C2M Simulations with Improved CTLE

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IEEE 802.3ck Task Force Meeting

Bangkok

November 14, 2018

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Overview

- **COM results are with improved CL120E CTLE scaled to 53.1 GBd which uses CL120D style of parametric definition**
- **Updated results using COM 2.51**
  - COM 2.51 seems to do better job of CTLE/noise optimization
  - COM 2.41 results for the same set of channels, please see ghiasi_3ck_01_0918.pdf
  - Generally the results for COM 2.51 are within 0.1 dB of COM 2.41 results
- **Channel investigated are Tracy OSFP, Yamaichi QSFP28, Lim QSFP56, Qlogic QSFP28, and Yamaichi improved QSFP56/QSFP-dd/OSFP**
- **All the results here are for 4T TX FFE with CTLE+5T FFE (4 post) RX**
  - All COM results are with improved parametric CTLE with 14 dB gain and 2 dB LF gain
  - All COM results are with 15 mm package given the effort to modify and improve the BJ PKG
  - At least for TE OSFP and Yamaichi QSFP28 results for 30 mm are better than 15 mm
  - C2M channel studied have loss of ~16 dB and one may trade-off channel loss for more PKG loss.

COM Code 2.51

- **Filter coefficient selected to have the improved CL120E response scaled for 53.1 GBd**
  - http://www.ieee802.org/3/ck/public/tools/tools/mellitz_3ck_adhoc_01_100318_COM2p51.zip

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	53.1	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[0.9e-4 0]	nF	[TX RX]
z_p select	[1]		[test cases to run]
z_p (TX)	[15. 30]	mm	[test cases]
z_p (NEXT)	[15 30]	mm	[test cases]
z_p (FEXT)	[15 30]	mm	[test cases]
z_p (RX)	[0 0]	mm	[test cases]
C_p	[0.9e-4 0]	nF	[TX RX]
R_0	50	Ohm	
R_d	[45 45]	Ohm	[TX RX]
A_v	0.45	V	
A_fe	0.45	V	
A_ne	0.63	V	
L	4		
M	32		
filter and Eq			
f_r	1	*fb	
c(0)	0.65		min
c(-1)	[-0.2:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.1]		[min:step:max]
c(-3)	0		[min:step:max]
c(-4)	0		[min:step:max]
c(1)	[0:0.02:0.2]		[min:step:max]
N_b	0	UI	
b_max(1)	0.6		
g_DC	[-14:0.5:-6]	dB	[min:step:max]
f_z	1.8553E+01	GHz	
f_p1	5.3100E+01	GHz	
f_p2	2.8200E+01	GHz	
g_DC_HP	[-2:0.25:-1]		[min:step:max]
f_HP_PZ	1.20E+00	GHz	
ffe_pre_tap_len	**0**	UI	
ffe_post_tap_len	4	UI	

I/O control			
DIAGNOSTICS	1	logical	
DISPLAY_WINDOW	1	logical	
CSV_REPORT	1	logical	
RESULT_DIR	.\results\100GEL_WG_{date}\		
SAVE_FIGURES	0	logical	
Port Order	[1 3 2 4]		
RUNTAG	C2M_DFE1_RxFFE		
COM_CONTRIBUTION	0	logical	
Operational			
COM Pass threshold	2.5	dB	
EH_min	10	Value	EH limit
EH_max	1000	Value	EH limit
DER_0	1.00E-05		
Include PCB	1	Value	
T_r	6.16E-03	ns	
FORCE_TR	1	logical	
TDR and ERL options			
TDR	0	logical	
ERL	0	logical	
ERL_ONLY	0	logical	
TR_TDR	0.01	ns	
N	1000		
TDR_Butterworth	1	logical	
beta_x	1.70E+09		
rho_x	**0.18**		
fixture delay time	0		
Receiver testing			
RX_CALIBRATION	0	logical	
Sigma BBN step	5.00E-03	V	
Noise, jitter			
sigma_RJ	0.01	UI	
A_DD	0.02	UI	
eta_0	0.00E+00	V^2/GHz	
SNR_TX	33	dB	

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 1.734e-3 1.455e-4]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	90	Ohm (tdr sel)

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	[0 4.114e-4 2.547e-4]	
board_tl_tau	6.191E-03	ns/mm
board_Z_c	95	Ohm
z_bp (TX)	20	mm
z_bp (NEXT)	20	mm
z_bp (FEXT)	20	mm
z_bp (RX)	0	mm

CL120D and CL120E/OIF-56G-VSR

- **CL120D CTLE defined in CL93A by Eq. 93A-22**
  - Low frequency gain sum of $g_{DC}+g_{DC2}$
  - Low frequency zero/pole adjustable
  - g_{DC} 0 to -15 dB in 1 dB step
  - g_{DC2} 0 to -4 dB in 1 dB step
  - F_z=Fbaud/2.5
  - F_{p1}=Fb/2.5
  - F_{p2}=2*Fbaud
  - F_{lF}=Fbaud/40
  - f_r=0.75*Fbaud

$$H_{ctf}(f) = \frac{\left(10^{\frac{g_{DC}}{20}} + j\frac{f}{f_z}\right)\left(10^{\frac{g_{DC2}}{20}} + j\frac{f}{f_{LF}}\right)}{\left(1 + j\frac{f}{f_{p1}}\right)\left(1 + j\frac{f}{f_{p2}}\right)\left(1 + j\frac{f}{f_{LF}}\right)}$$

- **CL120E/OIF-56G-VSR CTLE**
  - Low frequency gain only determined by gain G
  - Low frequency Zero/Pole fixed to HF peaking

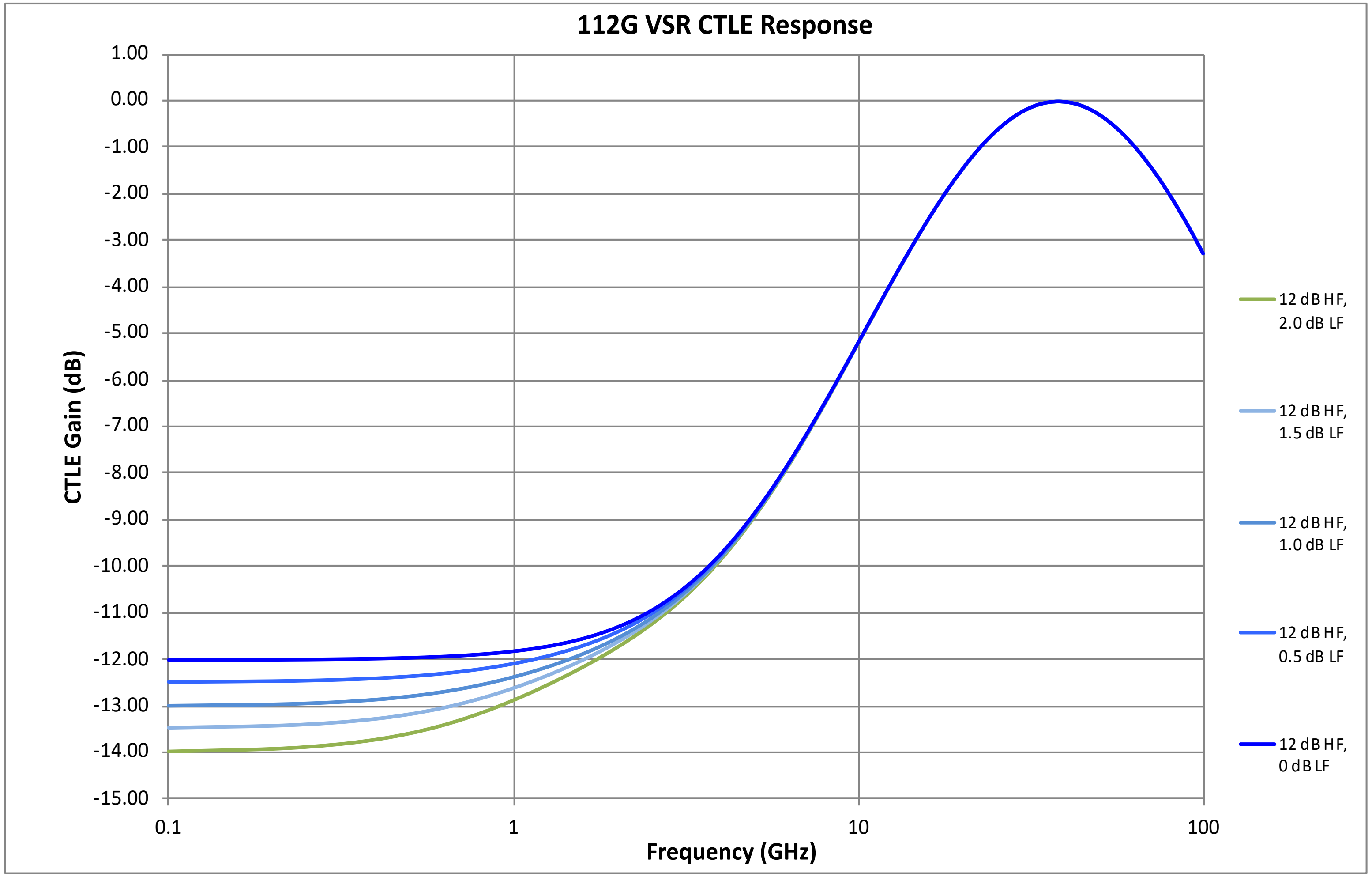
Peaking (dB)	G	$\frac{P_1}{2\pi}$	$\frac{P_2}{2\pi}$	$\frac{Z_1}{2\pi}$	$\frac{P_{LF}}{2\pi}$	$\frac{Z_{LF}}{2\pi}$	LF Gain
1	0.891251	26.5625	14.1	9.463748	1.2	1.2	0 dB
1.5	0.841395	26.5625	14.1	9.248465	1.2	1.15	0.33 dB
2	0.794328	26.5625	14.1	9.069645	1.2	1.1	0.72 dB
2.5	0.749894	26.5625	14.1	8.640319	1.2	1.075	0.69 dB
3	0.707946	26.5625	14.1	8.255665	1.2	1.05	1.12 dB
3.5	0.668344	26.5625	14.1	7.906766	1.2	1.025	1.33 dB
4	0.630957	26.5625	14.1	7.58765	1.2	1	1.55 dB
4.5	0.595662	26.5625	14.1	7.076858	1.2	1	
5	0.562341	26.5625	14.1	6.614781	1.2	1	
5.5	0.530884	26.5625	14.1	6.193091	1.2	1	
6	0.501187	26.5625	14.1	5.805801	1.2	1	
6.5	0.473151	26.5625	14.1	5.448395	1.2	1	
7	0.446684	26.5625	14.1	5.117337	1.2	1	
7.5	0.421697	26.5625	14.1	4.809777	1.2	1	
8	0.398107	26.5625	14.1	4.523367	1.2	1	
8.5	0.375837	26.5625	14.1	4.256129	1.2	1	
9	0.354813	26.5625	14.1	4.006377	1.2	1	

