Architecture and Methodology Considerations for Developing IEEE 802.3 400GPL C2M/CR PAM4/PAM6 Specifications

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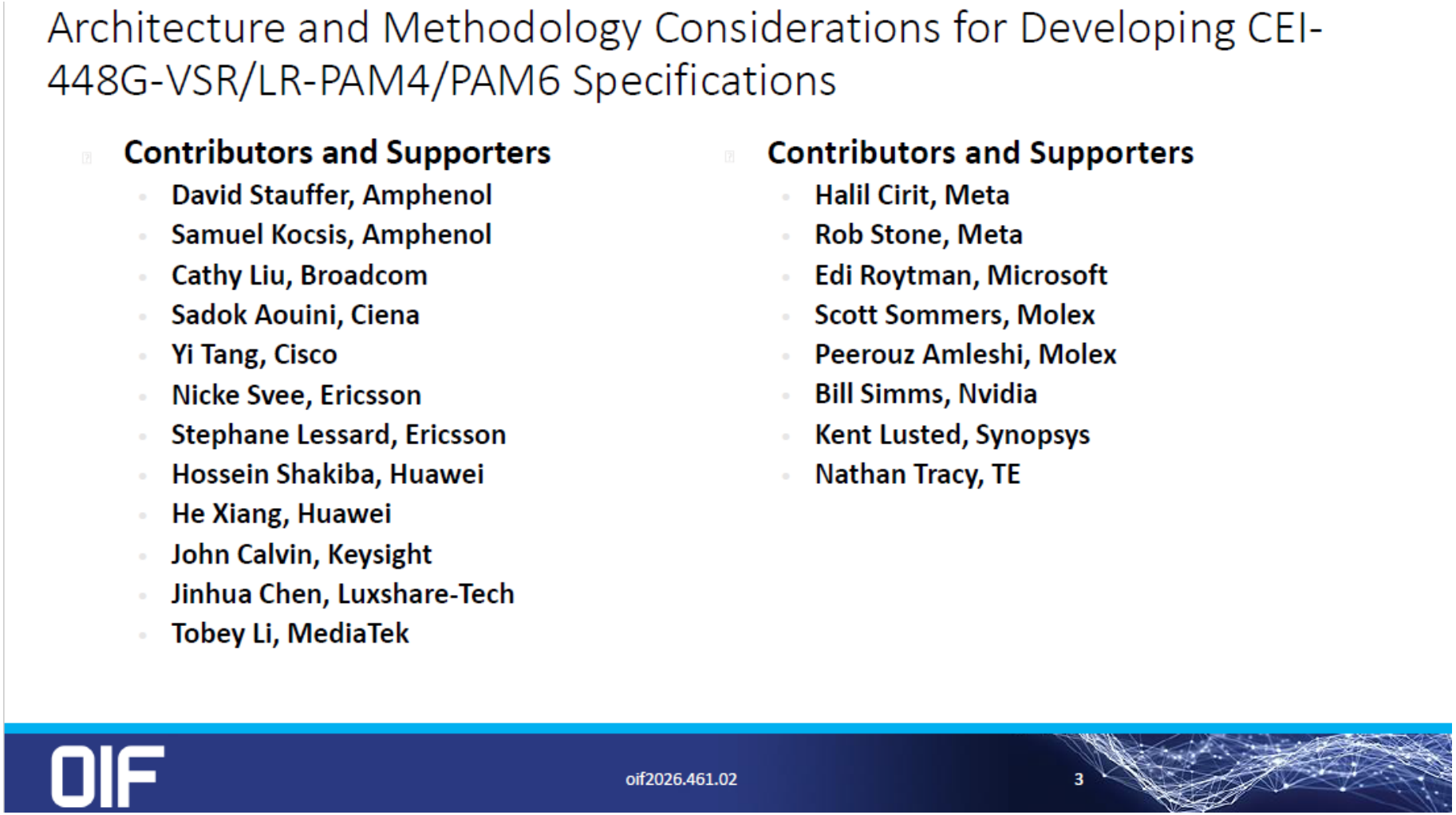
Background

