

Over-Moded Coaxial Test Cables for 425 Gbps PAM4 SerDes Validation Test Margin

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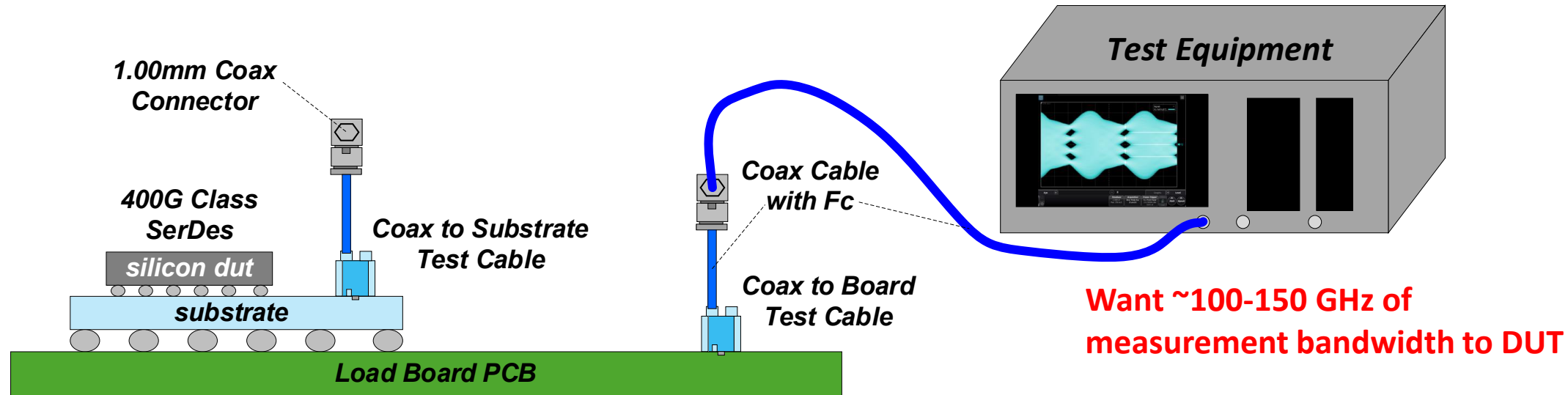


Agenda

- **400G Class SerDes Fixture Loss**
- **Practical modal bandwidth versus insertion loss tradeoff in coaxial cables**
- **Experiment**
 - Create a 425Gbps PAM4 marginal channel
 - Channel Emulator + Additional Test Cable
 - Vary coax diameter, insertion loss and cut off frequency (F_c) below 425 Gbps PAM4 Nyquist
 - Evaluate channel performance with COM and oscilloscope eye metrics
 - Demonstrate sub-Nyquist component optimization through simple case: over-moded coaxial test cable
 - Are there test margin benefits from lower sub-Nyquist loss test cables where IL performance is optimized up to some fraction of Nyquist ($F_c < F_n$)
- **Conclusions and Future Work**

Is the lower loss from over-moded coax exploitable once we've demonstrated sub-Nyquist channels?