$$H(f) = \frac{GP_1P_2P_{LF}}{Z_1Z_{LF}} \times \frac{j2\pi f + Z_1}{(j2\pi f + P_1)(j2\pi f + P_2)} \times \frac{j2\pi f + Z_{LF}}{j2\pi f + P_{LF}}$$

Proposed 112G C2M CTLE Based on CL120D Parametric Definition But with Improved CL120E Response

- **CTLE response shown is for 14 dB g_{DC} and g_{DC2} [0, 0.5, 1, 1.5, and 2 dB]**
- **C2M proposed CTLE**
  - g_{DC} [0 to 14 dB in 0.5 dB steps]
  - g_{DC2} [0 to 2 dB in 0.5 dB steps]
  - 0.5, 1, 1.5, and 2 dB]
  - f_Z = Baudrate/2.862
  - f_{P1} = 0.53082*Baudrate
  - f_{P2} = Baudrate
  - f_{LF} = Baudrate/44.271
  - f_r=1*Fbaud.

$$H_{ctf}(f) = \frac{\left(10^{\frac{g_{DC}}{20}} + j\frac{f}{f_z}\right)\left(10^{\frac{g_{DC2}}{20}} + j\frac{f}{f_{LF}}\right)}{\left(1 + j\frac{f}{f_{p1}}\right)\left(1 + j\frac{f}{f_{p2}}\right)\left(1 + j\frac{f}{f_{LF}}\right)}$$

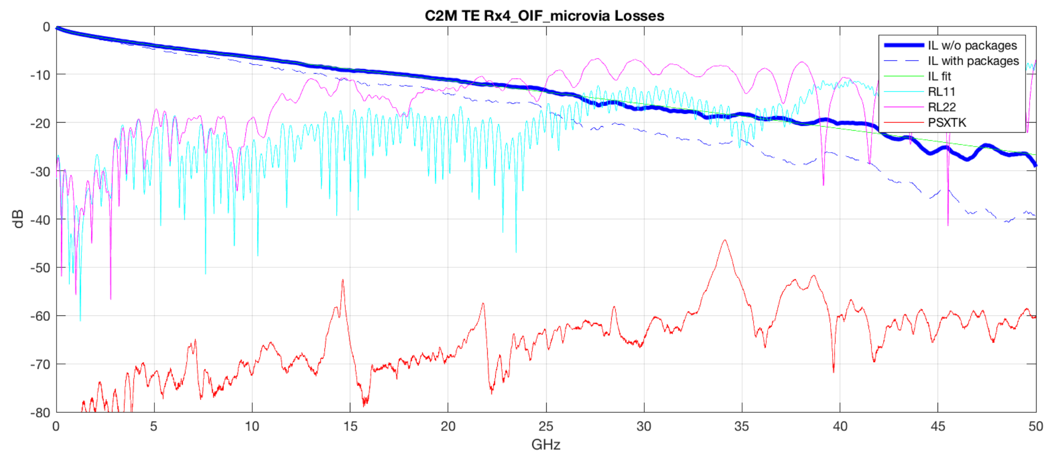


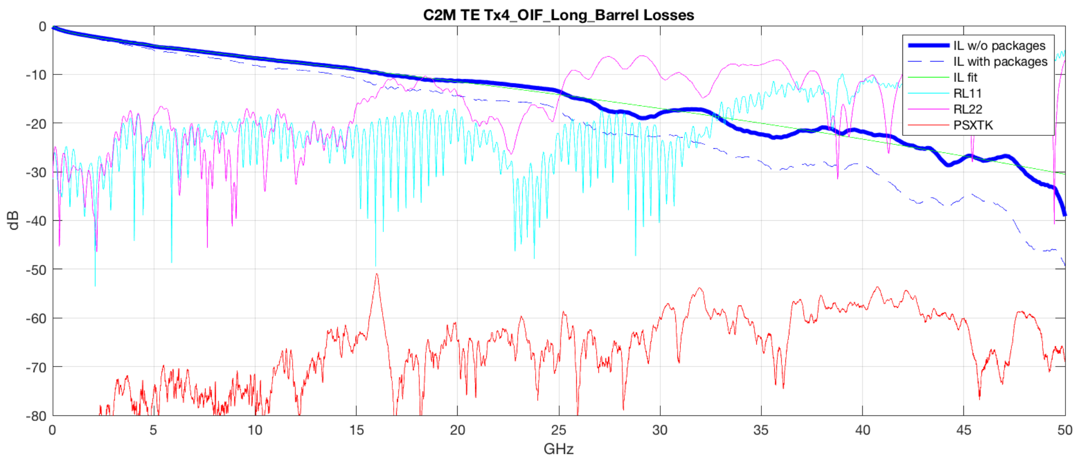
COM Analysis of Tracy Channels

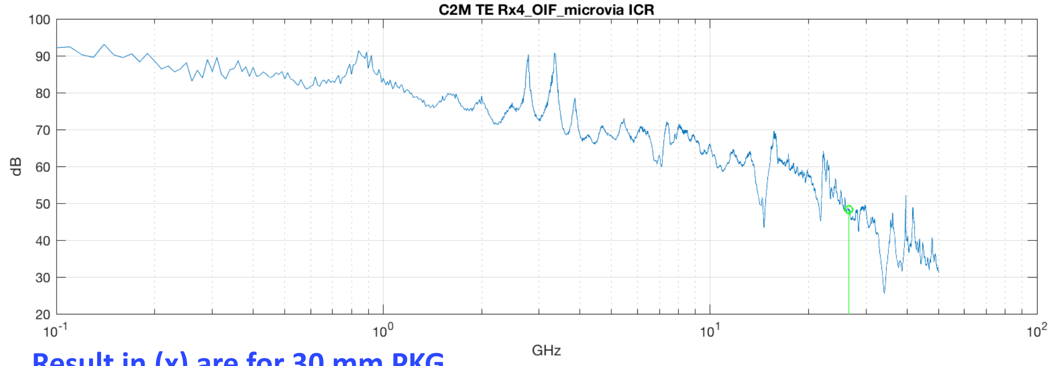
- **8.5” OSFP (16 dB) channels even the long barrel via having an ILD of 0.415 passes with just 5T FFE!**
  - http://www.ieee802.org/3/100GEL/public/tools/c2m/tracy_100GEL_02_0118.zip (long barrel)
  - http://www.ieee802.org/3/100GEL/public/tools/c2m/tracy_100GEL_06_0118.zip (Micro Via).