- This presentation is developed based on a recent and relevant contribution made at the OIF Q3/2026 [1], which has been updated to be appropriate for 802.3dv 400GPL C2M/CR electrical/copper interfaces



Source: OIF2026.461

KGM for Developing IEEE 802.3 Electrical Spec Gen-to-Gen

- KGM (known-good-method) used from 50GPL-PAM4 to 100GPL-PAM4, and to 200GPL-PAM4
  - 2x data rate/BAUD increase
  - 2x BW increase in AFE/CTLE, channel (including PKG/conn/PCB/cable)
  - 2x jitter reduction (i.e., DJ, RJ, EOJ)
  - 2x noise spectrum density reduction
  - More capable equalizations
    - at 50GPL: TX FIR+ RX CTLE+DFE (fixed)
    - at 100GPL: TX FIR+ RX CTLE+DFE (fixed + floating taps)
    - at 200GPL: TX FIR + RX CTLE+DFE+FFE (fixed + floating taps) + MLSD
- This KGM is assumed for the 400GPL electrical/copper interface spec development
  - 400GPL SERDES and channel R&D follow the similar trend and method

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM4 (I)

- Link

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM4	Notes
Modulation	PAM4	PAM4	
Data Rate	212.5 Gbps	425 Gbps	
Reach	1 m	1 m	
Nyquist Freq	53.125 GHz	106.25 GHz	
Raw BER	< 2.921e-4	< 2.921e-4	iFEC (inner FEC) could be used for 400GPL
Post FEC BER	< 1e-13	< 1e-13	FEC/oFEC (e.g., KP) must
AC coupled	Y	Y	
Diff impedance	92.5 ohm	85 ohm	Nominal
Gray coding	2 bits/symbol	2 bits/symbol	
FEC	Y	Y	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM4 (II)

- TX (at the PKG output)

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM4	Notes
Diff Voltage	800 -1000 mV	800-1000 mV	
BW	>= 53.125 GHz	>= 106.25 GHz	
Rise/fall	0.531 UI	0.531 UI	At driver output
FIR	3 pre+1+1 post	>= 3 pre+1+ >= 1 post	Needs to be same or more capable, specifics TBD
SNDR	32.5 dB	32.5 dB	
RLM	0.95	0.95	
JH3u03	0.106 UI	0.106 UI	
JHRMS03	0.023 UI	0.023 UI	
EOJ03	0.025 UI	0.025 UI	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM4 (III)

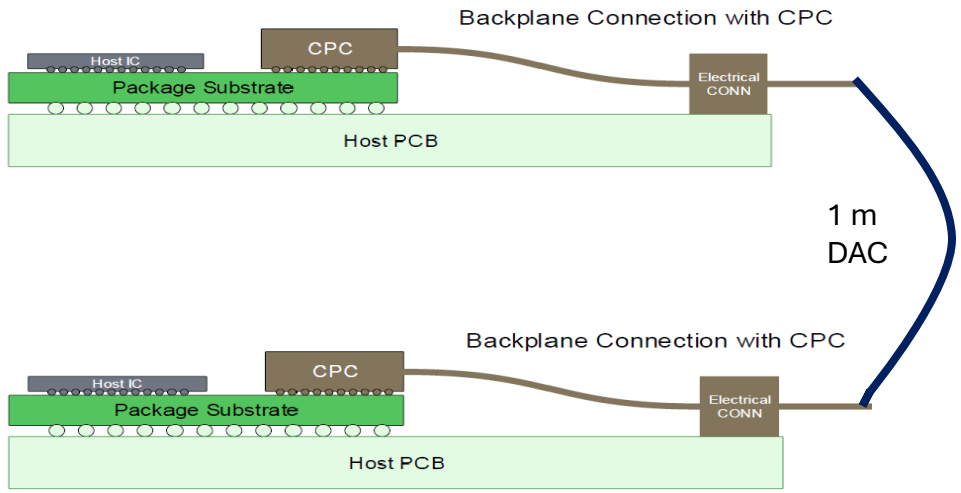
- Channel (bump-bump)

