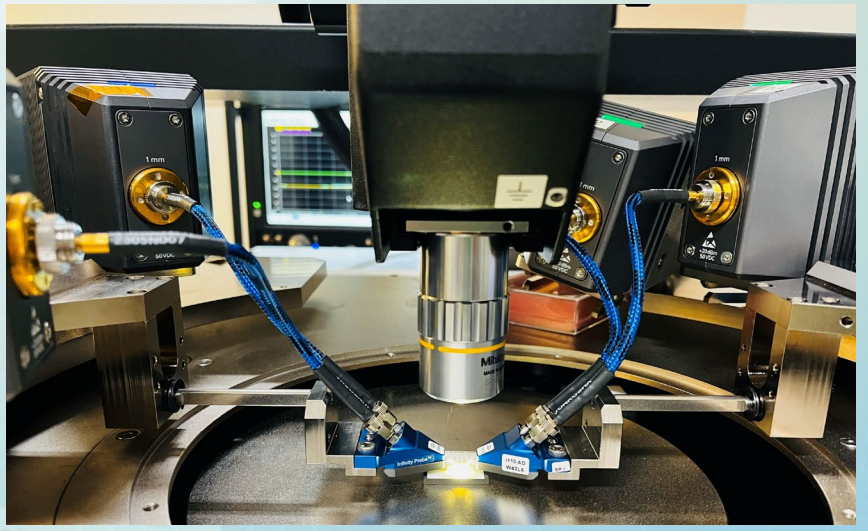
2nd Tier on Cal Sub

Wafer/ DUT Measurements

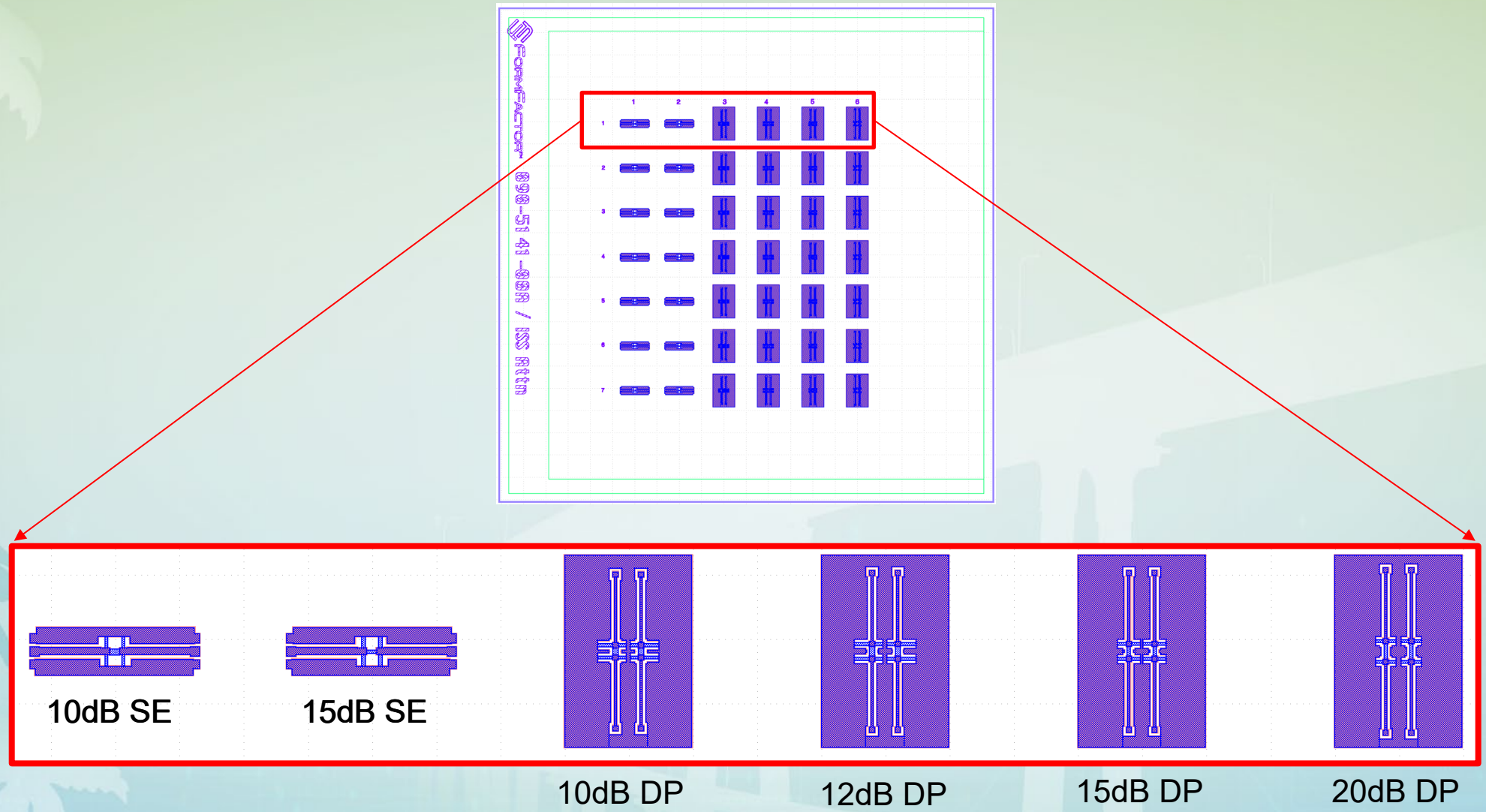
Experimental Setup

- FFI Summit 12000 semi-auto station
  - I110-D-GSGSG-100
  - I110-GSG-100
- Keysight PNA with mmWave test set and 4-port capability
  - 50 MHz – 110 GHz
  - 50 MHz steps (11000 Points)
- Keysight Mechanical Calibration Module
- Calibration Substrate - 2nd Tier