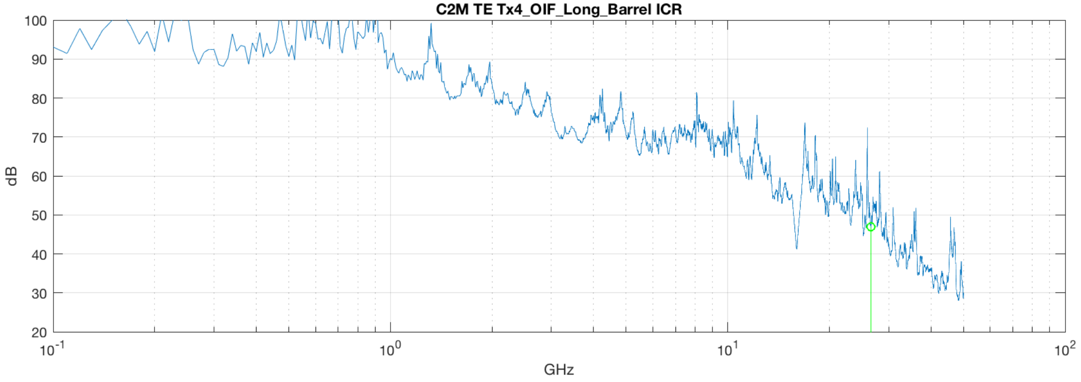
Tracy MicroVia, FOM_ILD=0.228, ICN=0.676 mV
COM=4.05 dB (6.22), EH=14.32 (17.01) mV, VEC=8.58 (5.8) dB
ICR=48 dB, CTLE Gain=-13 dB, G_DC2=-1.5 dB

Tracy LongBarrel, FOM_ILD=0.415, ICN=0.543 mV
COM=3.20 (3.36) dB, EH=10.44 (9.54) mV, VEC=10.23 (9.87) dB
ICR=46 dB, CTLE Gain=-13 dB, G_DC2=-1.5 dB







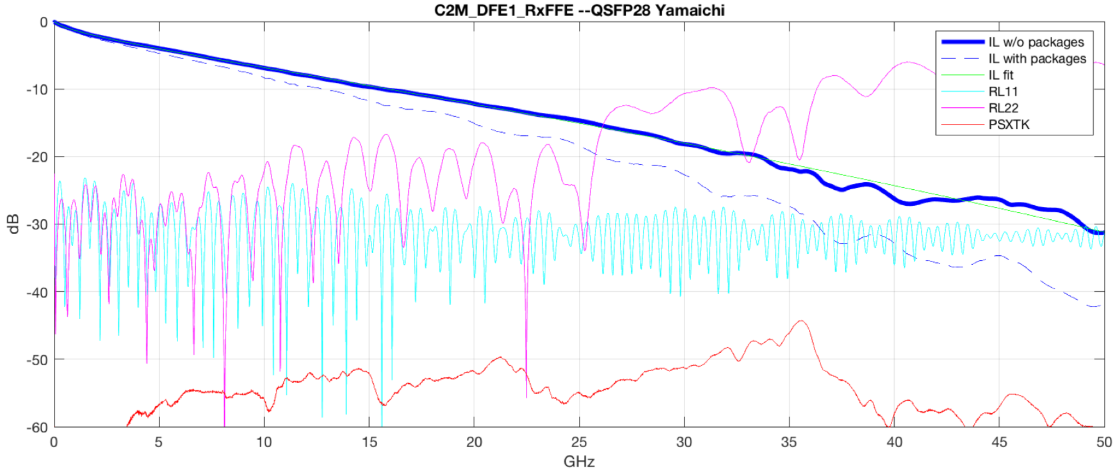


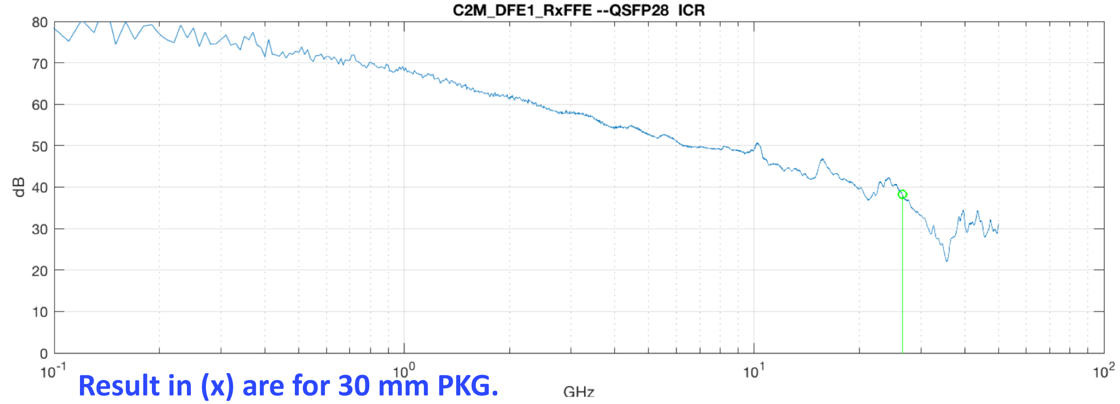
Result in (x) are for 30 mm PKG.

COM Analysis Yamaichi QSFP28 Mated Board

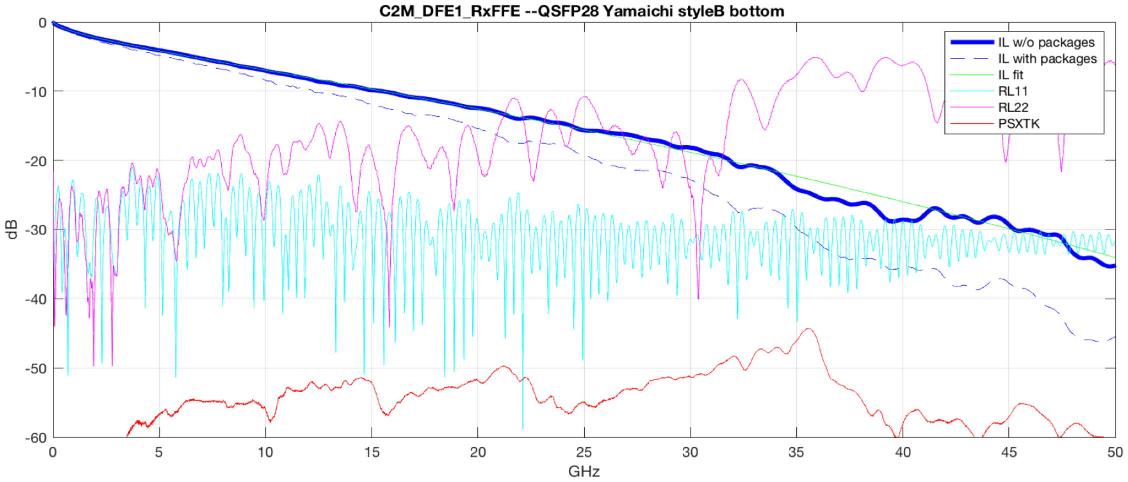
- **130 mm trace added in COM to increase mated board loss to 16 dB (Include 3 FEXT+ worst NEXT)**
  - Yamaichi QSFP28 board was extensively used for Cl120E C2M simulations in ghiasi_3bs_02a_0317.pdf

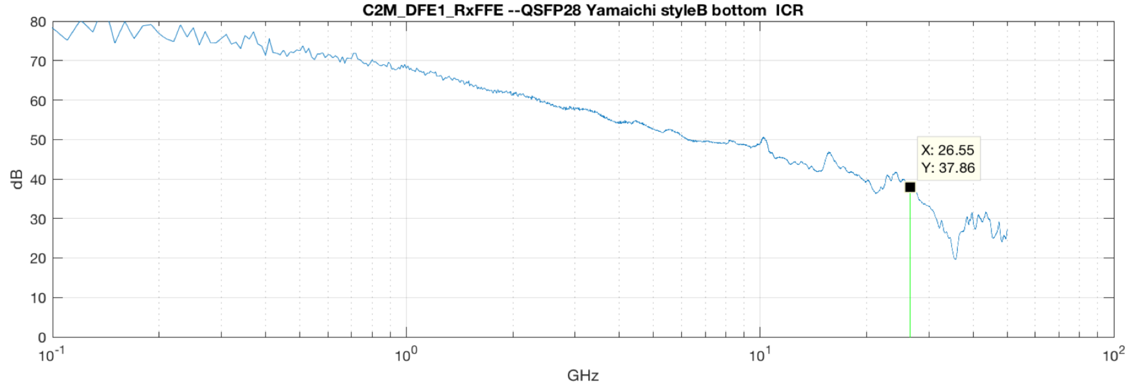
Top Contact, FOM_ILD=0.204, ICN=1.96 mV
COM=4.82 (5.62) dB, EH=16.4 (15.55) mV, VEC=7.42 (6.4) dB
ICR=38.2 dB, CTLE Gain=-11 dB, G_DC2=-2 dB





Bottom Contact, FOM_ILD=0.291, ICN=1.96 mV
COM=4.31 (5.0) dB, EH=16.4 (13.6) mV, VEC=8.15 (7.2) dB
ICR=37.9 dB, CTLE Gain=-7 dB, G_DC2=-2 dB



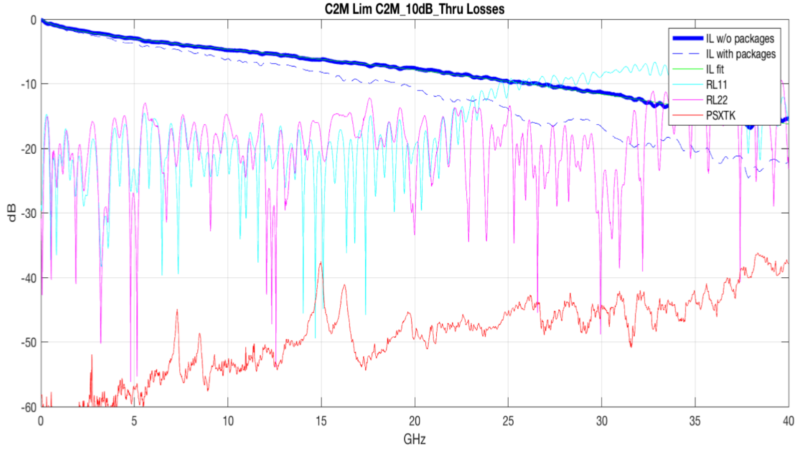


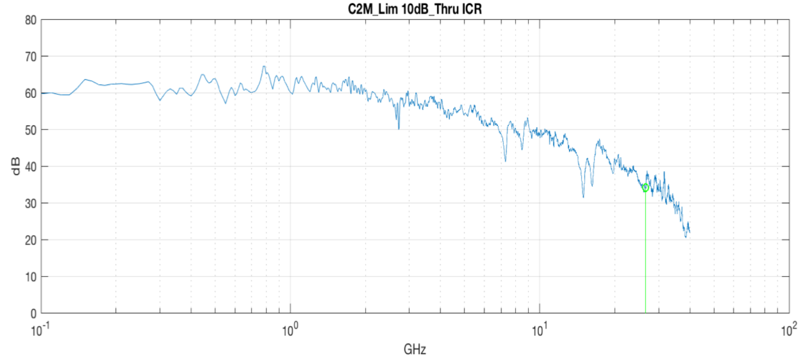
Result in (x) are for 30 mm PKG.