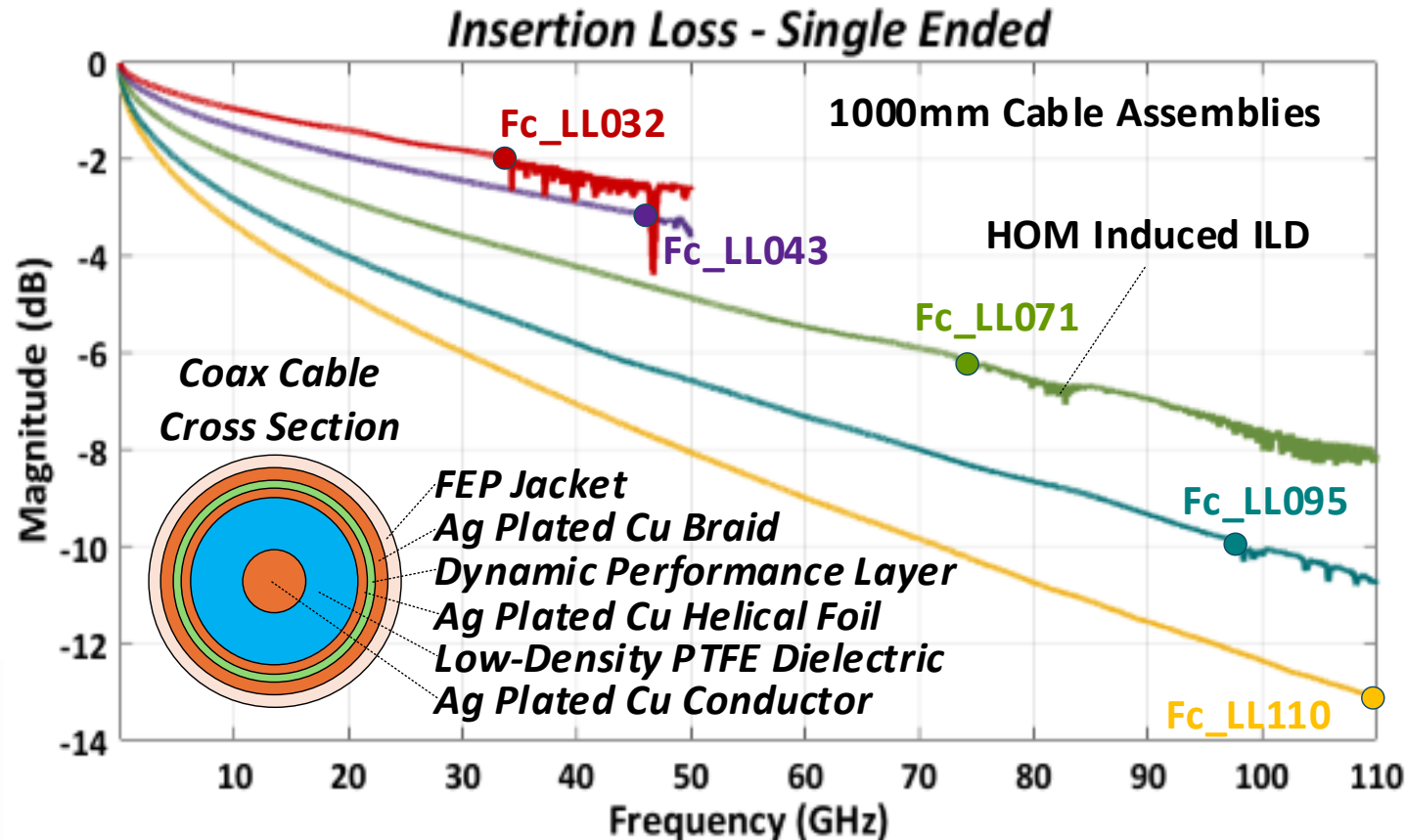
400G Class SerDes Validation Fixture Loss



- **Problem: Connect 400 Gbps Class silicon DUT to test equipment with minimum added distortion from fixture and cabling.**
- **IL per 25 mm at 100 GHz**
 - Substrates : ~6-12 dB
 - PCBs : ~3-6 dB
 - Coax Cables : ~0.3-0.6 dB

Interface silicon phy to coax as quickly as possible.