  - 129-239C– Differential (GSGSG) - 100um- 125um
  - 138-357 – Single (GSG) - 100um- 125um



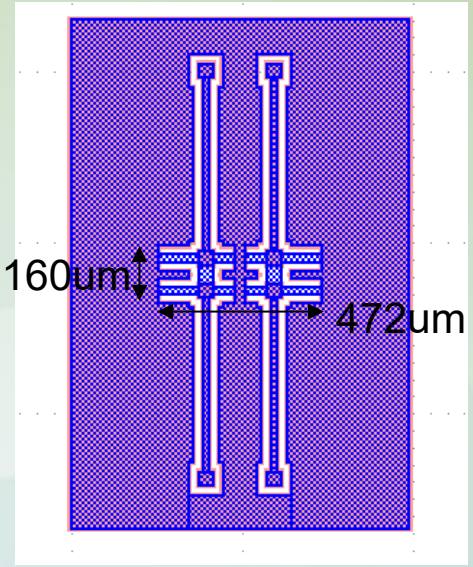


H–Attenuator Design

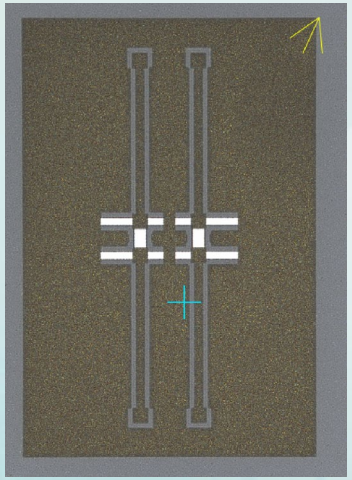


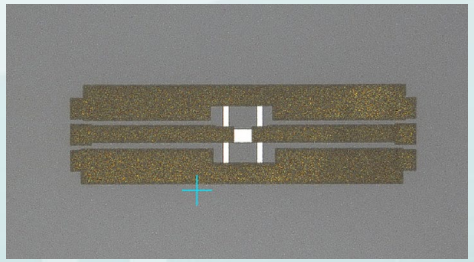
Why H Attenuators?

- Stable broadband performance
- Suitable for single and differential configurations
- Better EM parasitics
- Tolerant to process variations
- Better thermal distribution