COM Analysis on Lim Channels

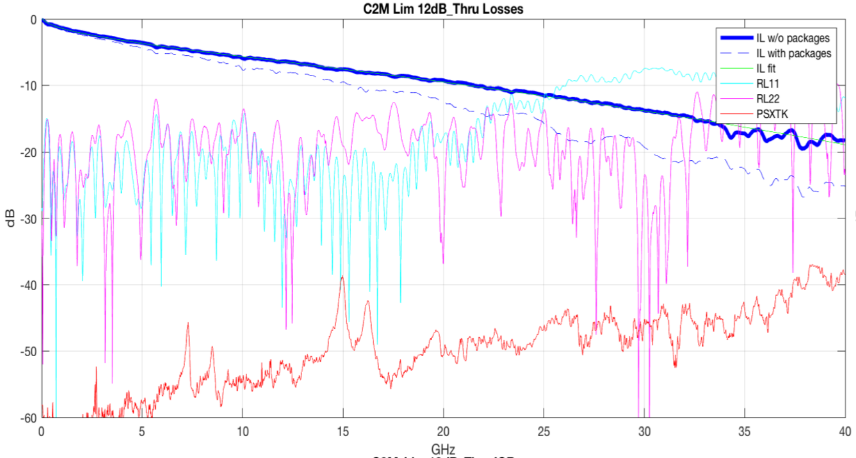
- Lim channels all including 10 dB fails due to high crosstalk and reflections
  - http://www.ieee802.org/3/ck/public/tools/c2m/lim_3ck_01_0718.zip
  - ghiasi_3ck_01_0918.pdf showed to equalize Lim channel combination of improving crosstalk, longer FFE with 1T DFE required
  - Lim channel marginally fails even at 50Gbps if one adjust the loss to 10.2 dB@13.275 GHz!

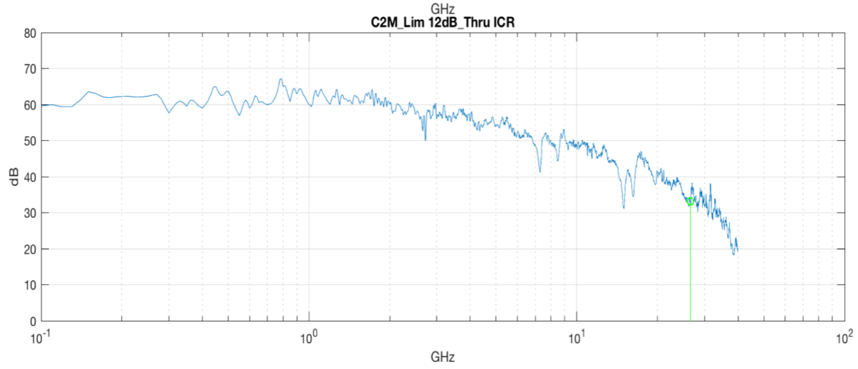
Lim 10 dB, FOM_ILD=0.145, ICN=3.65 mV
COM=2.17 dB, EH=13.2, VEC=13.11 dB
ICR=34 dB, CTLE Gain=-6 dB, G_DC2=-1.5 dB



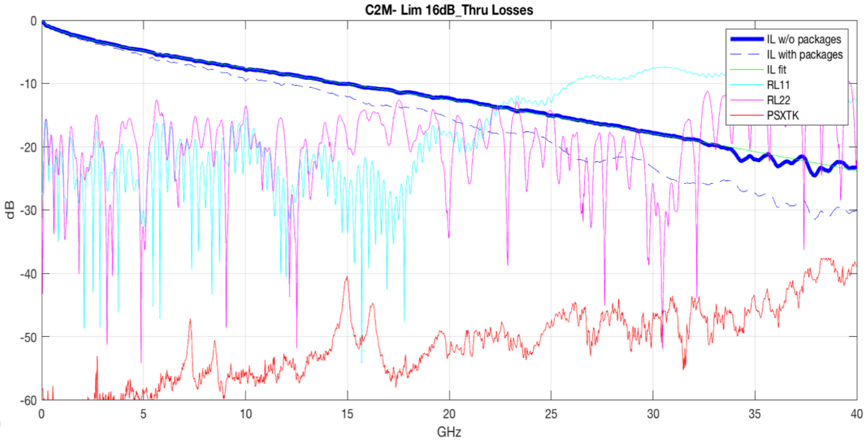


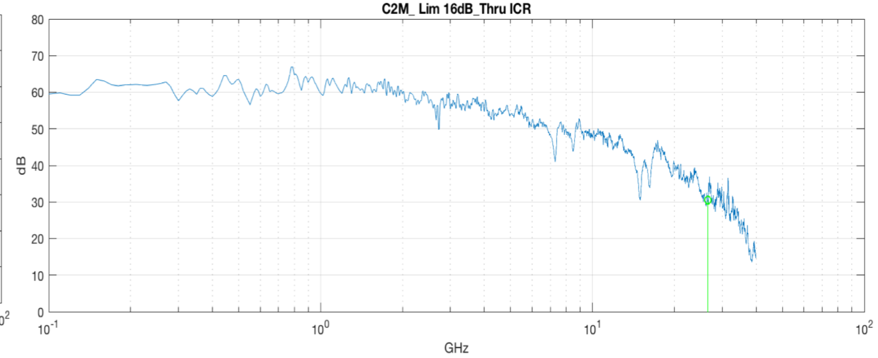
Lim 12 dB, FOM_ILD=0.143, ICN=3.26 mV
COM=1.53 dB, EH=5.18 mV, VEC=18.11 dB
ICR=33 dB, CTLE Gain=-12 dB, G_DC2=-1.5 dB





Lim 16 dB, FOM_ILD=0.15, ICN=2.77 mV
COM=0.622 dB, EH=2.2 mV, VEC=23.2 dB
ICR=30 dB, CTLE Gain=-11.5 dB, G_DC2=-2 dB





Comparing Yamaichi QSFP28 vs Lim 16 dB

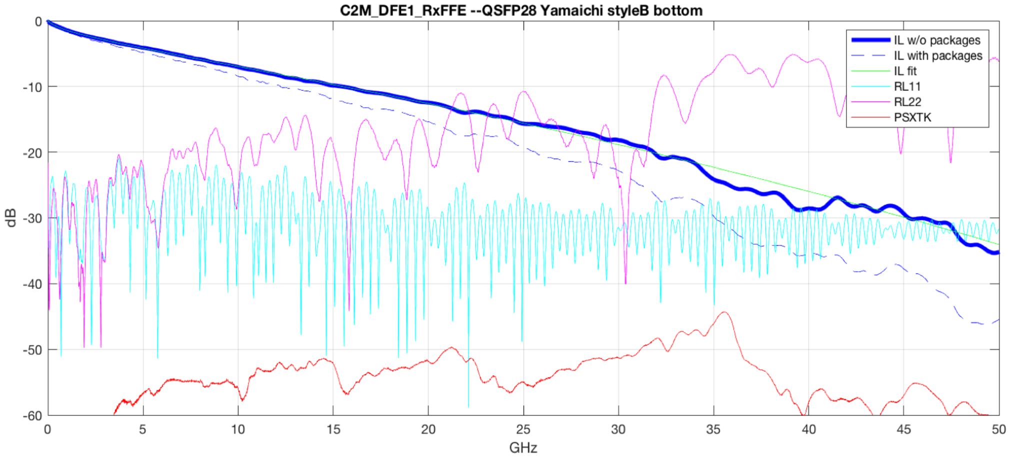
©

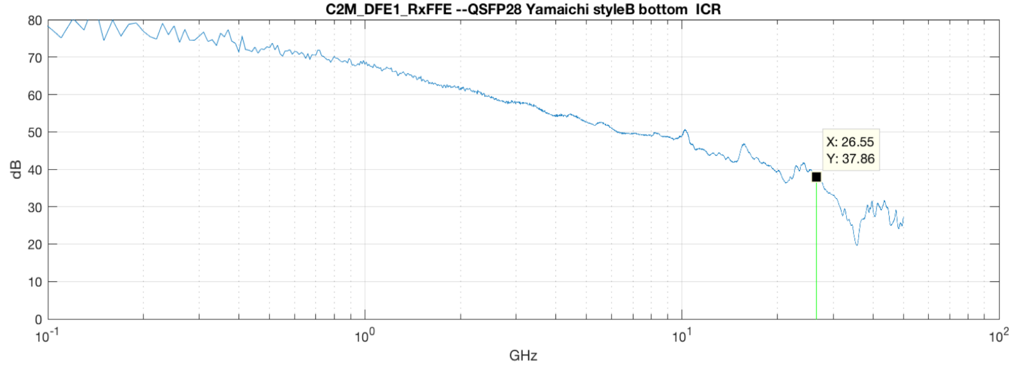
- **An ICR of 30 dB is just too low for a compliant channel**
  – Yamaichi QSFP28 board extensively studied in 802.3bs for 50G simulations, see ghiasi_3bs_02a_0317.pdf.