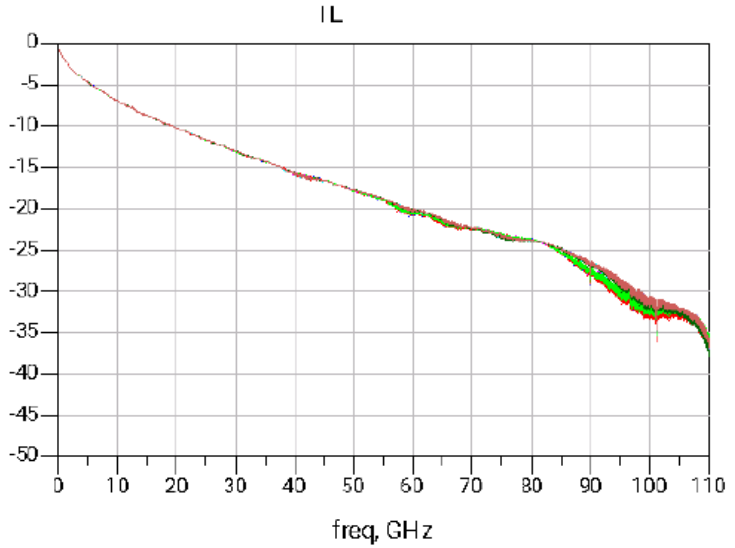
Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM4	Notes
IL	40 dB at Nyquist	40 dB at Nyquist	Informative
COM TX FIR	3 pre+1+1 post	>= 3 pre+1+ >= 1 post	Needs to be same or more capable, specifics TBD
COM TX RLM	0.95	0.95	
COM TX SNR	33.5	33.5	
COM TX DJ: A_{DD}	0.02 UI (pk)	0.02 UI (pk)	
COM TX RJ: σ_{RJ}	0.01 UI (RMS)	0.01 UI (RMS)	
COM RX CTLE	2 zeros, 3 poles, gain1, gain2	2 zeros, 3 poles, gain1, gain2, freq scaled	
COM RX FFE	6 pre+1+8 post (fixed) 2x4 floating to 80 UI	>6 pre+1+ >8 post (fixed) > 2x4 floating to > 80 UI	Needs to be more capable, specifics TBD
COM RX MLSD	1-tap	>= 1 tap	
COM DER0	2e-4	2e-4	
COM (min)	3 dB	3 dB	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM4 (IV)

- RX

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM4	Notes
ITOL pre FEC BER	< 1e-4	< 1e-4	
ITOL BLER	<1.45e-11	<1.45e-11	
ITOL IL at Nyquist	Test1: ~15 dB Test2: ~23 -34.5 dB	Test1: ~15 dB Test2: ~23 -34.5 dB	
ITOL COM (w BB noise)	>= 3 dB	>= 3 dB	
JTOL Corner Freq	4 MHz	4 MHz	





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Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM4 (V)

- FEC

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM4	Notes
FEC	Yes (e.g., RS(544, 514, 10))	Y: (e.g., RS(544,514,10))	
iFEC	NA	Optional	To extend the needed > 1 m DAC reach and if no significant IL increase from Nyquist to 1.1xNyquist

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM6 (I)

- Link

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM6	Notes
Modulation	PAM4	PAM6	
Data Rate	212.5 Gbps	425 Gbps	
Symbol Rate	106.25 Gsym/s	170 Gsym/s	
Nyquist Freq	53.125 GHz	85 GHz	
Reach	1 m	1 m	
Raw BER	< 2.921e-4	< 1e-3	iFEC needed
Post FEC BER	< 1e-13	< 1e-13	FEC (e.g., RS(544.514,10)) must
AC coupled	Y	Y	
Diff impedance	92.5 ohm	85 ohm	Nominal
Gray coding	2 bits/symbol	2.5 bits/symbol	
FEC	Yes	Yes	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM6 (II)

- TX (at PKG output)

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM6	Notes
Diff Voltage	800 -1000 mV	1000-1200 mV	Needed to compensating PAM6 SNR penalty
BW	>= 53.125 GHz	>= 85 GHz	
Rise/fall	0.531 UI	0.531 UI	At driver output
FIR	3 pre+1+1 post	>= 3 pre+1+ >= 1 post	Needs to be same or more capable, specifics TBD
SNDR	32.5 dB	36 dB	
RLM	0.95	>= 0.95	
JH3u03/05	0.106 UI	0.106 UI	
JHRMS03/05	0.023 UI	0.023 UI	
EOJ03/05	0.025 UI	0.025 UI	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM6 (III)