10dB DP

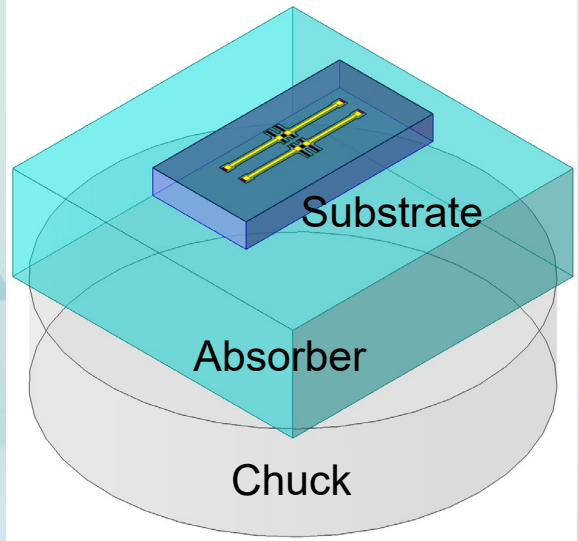

10dB DP

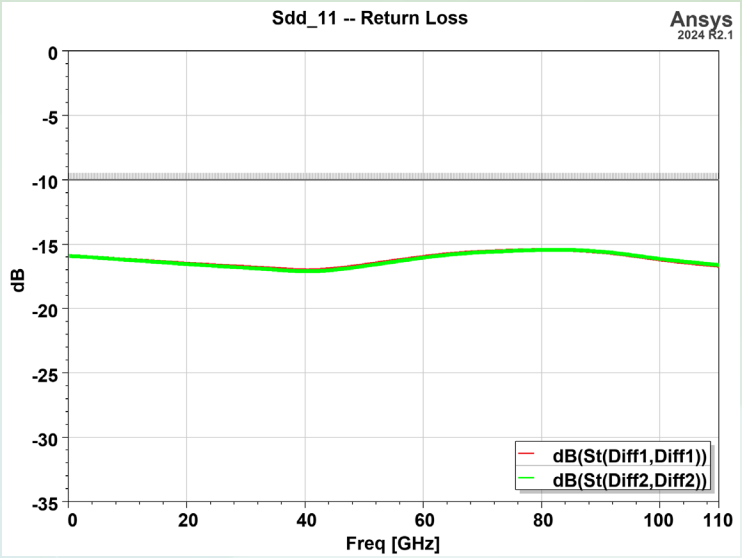

10dB SE

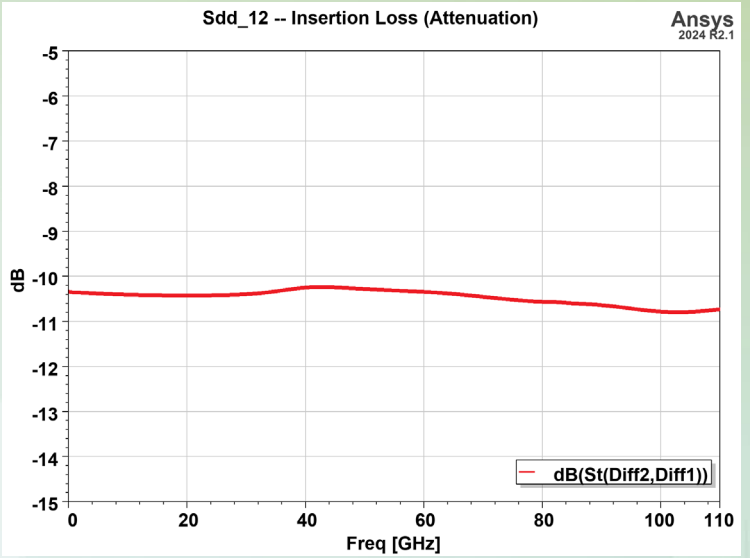
Results

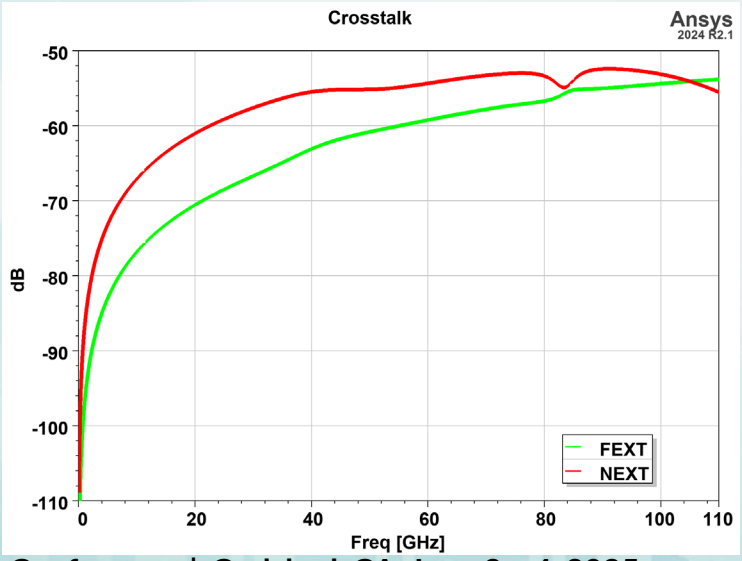
Simulation Results

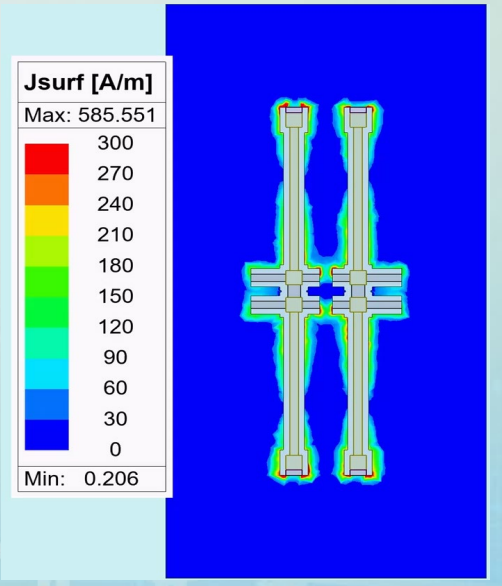
- Ansys HFSS 2024 R1
- Over Simulated performance
  - RL <-15dB till 110GHz
  - IL – Variations less than ±0.5dB
  - Crosstalk – Better than 50dB





