Initial C2M Results and Choice of CTLE

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September 14, 2018

Overview

- Clause 120D and 120E CTLE
- Benefit of CL120E CTLE for non-DFE receivers
- Starting point for 100G CTLE
- Some early results using above CTLE+5T FFE for Lim, Tracy, and Yamaichi channels.

CL120D and CL120E CTLEs Defined by 802.3bs

- **CL120D CTLE defined in CL93A by Eq. 93A-22**
  - Low frequency gain sum of g_{DC}+g_{DC2}
  - 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

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

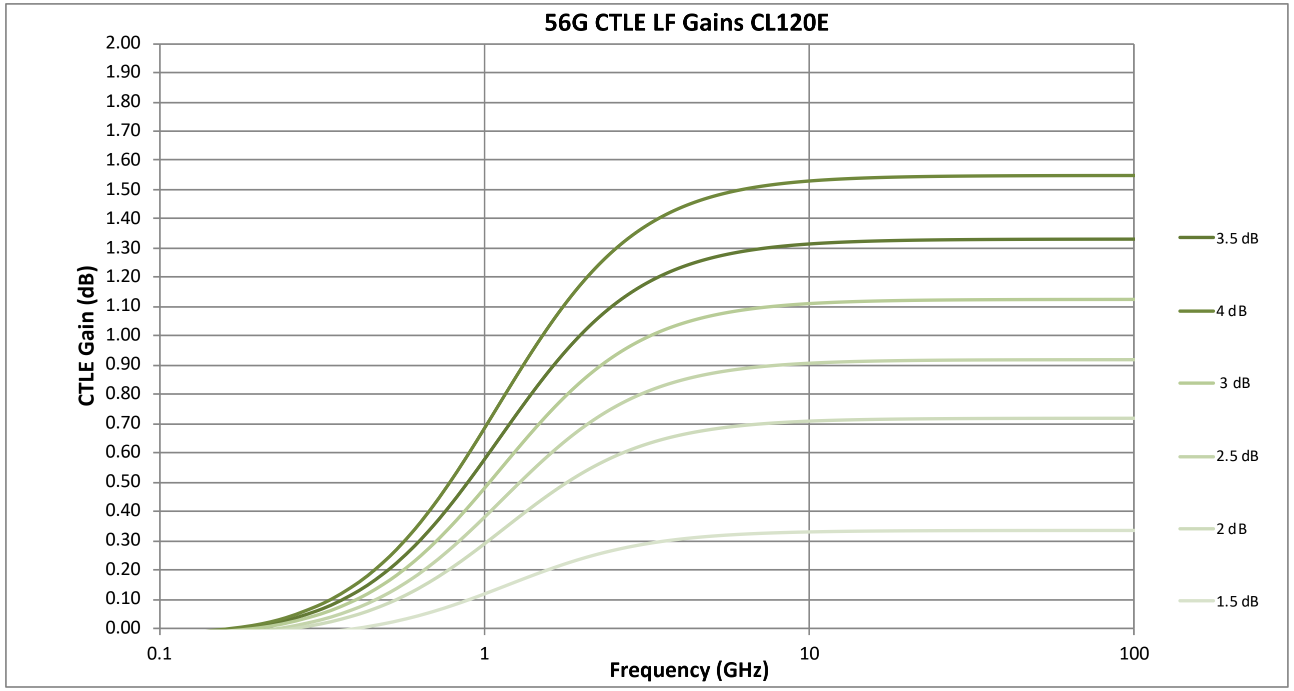
- **CL120E CTLE defined in CL120E by Eq. 120E-2**
  - Low frequency gain only determined by gain G
  - COM f_r=Fbaud.

Peaking (dB)	G	$\frac{P_1}{2\pi}$	$\frac{P_2}{2\pi}$	$\frac{Z_1}{2\pi}$	$\frac{P_{LF}}{2\pi}$	$\frac{Z_{LF}}{2\pi}$
1	0.891251	26.5625	14.1	9.463748	1.2	1.2
1.5	0.841395	26.5625	14.1	9.248465	1.2	1.15
2	0.794328	26.5625	14.1	9.069645	1.2	1.1
2.5	0.749894	26.5625	14.1	8.640319	1.2	1.075
3	0.707946	26.5625	14.1	8.255665	1.2	1.05
3.5	0.668344	26.5625	14.1	7.906766	1.2	1.025
4	0.630957	26.5625	14.1	7.58765	1.2	1
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