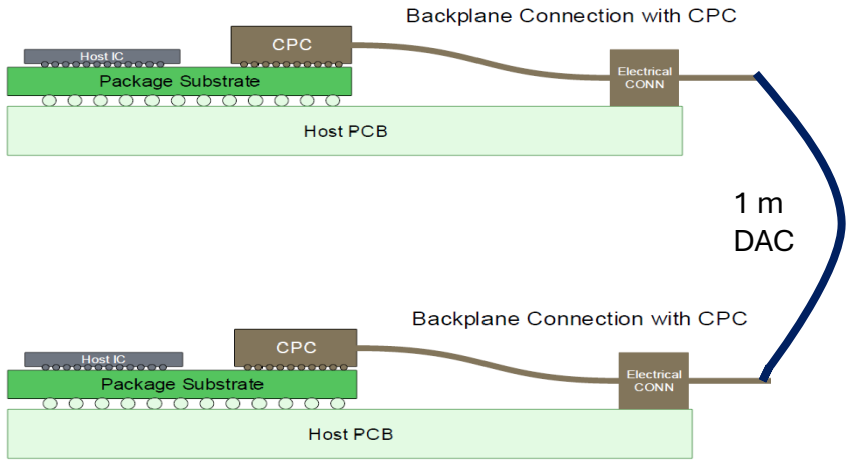
- Channel (bump-bump)

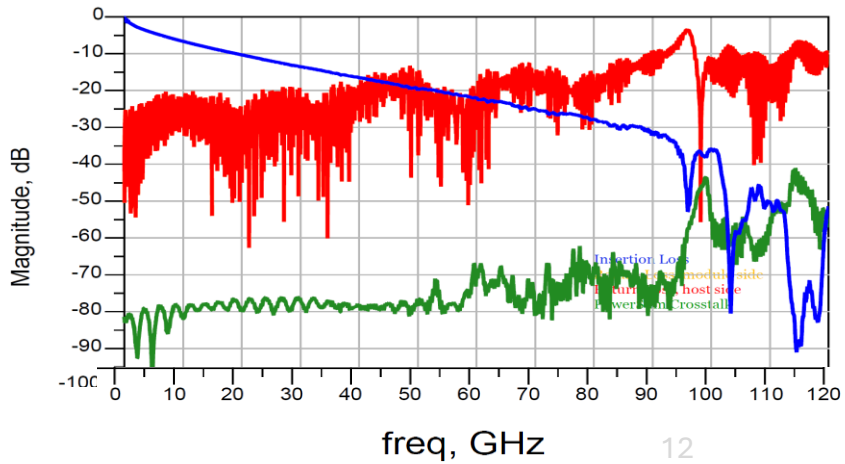
Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM6	Notes
IL	40 dB at Nyquist	40 dB at Nyquist	Informative
COM TX FIR	3 pre+1+1 post	>= 3 pre+1+ >= 1 post	Needs to be same or more capable, specifics TBD
COM TX RLM	0.95	>=0.95	
COM TX SNR	33.5	37	
COM TX DJ: A_{DD}	0.02 UI (pk)	0.02 UI (pk)	
COM TX RJ: σ_{RJ}	0.01 UI (RMS)	0.01 UI (RMS)	
COM RX CTLE	2 zeros, 3 poles, gain1, gain2	2 zeros, 3 poles, gain1, gain2, freq scaled	
COM RX FFE	6 pre+1+8 post (fixed) 2x4 floating to 80 UI	>6 pre+1+ >8 post (fixed) > 2x4 floating to > 80 UI	Needs to be more capable, specifics TBD
COM RX MLSD	1-tap	>= 1 tap	
COM DER0	2.4e-4	1e-3	
COM (min)	3 dB	3 dB	

Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM6 (IV)