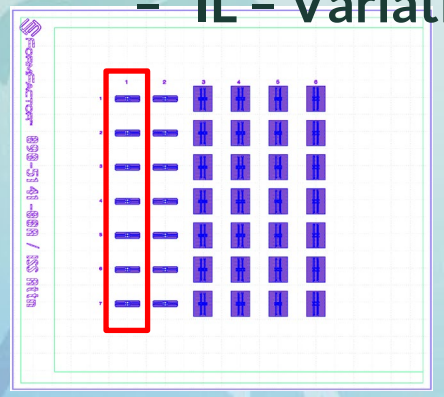


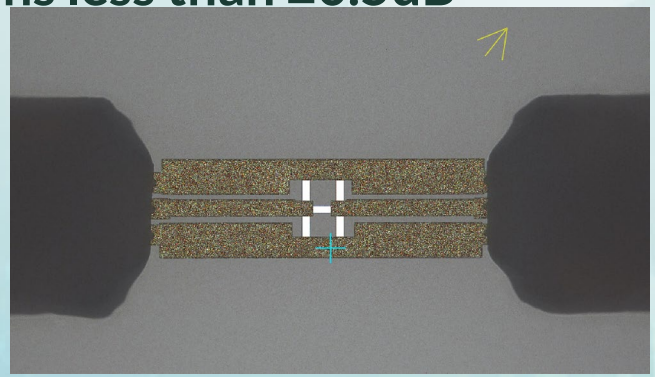


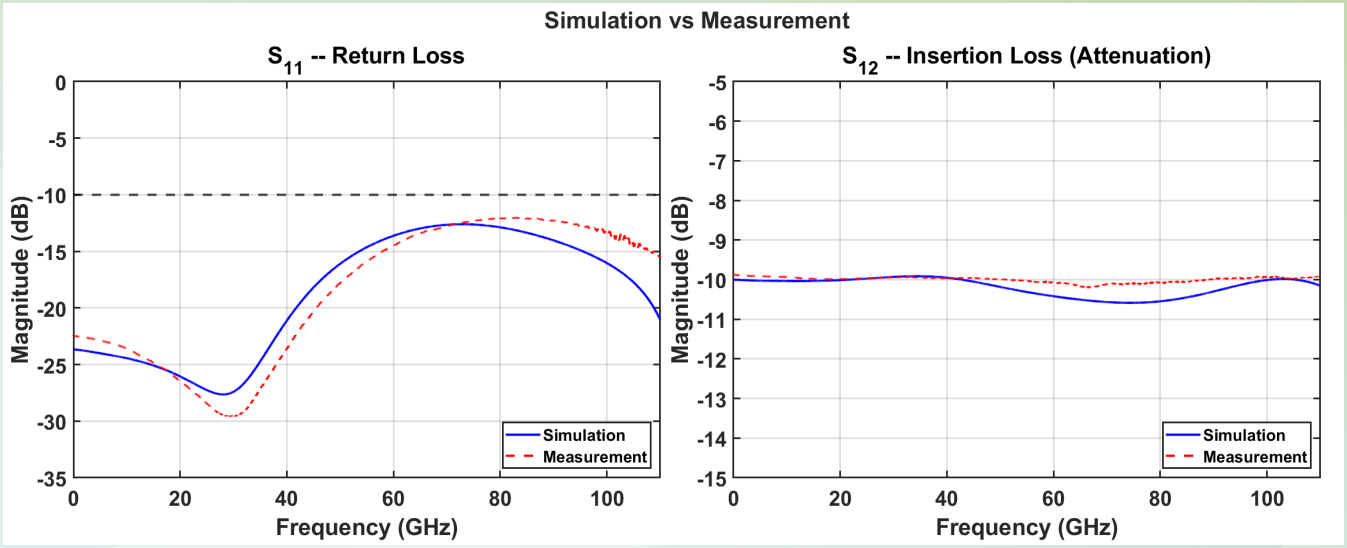


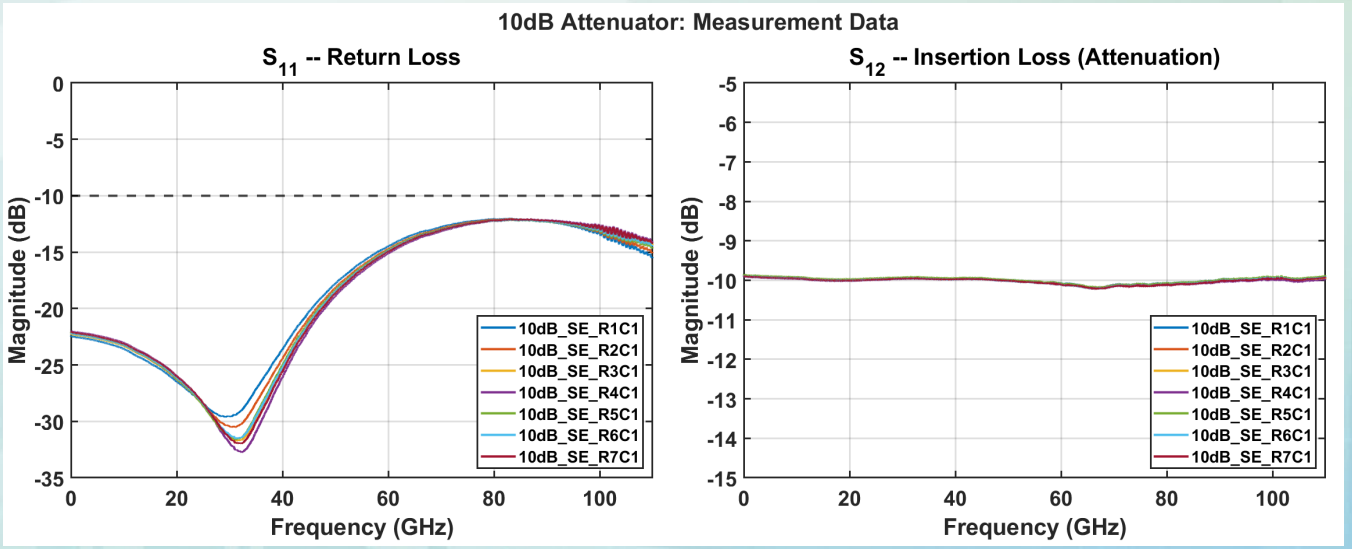
10dB Single Ended

- Measured data matches very closely with 3D EM simulations.
- Some RL difference >70GHz between measurement and simulations, but follow similar trend
- Over measured performance