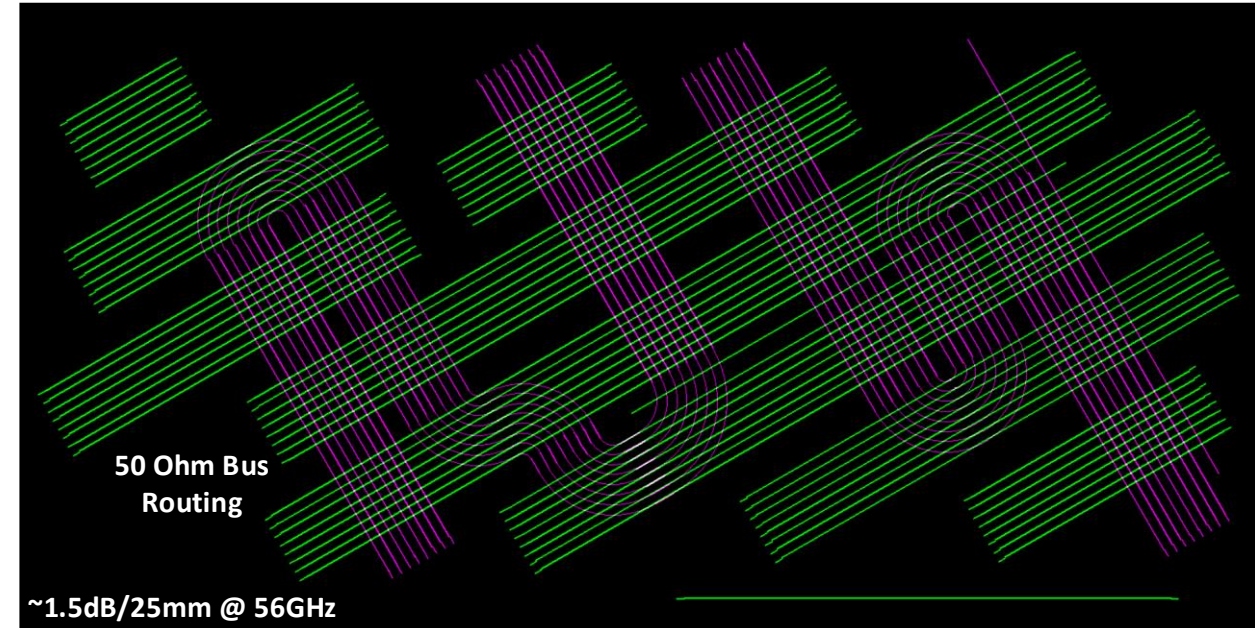
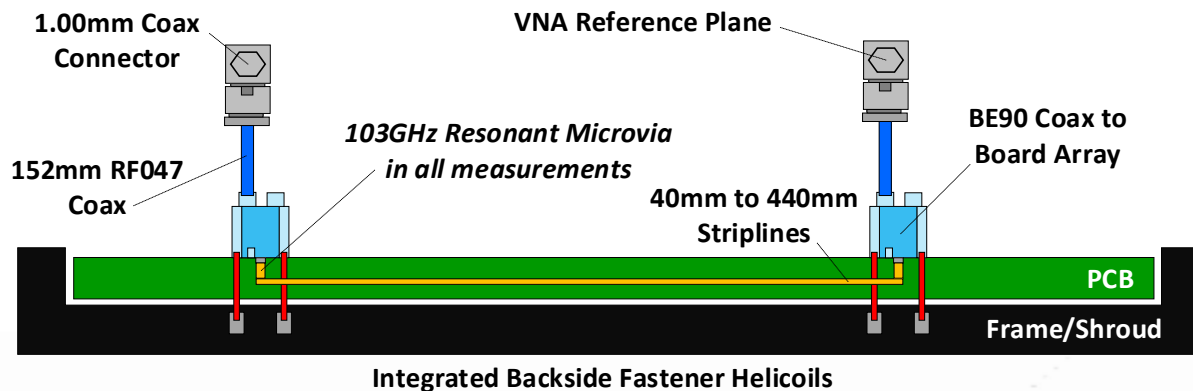
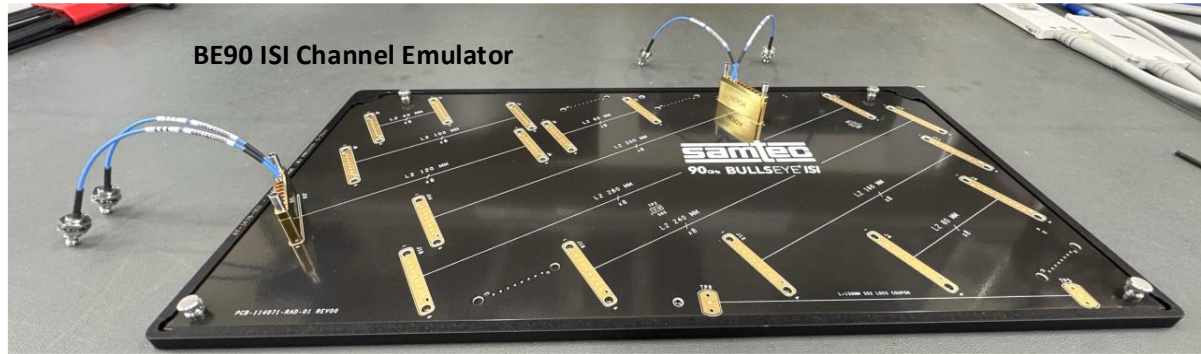
Higher Order Modes in Coaxial Test Cables



- Center conductor diameter dominates test cable loss performance.
- For a 50 Ohm test cable, dielectric outer diameter is determined from chosen center conductor gauge.
- Higher Order Modes (HOM) established ~sum of the conductor perimeters exceeds two wavelengths.
- Terminating a cable in a higher Fc rated coax connector allows observing HOM above Fc as Insertions Loss Deviation (ILD)

Insertion loss improves up to a decreasing Fc modal cutoff as center conductor diameter increases.