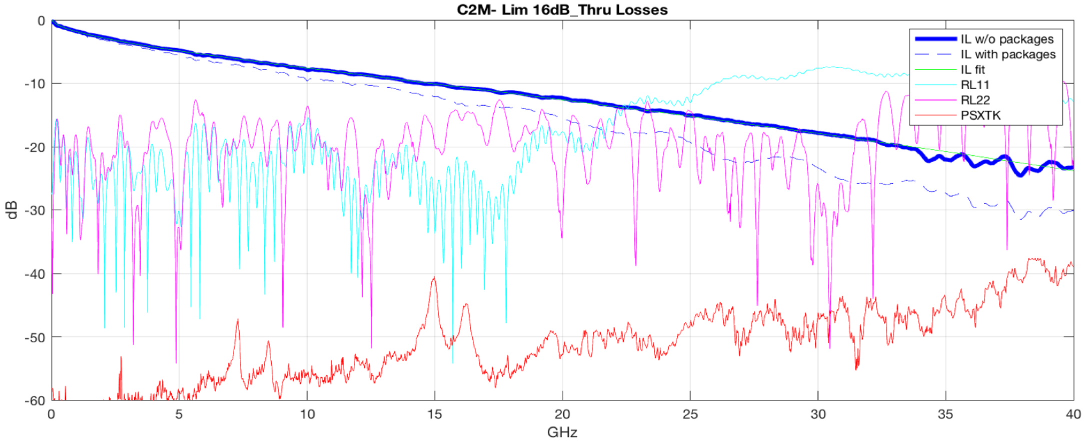
Key source of problem

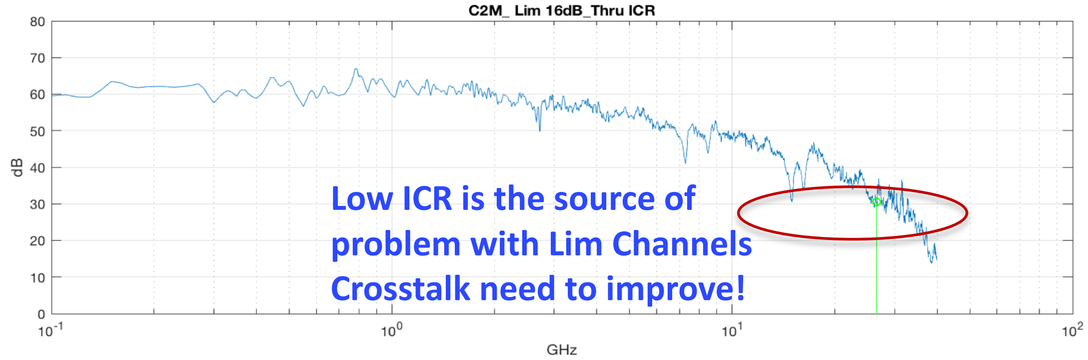
Bottom Contact, FOM_ILD=0.291, ICN=1.96 mV
COM=4.31 dB, EH=16.4 mV, VEC=8.15 dB
ICR=37.9 dB, CTLE Gain=-7 dB, G_DC2=-2 dB

Lim 16 dB, FOM_ILD=0.15, ICN=2.77 mV
COM=0.622 dB, EH=2.2 mV, VEC=23.2 dB
ICR=30 dB, CTLE Gain=-11.5 dB, G_DC2=-2 dB









Low ICR is the source of problem with Lim Channels Crosstalk need to improve!

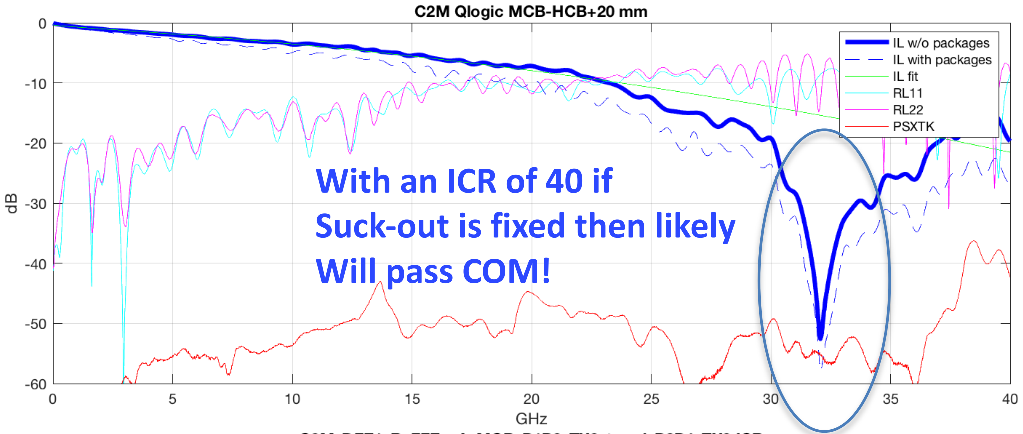
Comparing a Legacy QSFP28 Board to Lim 16 dB

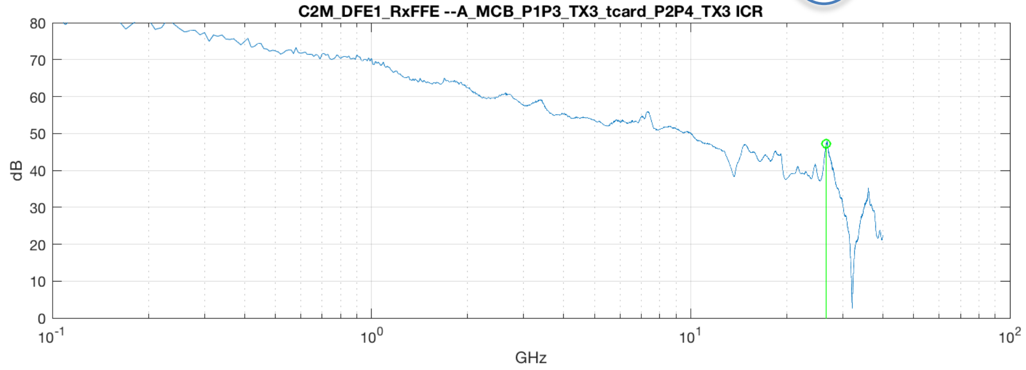
- **Qlogic QSFP28 board studied for CL120E dudek_3bs_01_0317.pdf and ghiasi_01_051517_elect.pdf**
  - The Qlogic board with huge suck-out not designed for 53 GBd operation even performs better than Lim 16 dB!