- RX

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM6	Notes
ITOL pre FEC BER	< 2.921e-4	< 1e-3	
ITOL BLER	<1.45e-11	<1.45e-11	
ITOL IL at Nyquist	Test1: ~15 dB Test2: ~23 -34.5 dB	Test1: ~15 dB Test2: ~23 -34.5 dB	
ITOL COM (w BB noise)	>= 3 dB	>= 3 dB	
JTOL Corner Freq	4 MHz	4 MHz	





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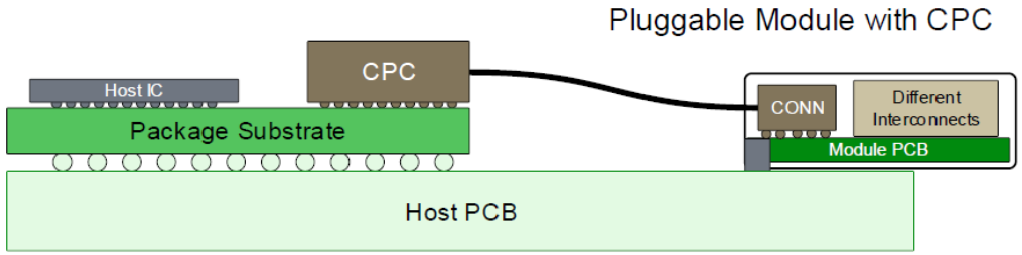
Scaling from 200GPL-CR-PAM4 to 400GPL-CR-PAM6 (V)

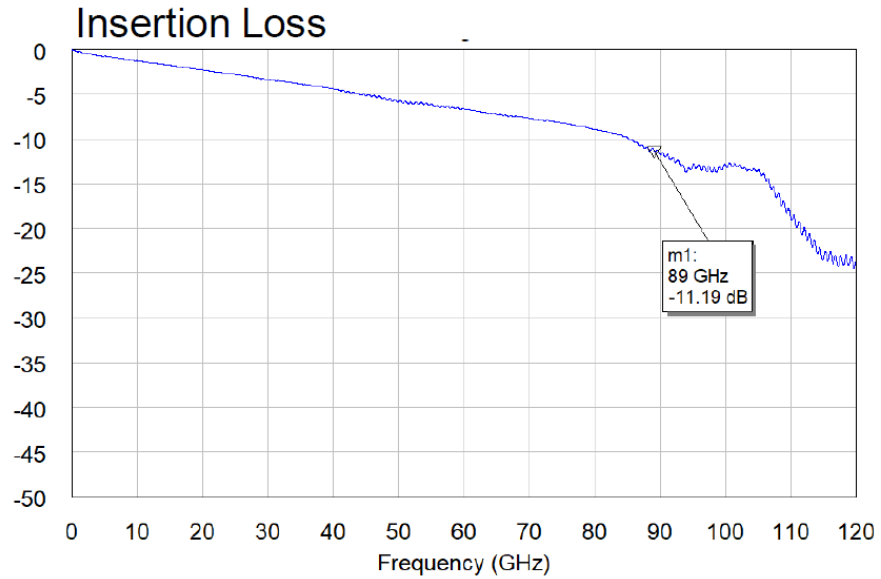
- FEC

Key Parameters	200GPL-CR-PAM4	400GPL-CR-PAM6	Notes
FEC	Y (e.g., RS(544, 514, 10))	Y (e.g., RS(544,514,10))	
iFEC	NA	Y (e.g., PAM6 coded/zero overhead, or w overhead (e.g., BCH, Hamming), etc..)	iFEC is needed for the PAM6 SNR penalty compensation, reach, and perf

Scaling from 200GPL-C2M-PAM4 to 400GPL-C2M-PAM4

- Link: similar to 400GPL-CR-PAM4, except
  - Shorter C2M channel IL: ~32 dB at Nyquist
  - Better pre-FEC BER: ~1e-5
- TX: similar to 400GPL-CR-PAM4
- Channel: ~32 dB C2M
  - COM Ref TX: similar to 400GPL-CR-PAM4
  - COM ref RX: similar to 400GPL-CR-PAM4, except DER0 at 2e-5
- RX: similar to 400GPL-CR-PAM4, except
  - C2M IL: ~32 dB
  - DER0: 2e-5
- FEC: similar to 400GPL-CR-PAM4, no iFEC