Create a 425Gbps Marginal Channel - Emulator

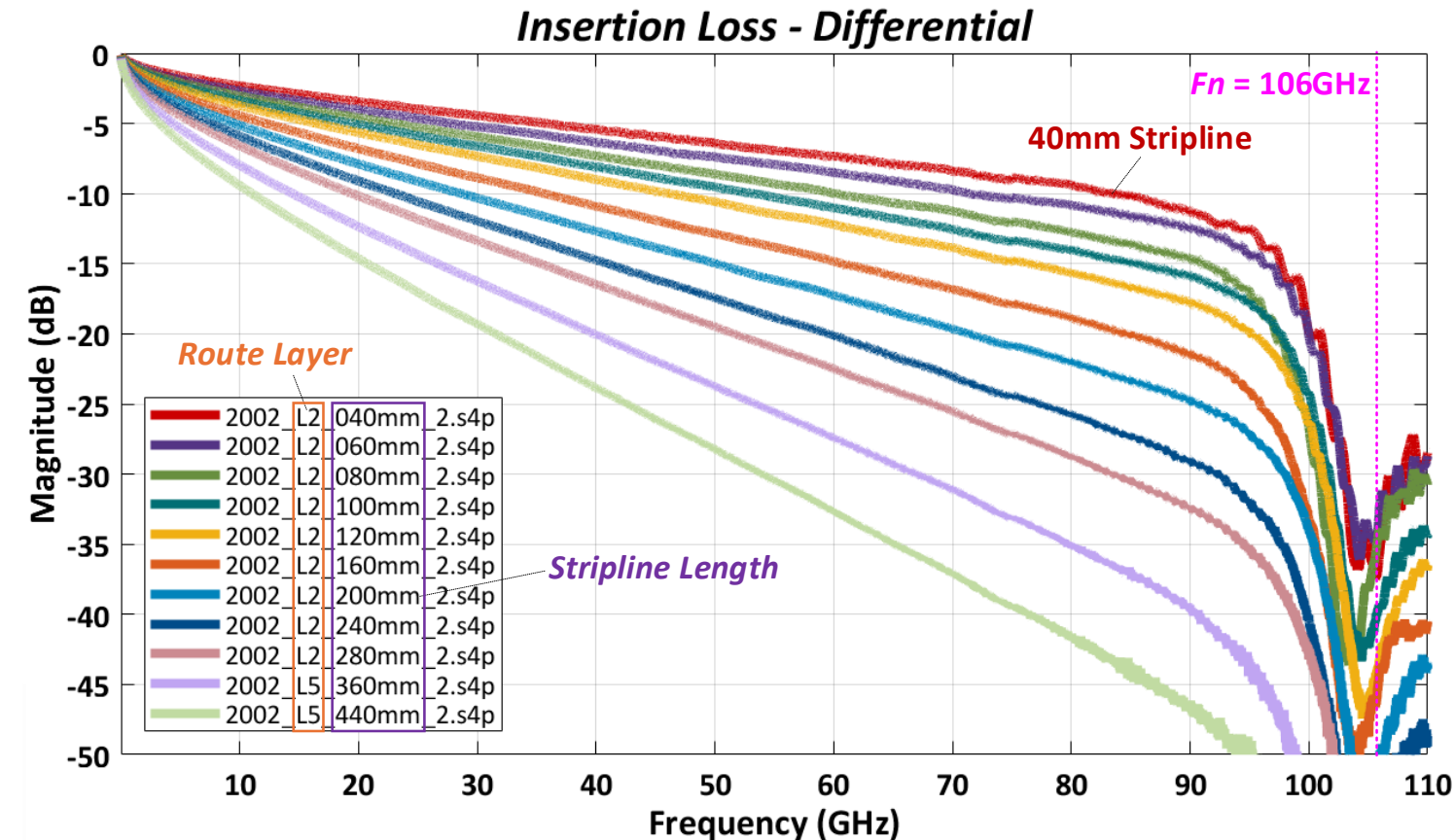


Samtec BE90 ISI Channel Emulator

- Coax test cable to board array to stepped PCB striplines mounted in frame/stiffener
- Measured channel data set available to public as IEEE 802.3 contribution.

https://www.ieee802.org/3/ad_hoc/E4AI/public/channel/C2M/josephson_e4ai_03_250430.zip