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

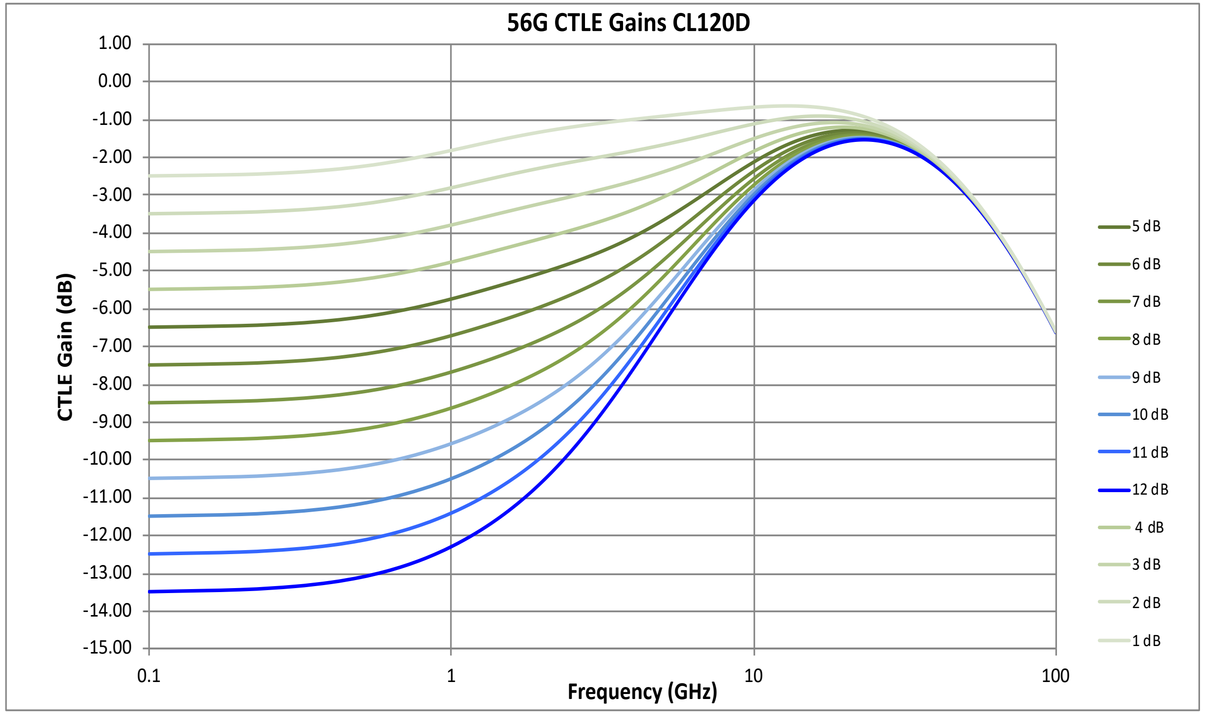
CL120D vs CL120E CTLE LF Response

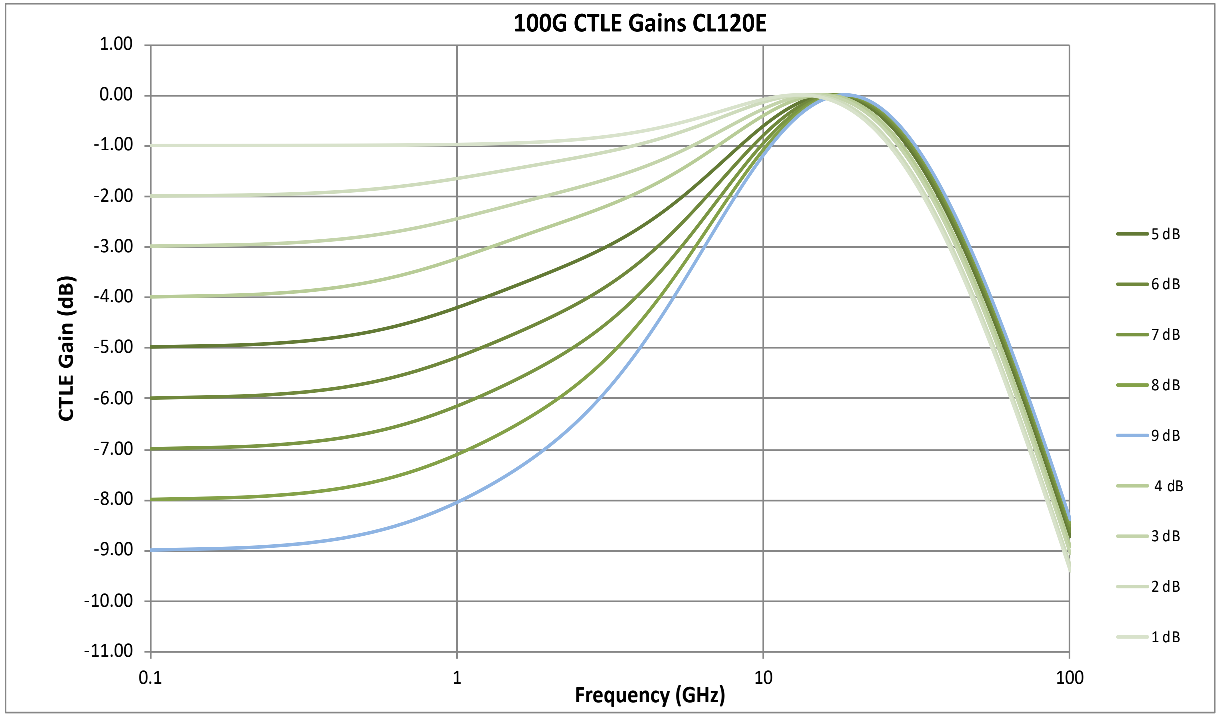
- **Clause 120D LF gain g_{DC2} can vary from 0 to -4 dB**
  - Steps are 1 dB each
  - Any of CTLE setting may have 0 to -4 dB LF gain.
- **CL120 LF gain is function of peaking gain, with LF gain fixed at ~1.5 dB for ≥ 4 dB peaking gain as shown below (LF loss adjusted to 0)**
  - Steps varies from ~0.5 dB to ~0.2 dB