  - RL <-12dB till 110GHz
  - IL – Variations less than ±0.5dB



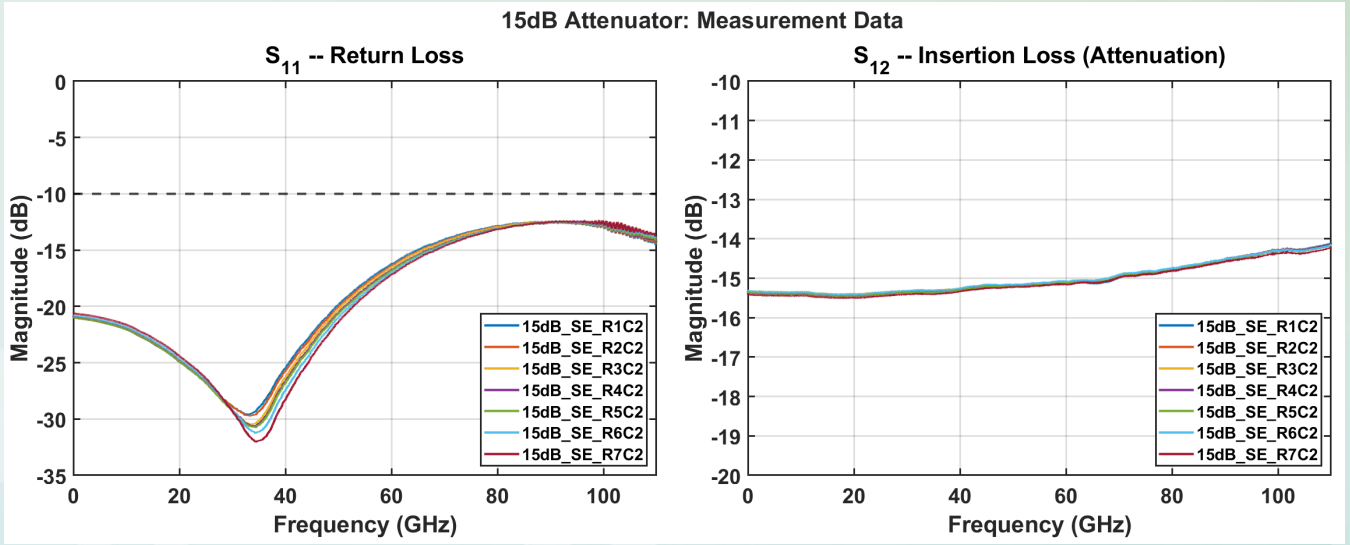


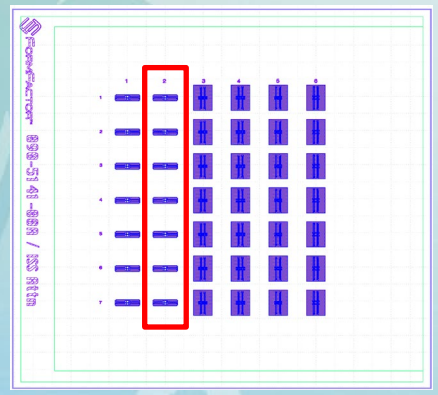




15dB Single Ended

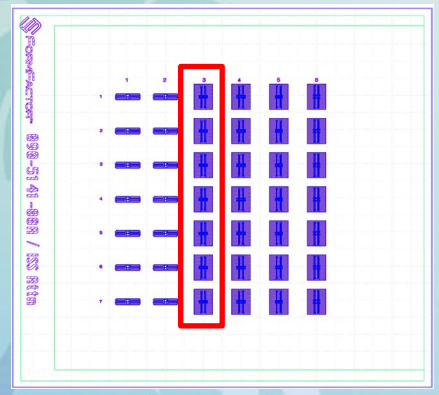
- Measured attenuation values matches very closely with 3D EM simulations.
- Over measured performance
  - RL <-12dB till 110GHz
  - IL – Variations less than ±0.5dB