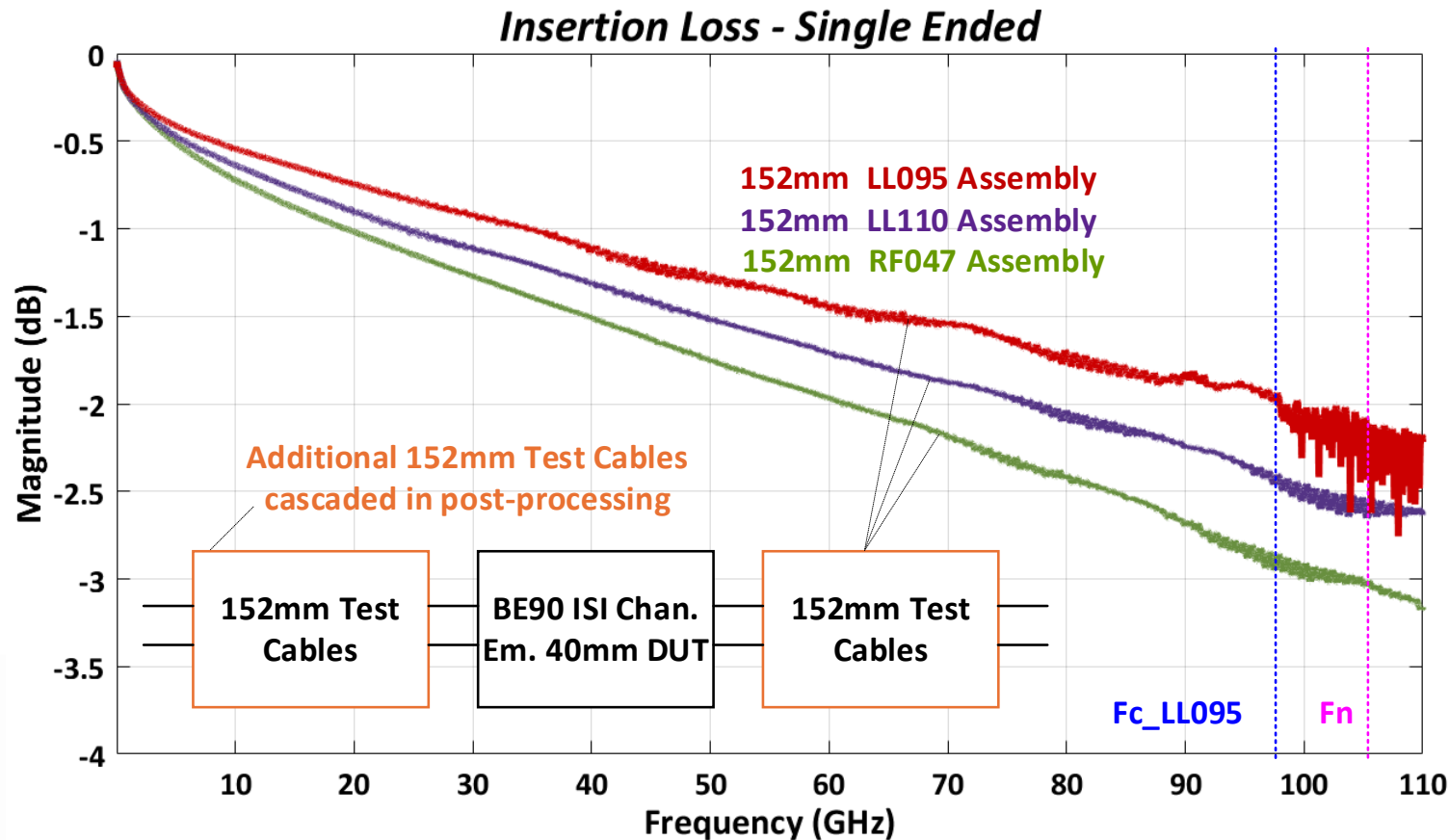
Channel Emulator Measurements



- All channels exhibit ~**103 GHz resonance** from the coax to stripline laser via transition
- 1 dB rolloff bandwidth ~90 GHz
 - ✓ ~100 GHz of compensable interconnect bandwidth.
 - ✓ Real world resonance ~35 dB down for short channels
- Several short channels pass 425 Gbps Channel Operating Margin (COM) with reasonable assumptions.

Cascade additional coax test cable onto the lowest loss 40 mm channel creating a marginal COM condition.