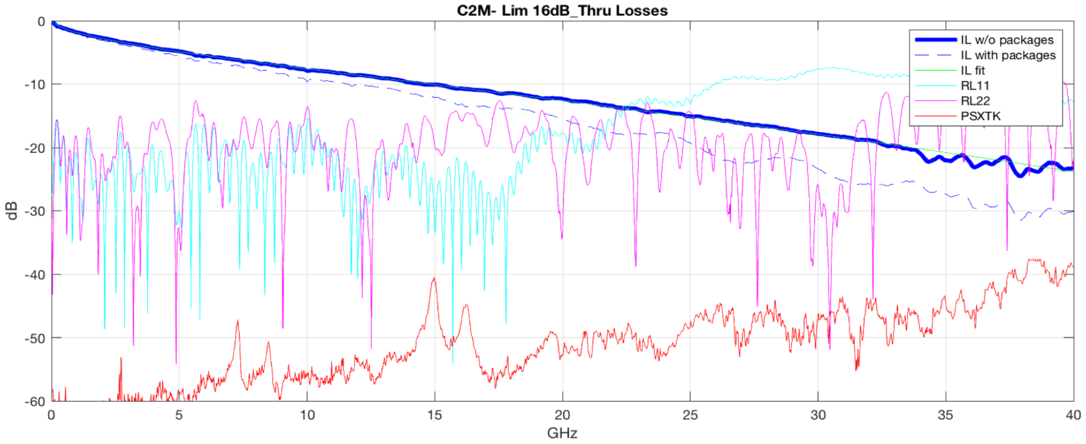
Key source of problem

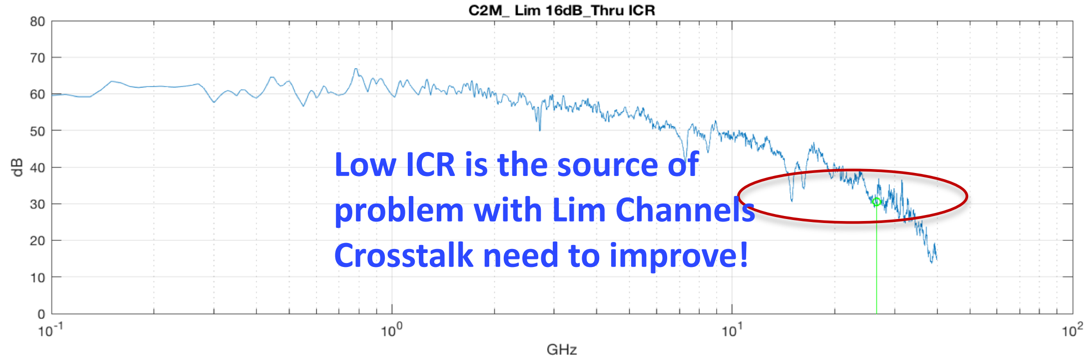
Qlogic QSFP28 MCB/HCB, FOM_ILD=2.88, ICN=2.74 mV
COM=0.84 dB, EH=4.9, VEC=20.7 dB
ICR=40 dB, CTLE Gain=-12 dB, G_DC2=-1 dB

Lim 16 dB, FOM_ILD=0.15, ICN=2.77 mV
COM=0.622 dB, EH=2.2 mV, VEC=23.2 dB
ICR=30 dB, CTLE Gain=-11.5 dB, G_DC2=-2 dB

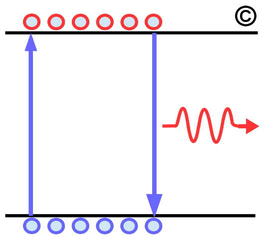






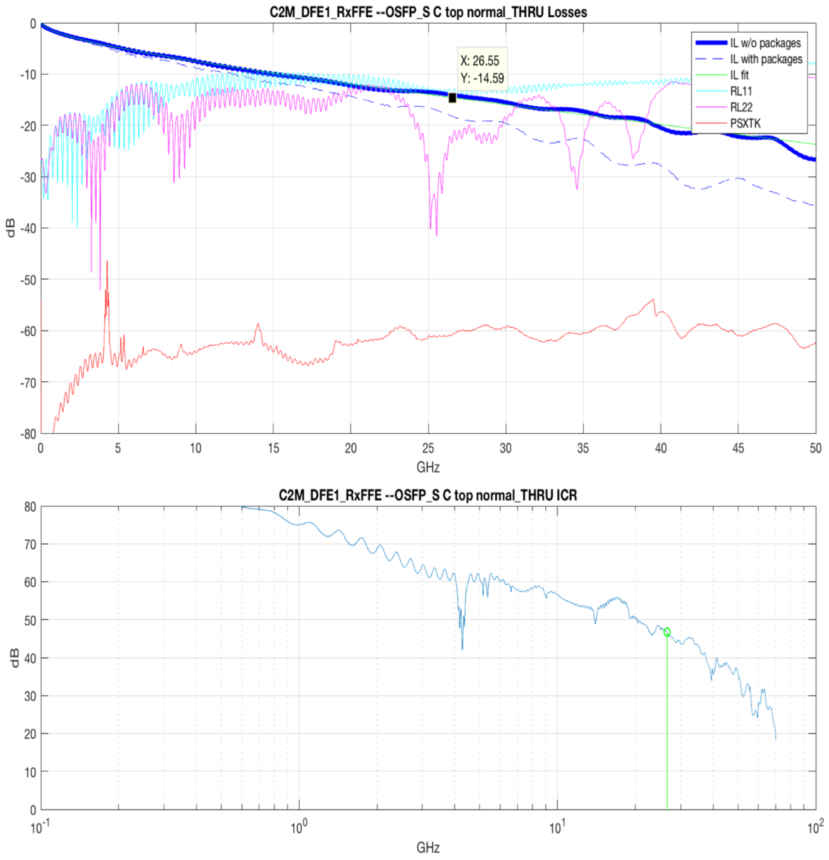


COM Analysis of Yamaichi Improved OSFP

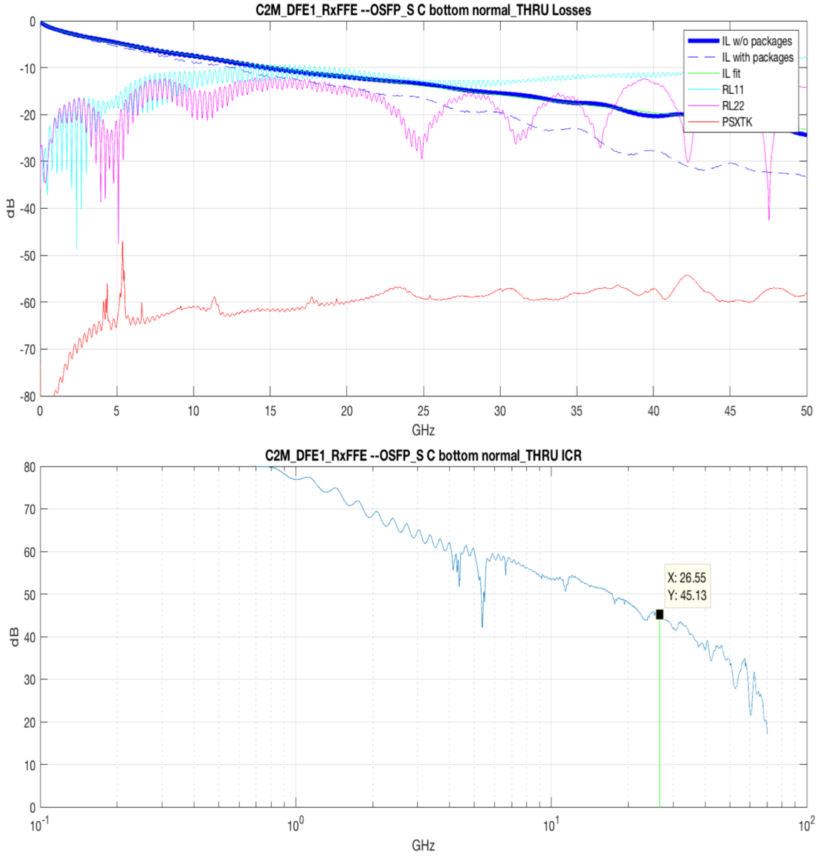


- **These board have dramatically improved ICN (Include 7 FEXT+ 4 NEXT)**
  - Top-contact loss 14.6 dB, bot-dd-contact loss 14.5 dB dB, bot-dd contact worst matting 14.7 dB.

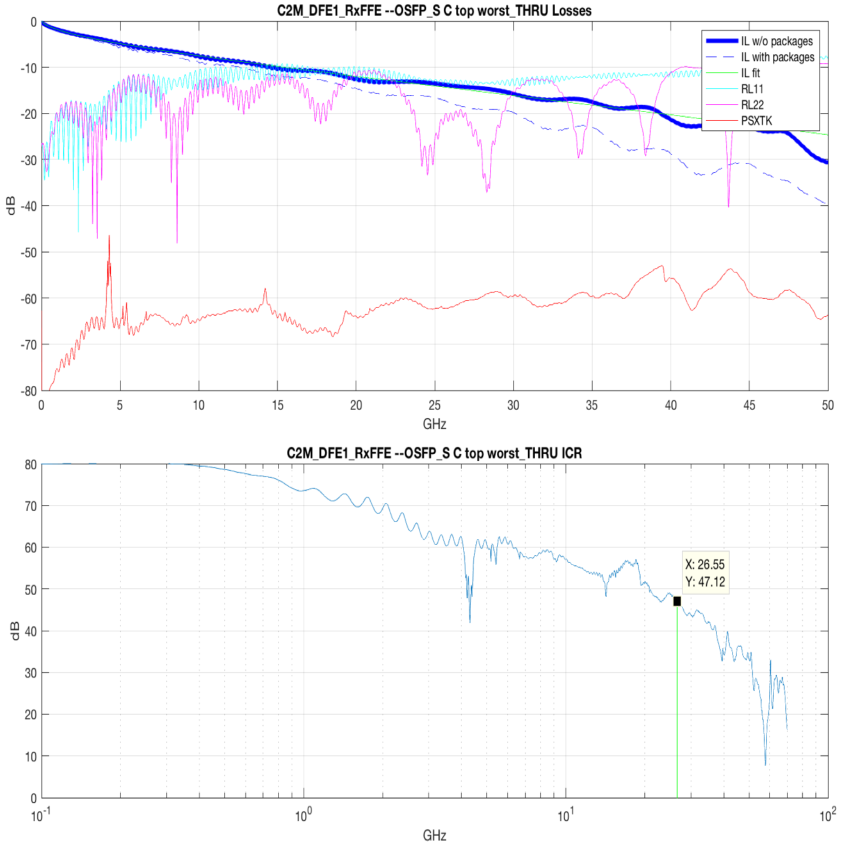
Top Contact, FOM_ILD=0.179, ICN=0.72 mV
COM=5.85 dB, EH=18.2mV, VEC=6.19 dB
ICR=46.7 dB, CTLE Gain=-10.5 dB, G_DC2=-2 dB