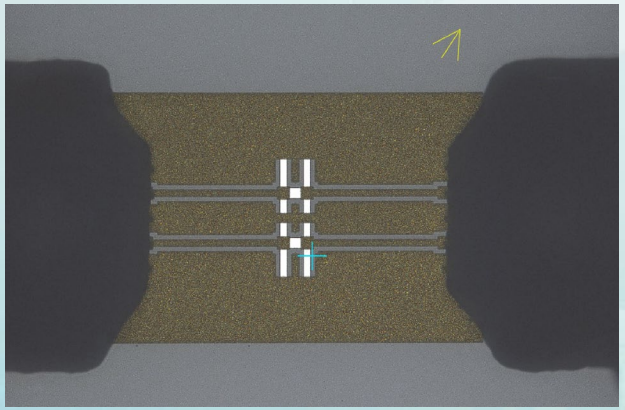


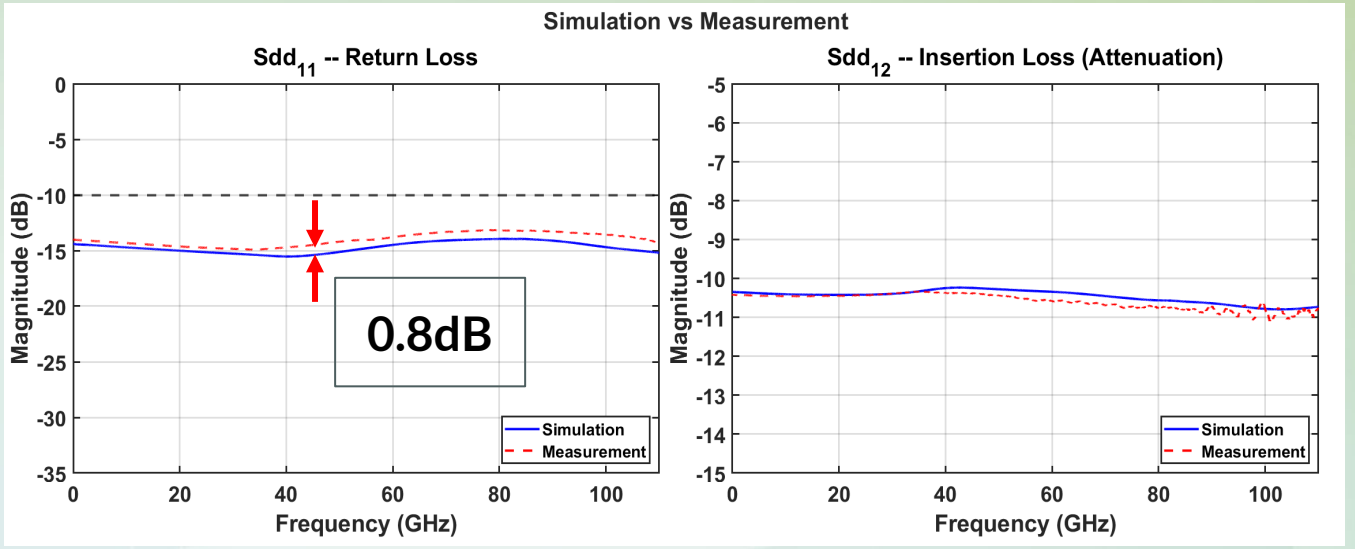


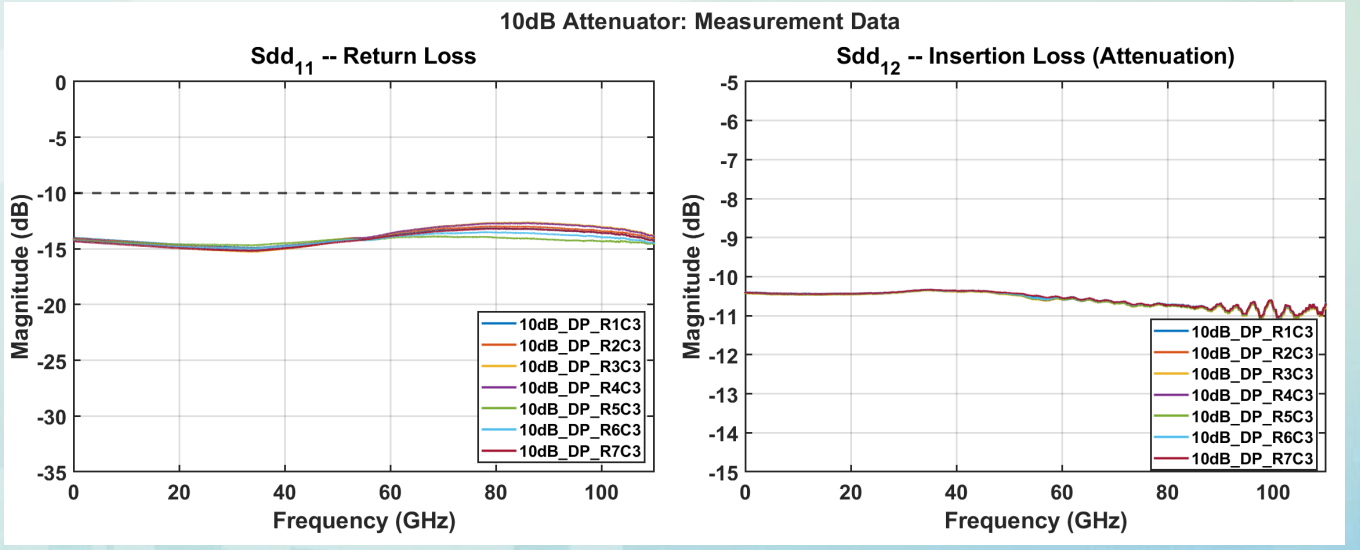
10dB Differential Pair

- Measured data matches very closely with 3D EM simulations.
- Over measured performance
  - RL <-12dB till 110GHz
  - IL – Variations less than ±0.5dB