Cascaded Coaxial Test Cables

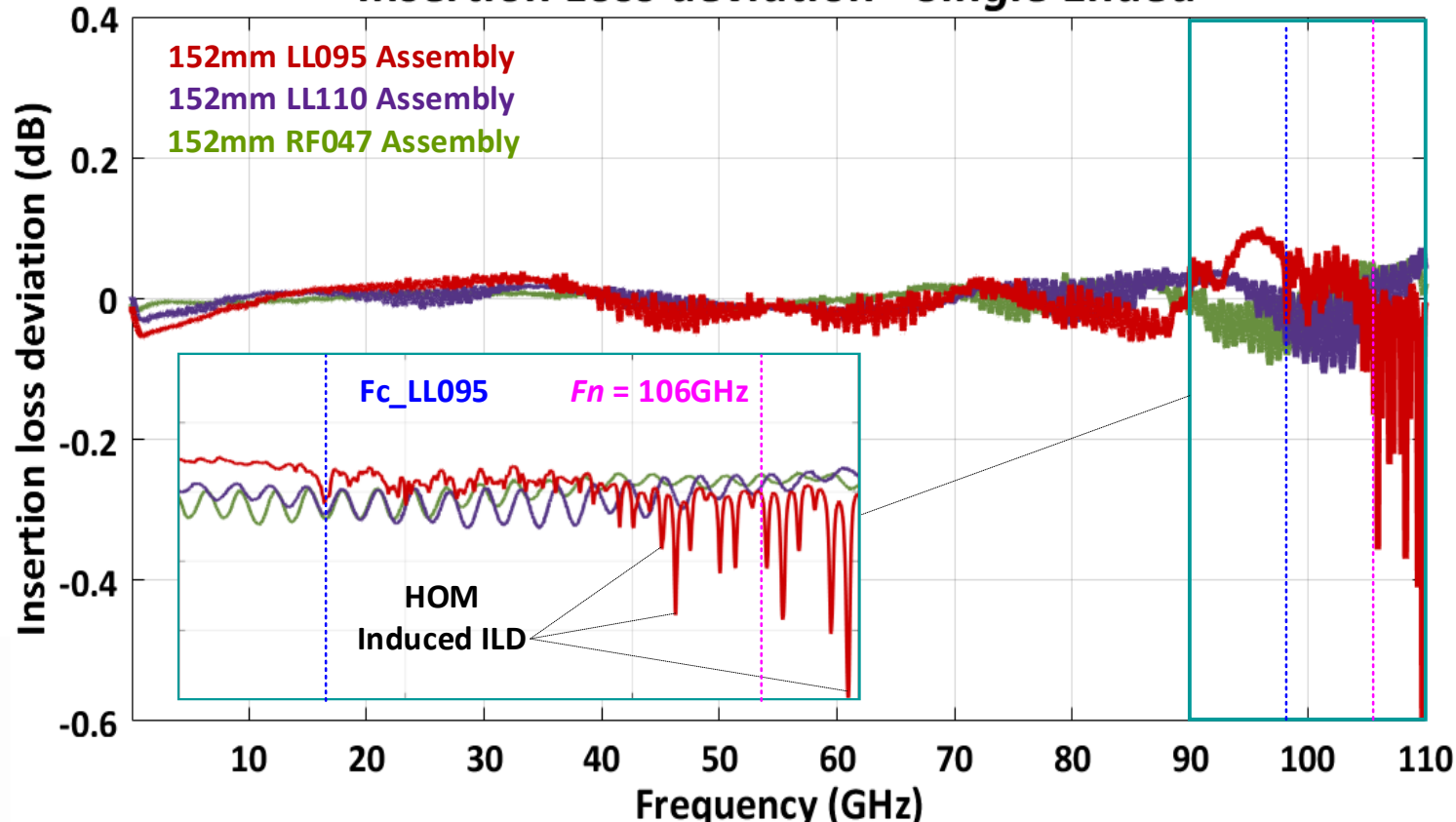


- Three different microwave test cables terminated to 1.00 mm coax connectors.
- Two 110 GHz rated cable assemblies with different dielectrics
 - ✓ $F_c = 110\text{GHz} > F_n$
- One 95 GHz loss optimized coax
 - ✓ HOM empirically visible above 98GHz
 - ✓ +3 GHz design margin
 - ✓ HOM penalty is ILD $\sim 0.6\text{dB}$ above F_c

Can the lower IL from over-moded coax test cable benefit a 400G class SerDes DUT?