Bot contact, FOM_ILD=0.159, ICN=0.87 mV
COM=6.64 dB, EH=19.7 mV, VEC=5.44 dB
ICR=45.1 dB, CTLE Gain=-11.5 dB, G_DC2=-2 dB



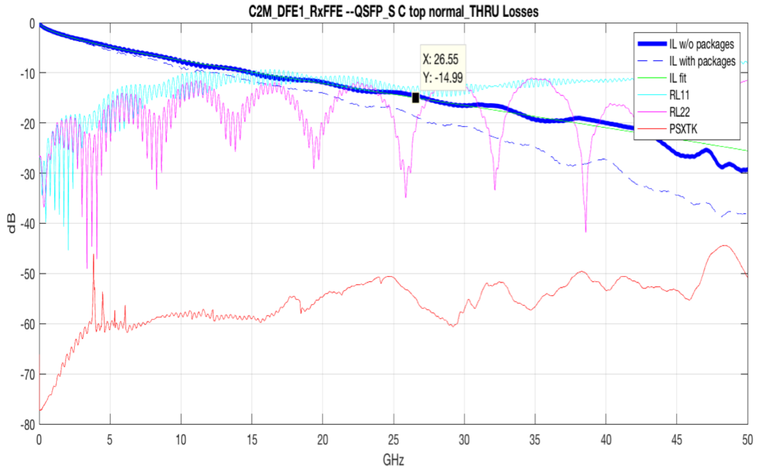
Top worst matting, FOM_ILD=0.249, ICN=0.711 mV
COM=4.75 dB, EH=15.8 mV, VEC=7.51 dB
ICR=47.12 dB, CTLE Gain=-11 dB, G_DC2=-2 dB

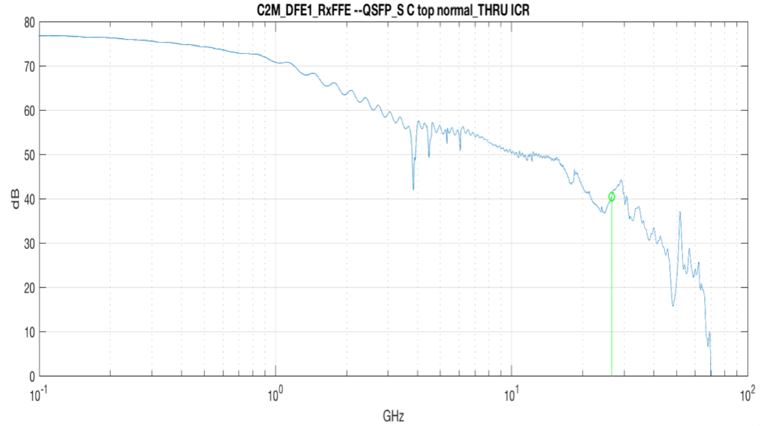


COM Analysis of Yamaichi Improved QSFP56

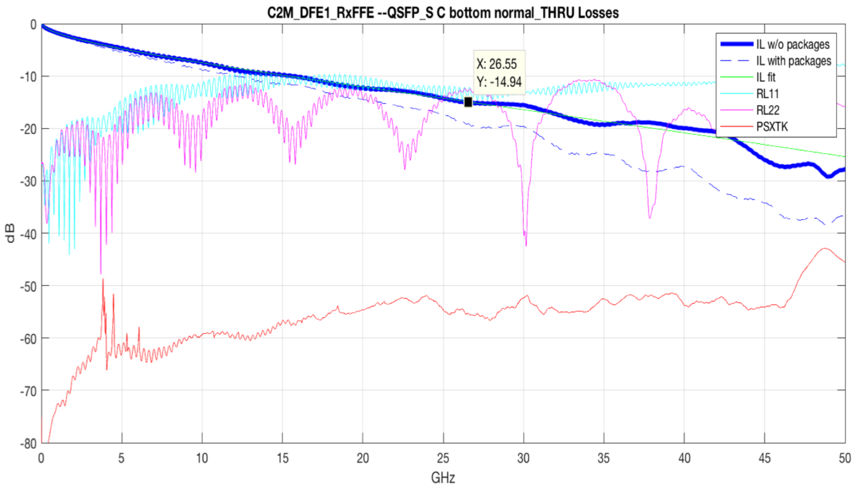
- **These board have dramatically improved ICN (Include 3 FEXT+ 4 NEXT)**
  - Top-contact loss 15.0 dB, bot-contact loss 14.9 dB dB, bot-contact worst matting 15.6 dB.

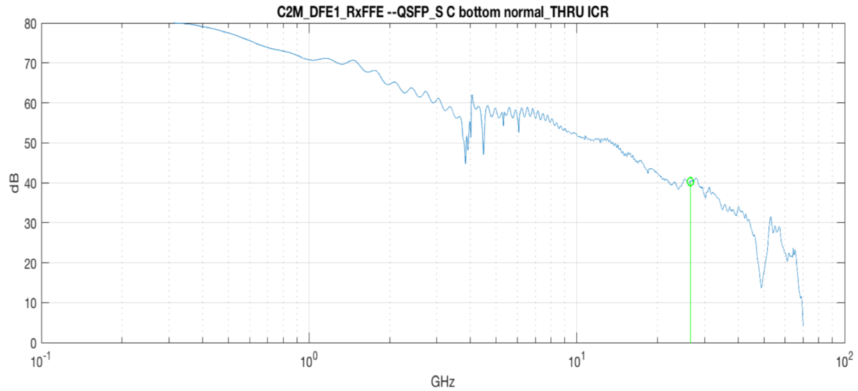
Top-legacy Contact, FOM_ILD=0.211, ICN=1.42 mV
COM=6.01 dB, EH=19.6 mV, VEC=6.03 dB
ICR=40.4 dB, CTLE Gain=-10.5 dB, G_DC2=-2 dB



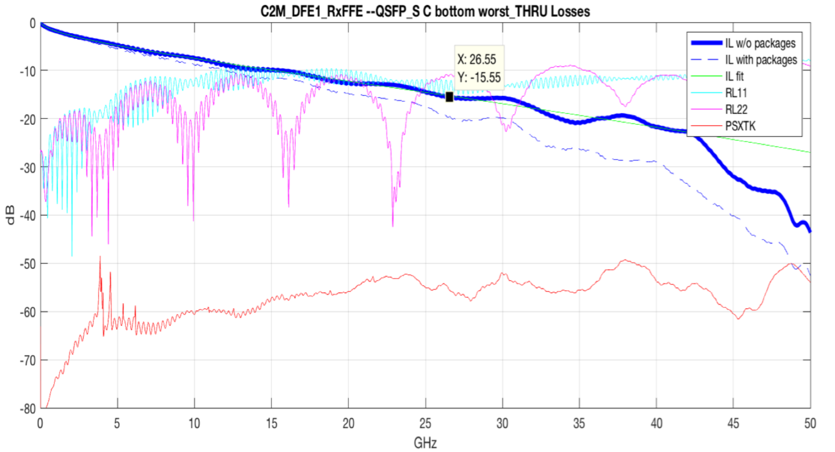


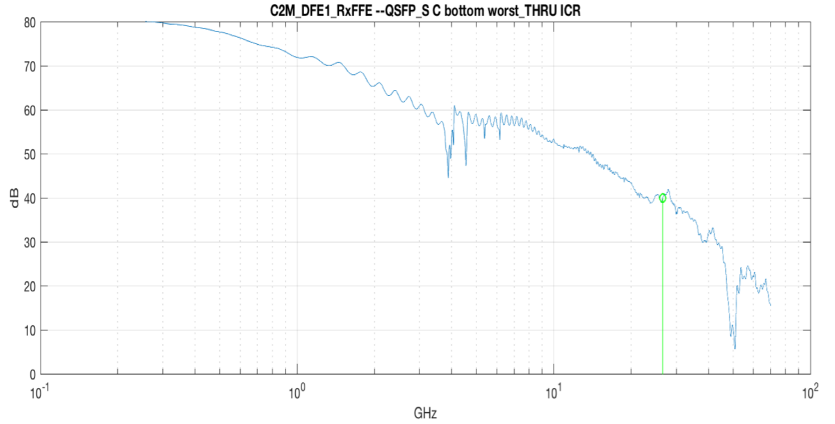
Bot.-dd contact, FOM_ILD=0.218, ICN=1.36 mV
COM=5.24 dB, EH=18.1 mV, VEC=6.89 dB
ICR=40.2 dB, CTLE Gain=-10.5 dB, G_DC2=-2 dB



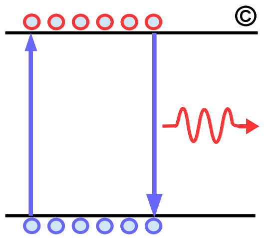


Bot.-dd worst matting, FOM_ILD=0.457, ICN=1.29 mV
COM=3.89 dB, EH=13.06 mV, VEC=8.84 dB
ICR=40.0 dB, CTLE Gain=-9.5 dB, G_DC2=-2 dB