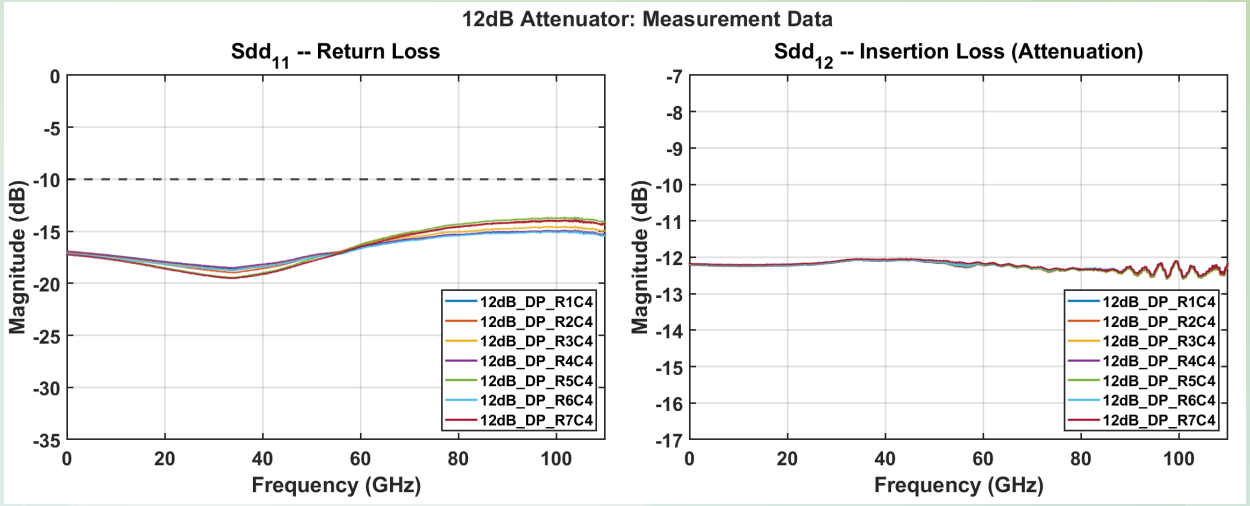


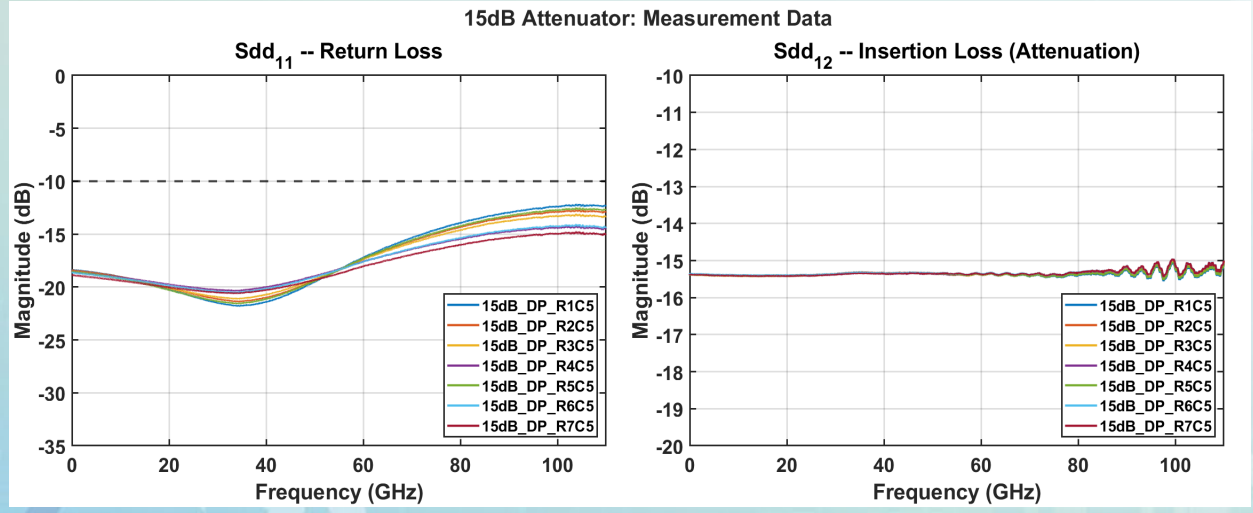


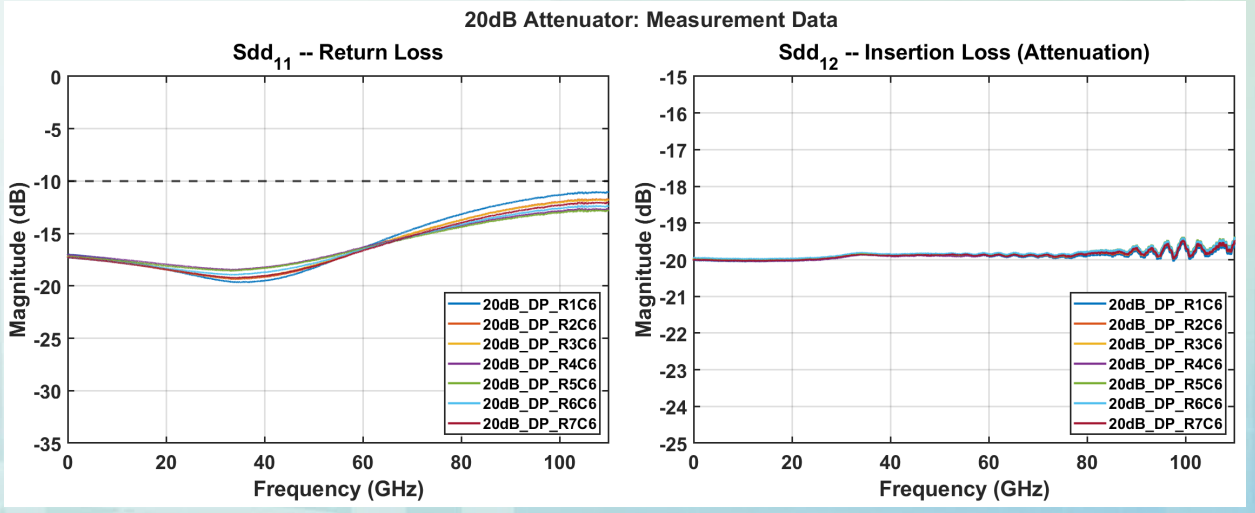


Other Value Differential Pair Attenuators

- Over measured performance
  - RL <-12dB till 110GHz
  - IL – Variations less than ±0.5dB







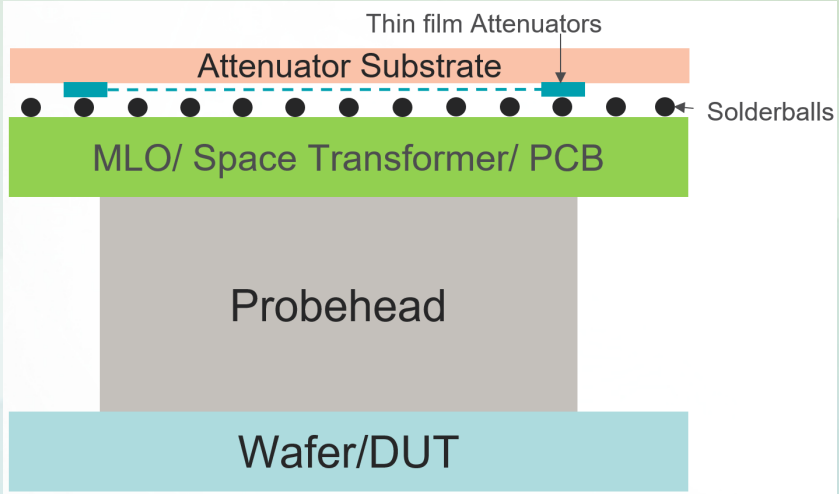
Key Takeaways

- Wide range of attenuation is possible
- Variation of <1dB for broadband frequencies (DC – 110GHz)
- Balanced and Unbalanced versions possible
- Wide range of resistor values
- Compact footprint for narrow pitch applications
- Better control on EM parasitics
- Solderball/reflowable on wafer
- Tolerant to resistance variations (Good fabrication tolerance)
- Balanced ground return upwards of 110GHz

What's Next?

Future Work

- System architecture showing thin film attenuators can be reflowed on the MLO/ space transformers or on PCBs or directly to the DUT.
- Other variations are possible
- Perform crosstalk measurements



Patent: P. Ghate, D. Bock, “Broadband Attenuators using Thin Film for Wafer Sort,” Filed 2025 US Provisional Patent Application, Application Number: US63/760534.

Questions