Aggregate Channel ILD Comparison

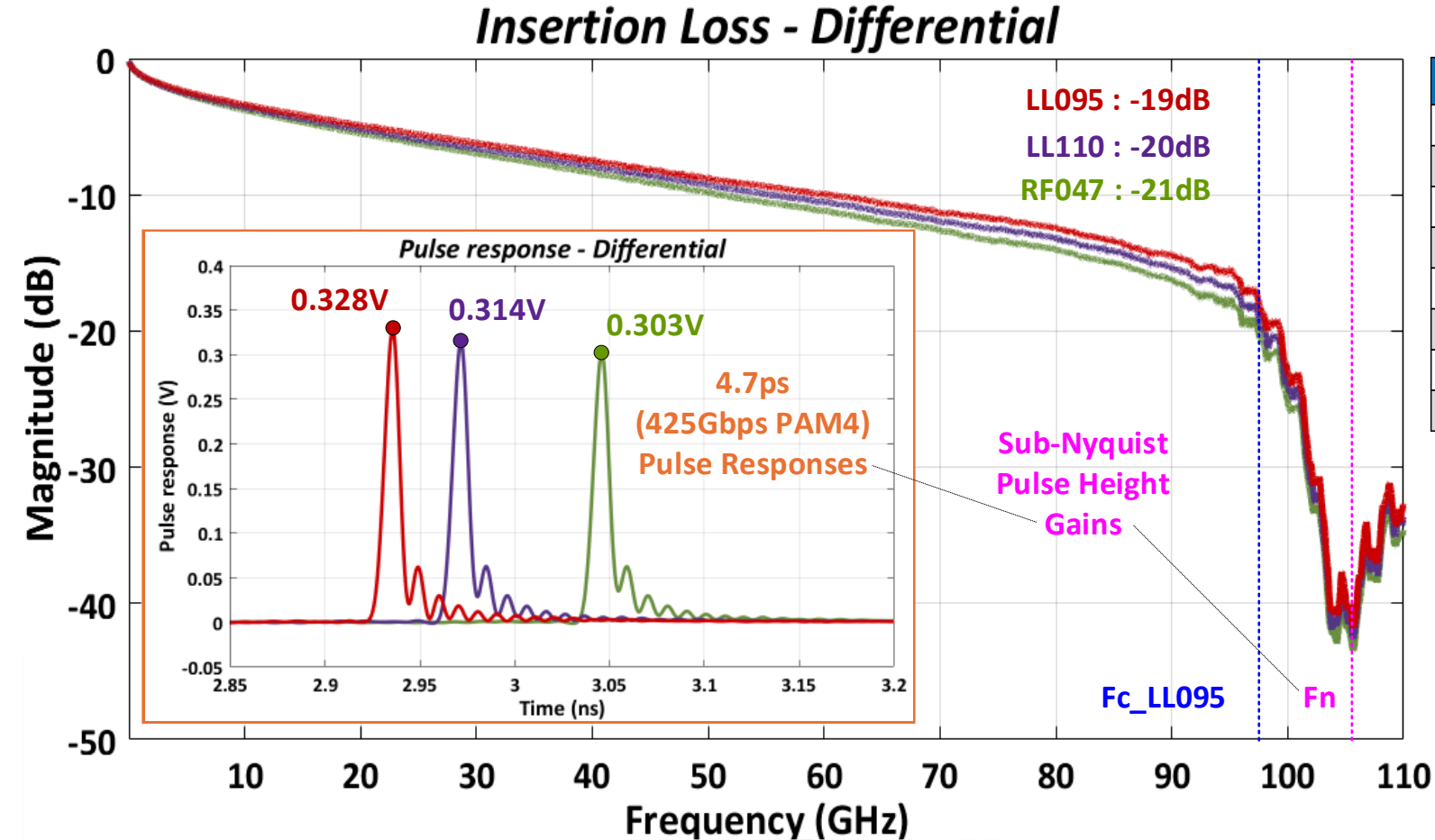
Insertion Loss deviation - Single Ended



- Each differential channel cascades 4 unique coax cable s-parameters per cable type
- ILD presented is total response of all 4 unique cables + 4-port channel emulator
- Peak ILD from over-moded coax channel is ~0.6dB

The over-moded test cable channel should demonstrate lowest IL up to it's $F_c = 98\text{ GHz}$

Aggregate Channel IL/PR/COM Comparison

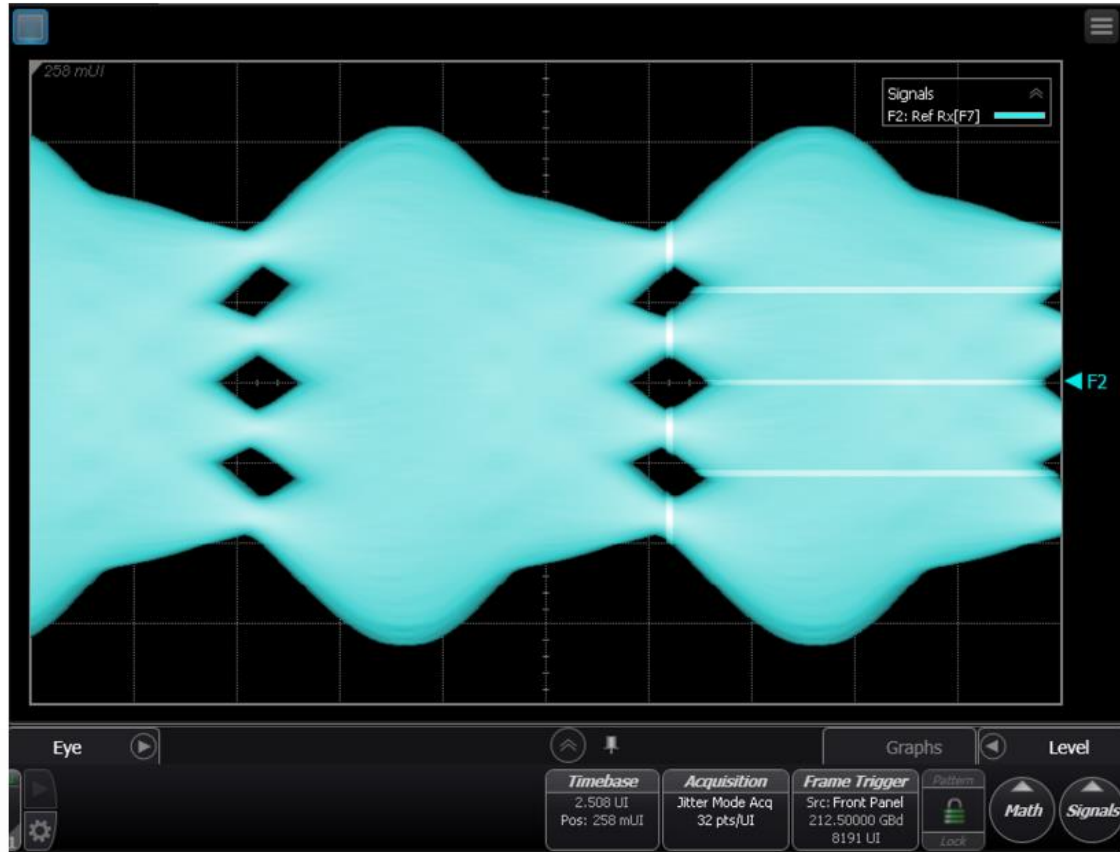


Metric	LL095	LL110	RF047
Com (dB)	3.36	3.20	2.60
A_signal_after_Eq (mV)	6.63	5.99	5.58
VEO (mV)	2.33	1.97	1.27
VEC (dB)	9.88	10.21	11.75
SNR_ISI (dB)	35.41	36.09	36.76
σ_n (mV)	0.88	0.86	0.87
DER DFE	7.5E-06	1.0E-05	3.0E-05
DER MLSE	5.1E-08	1.0E-07	6.6E-07