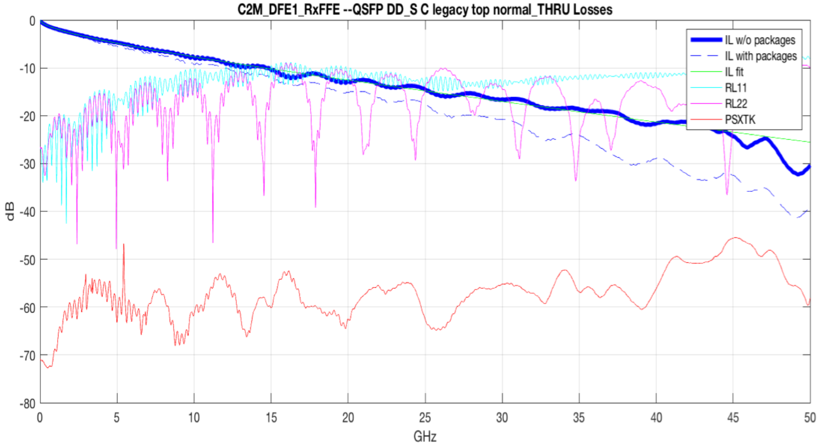


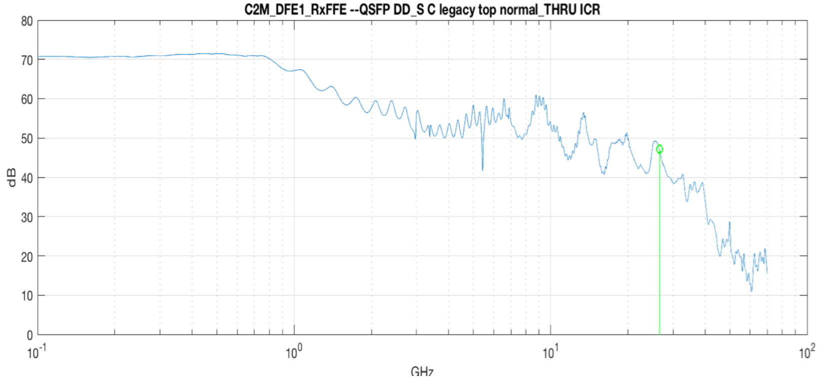
COM Analysis of Yamaichi Improved QSFP-dd



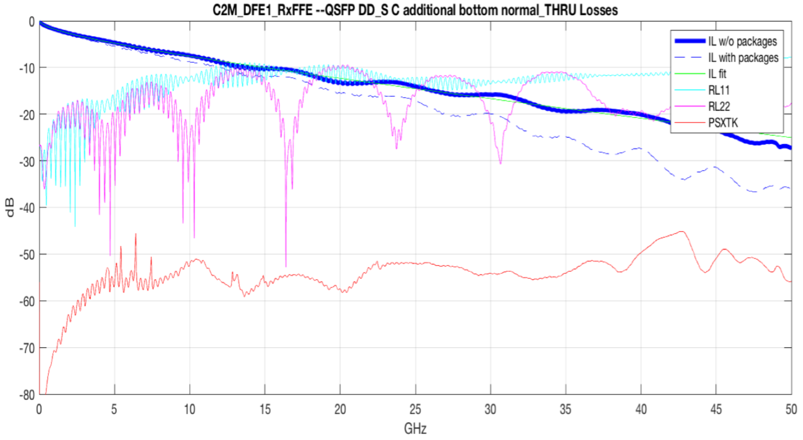
- **These board have dramatically improved ICN (Include 7 FEXT+ 8 NEXT)**
  - Top-contact loss 15.5 dB, bot-dd-contact loss 15.2 dB dB, bot-dd contact worst matting 15.7 dB.

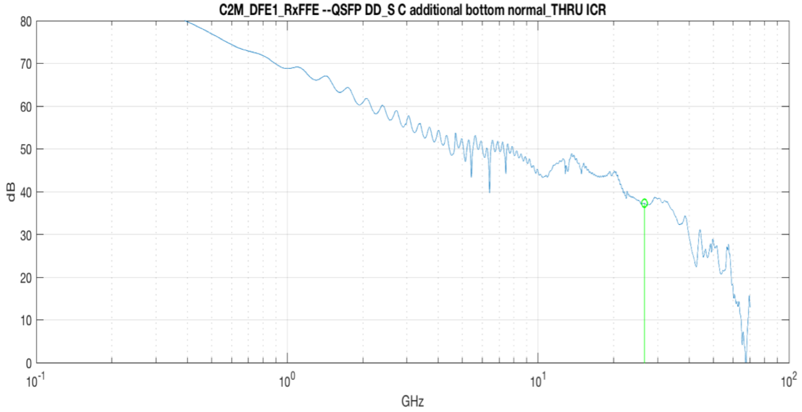
Top-legacy Contact, FOM_ILD=0.265, ICN=1.25 mV
COM=3.9 dB, EH=13.1 mV, VEC=8.78 dB
ICR=~41 dB, CTLE Gain=-13 dB, G_DC2=-1.5 dB



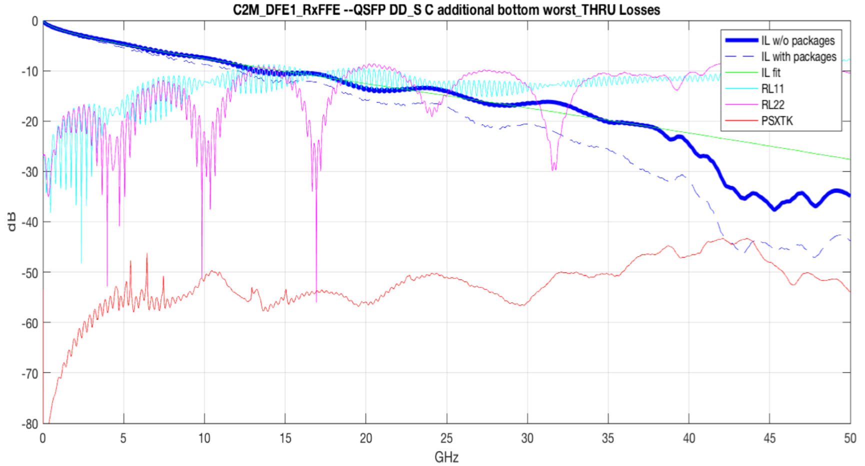


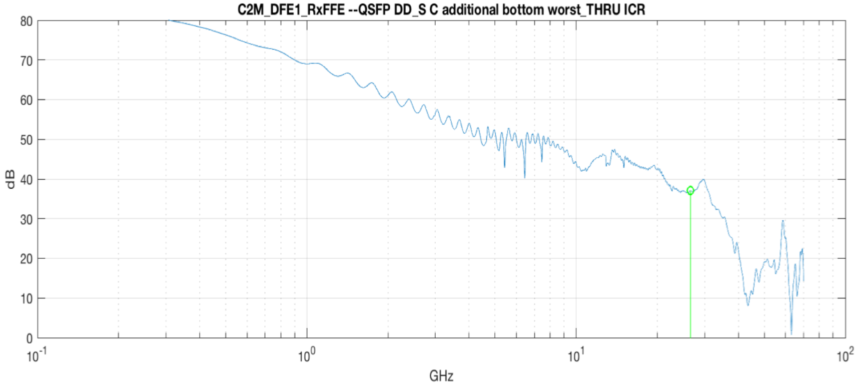
Bot.-dd contact, FOM_ILD=0.269, ICN=1.76 mV
COM=3.6 dB, EH=12.1 mV, VEC=9.34 dB
ICR=37.2 dB, CTLE Gain=-10 dB, G_DC2=-2 dB





Bot.-dd worst matting, FOM_ILD=0.704, ICN=2.02 mV
COM=3.19 dB, EH=10.4 mV, VEC=10.24 dB
ICR=37.1 dB, CTLE Gain=-10.5 dB, G_DC2=-2 dB





Summary

- **Proposed C2M CTLE uses parametric definition of CL120D but with filter response of CL120E scaled for 53.1 GBd operation**
- **Initial COM results indicate an RX equalizer with CTLE+5T FFE (4 post) is sufficient for reasonably well constructed 16 dB channels**
  - The above equalizer is sufficient for TE OSFP 16 dB channels, Yamaichi QSFP28 16 dB, Yamaichi QSFP56, QSFP-dd, and OSFP
  - Qlogic QSFP28 board not designed for 53 GBd performs better than Lim channels
  - Lim channels fails even for 12T FFE or 5T FFE+1T DFE receiver due to high crosstalk, therefore these channels are non-compliant
- **Technically is possible to equalize Lim channels but given that these boards have excessive crosstalk possibly due to HCB at this point there is no reason to saddle every C2M interface with higher power**
  - Propose for now to stay with following low power de-facto architecture 4T FFE TX and CTLE+5T FFE (4 post) RX
- **Although Clause 120E only provides a recommendation on the insertion loss of the Chip to Module channel it would be helpful to provide more guidance to host designers**
  - This could be done with masks for return loss, FOM-ILD, ICN, in addition to IL but this will result in over-design with some good channels failing, a better option is to use COM
  - I have support of Mr. Dudek and Mellitz to bring a full proposal for January interim how to use COM as a informative metric for C2M.