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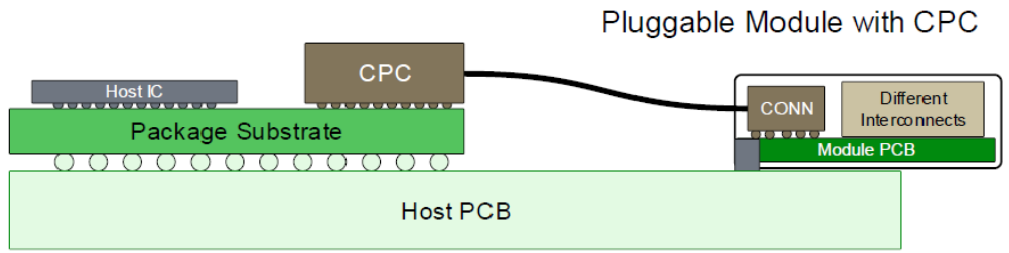
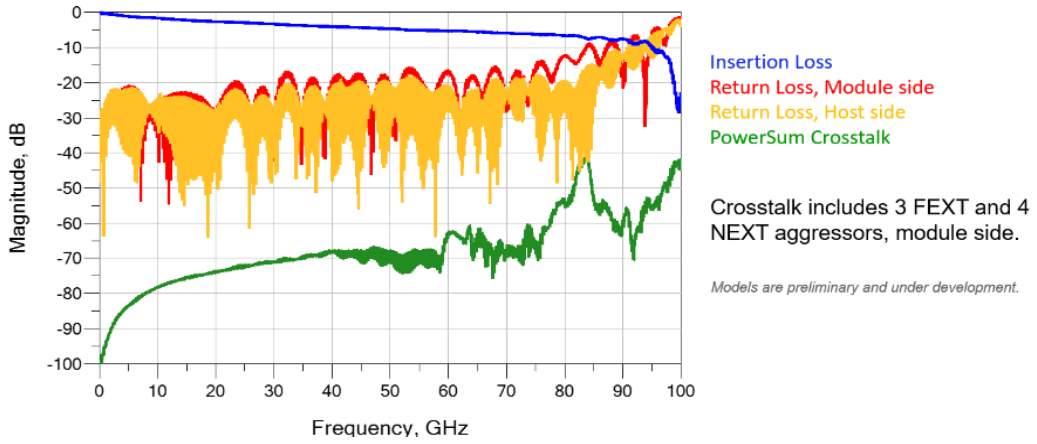
Scaling from 200GPL-C2M-PAM4 to 400GPL-C2M-PAM6

- Link: similar to 400GPL-CR-PAM6, except
  - Shorter C2M channel IL: ~32 dB at Nyquist
  - Better pre-FEC BER: ~1e-5
- TX: similar to 400GPL-CR-PAM6
- Channel: ~32 dB C2M
  - COM Ref TX: similar to 400GPL-CR-PAM6
  - COM ref RX: similar to 400GPL-CR-PAM6, except DER0 at ~1e-5
- RX: similar to 400GPL-CR-PAM6, except
  - IL: ~32 dB,
  - DER0: ~1e-5
- FEC: iFEC optional (used for difficult channels)





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Summary

- Architect and methodology to develop IEEE 802.3 400GPL-C2M/CR-PAM4/PAM6 are presented and discussed
- KGM (known-good-method) for IEEE 802.3 gen-to-gen electrical/copper spec developments (e.g., 50G->100G->200G) via frequency and time scaling are reviewed and applied to 400GPL-C2M/CR-PAM4/PAM6 spec development
  - SERDES and channel R&D follow the similar trend/method
- High-level 400GPL-C2M/CR-PAM4/PAM6 spec via KGM frequency/time scaling are presented
  - subject to further improvements via simods (e.g., circuit/sub system/system, COM), and actual silicon/device and link system measurements and correlations

References

1. M. Li, E. Frlan, “Architecture and Methodology Considerations for Developing CEI-448G-VSR/LR-PAM4/PAM6 Specifications”, OIF, OIF2026.461, 2026

Thank You!