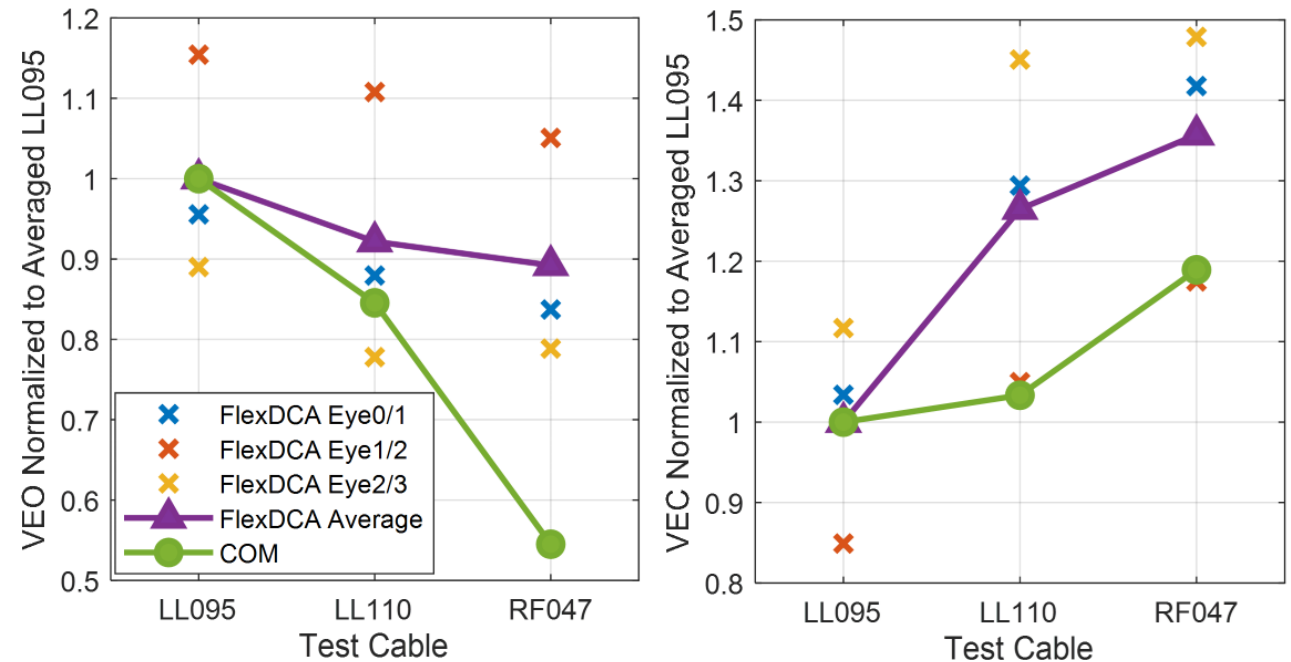
- 3 stepped coax cable channels with lossiest cable type providing marginal COM baseline of 2.60 dB
- COM score improves with cascaded cable IL performance.
- Over-moded 95 GHz optimized cable provides ~0.2dB additional margin

Over-moded channel exhibits largest raw and equalized pulse heights and largest COM score.

Eye Metrics with FlexDCA Sampling Scope



Rx equalizer includes CTLE/FFE/DFE



- Define a 400G Class SerDes capability for pre-silicon emulation in Keysight FlexDCA
- Assumptions of Tx/Rx noise parameters and SerDes equalizer implementation.

COM Trends are supported in emulated statistical channel eye metrics.

Conclusion and Future Work

- **We demonstrated a 425 Gbps sub-Nyquist channel optimization, with a modal bandwidth limited microwave grade coaxial test cable as a sub-Nyquist component, through analysis of measured interconnect.**
 - ✓ Analysis in Channel Operating Margin shows pulse height trends from lower loss test cable correlate with gains to post-equalized A_signal in the presence of ISI and COM.
 - ✓ Analysis in emulated statistical channel measurement in Keysight FlexDCA show trends from lower loss test cable correlate with improvements to VEC measurements.
- **Future Work**
 - ✓ Demonstrate test margin benefits with over-moded test coax cable on real silicon Phy
 - ✓ Investigate larger diameter lower loss over-moded coax with Fc as low 72GHz.
 - ✓ Work with the T/M community to consider impacts on de-embedding above Fc.
 - ✓ Participate in maturation of 0.8 mm coaxial test solutions and methods