CL120D vs CL120E CTLE Response

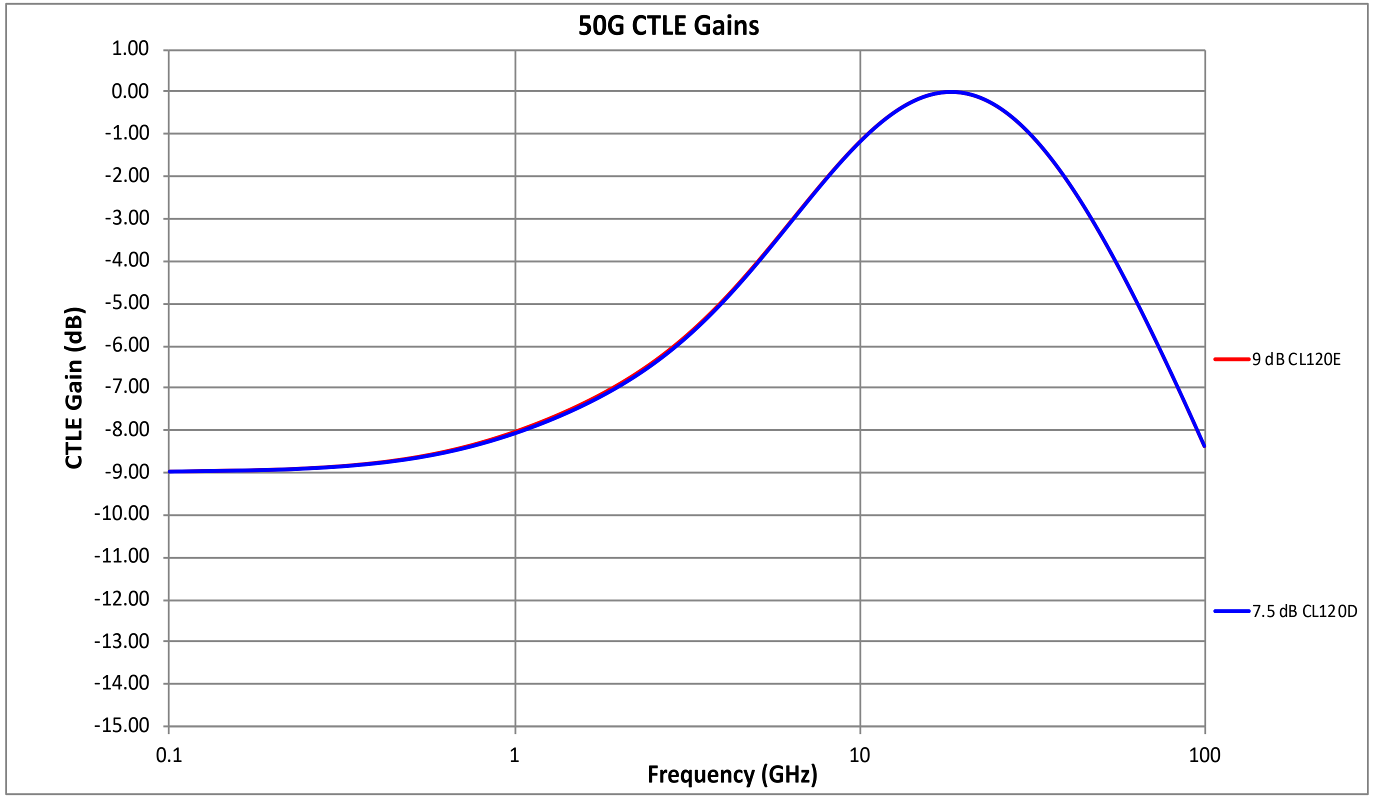
- **Response of 50G CL120D with 1.5 dB g_{DC} and CL120E CTLE**
  - Key differences
    - CL120E has 0 dB resonance peak where CL120D has ~1.5 dB loss
    - CL120D CTLE peaks ~15.3 GHz where CL120E peaks ~19 GHz, higher BW CTLE is beneficial specially for non-DFE receiver
    - CL120D DC gain is sum of low+high frequency gains where CL120E DC gain determined only by high frequency gain
    - The 3 dB roll-of for CL120D is ~53 GHz where CL120E is ~31 GHz!





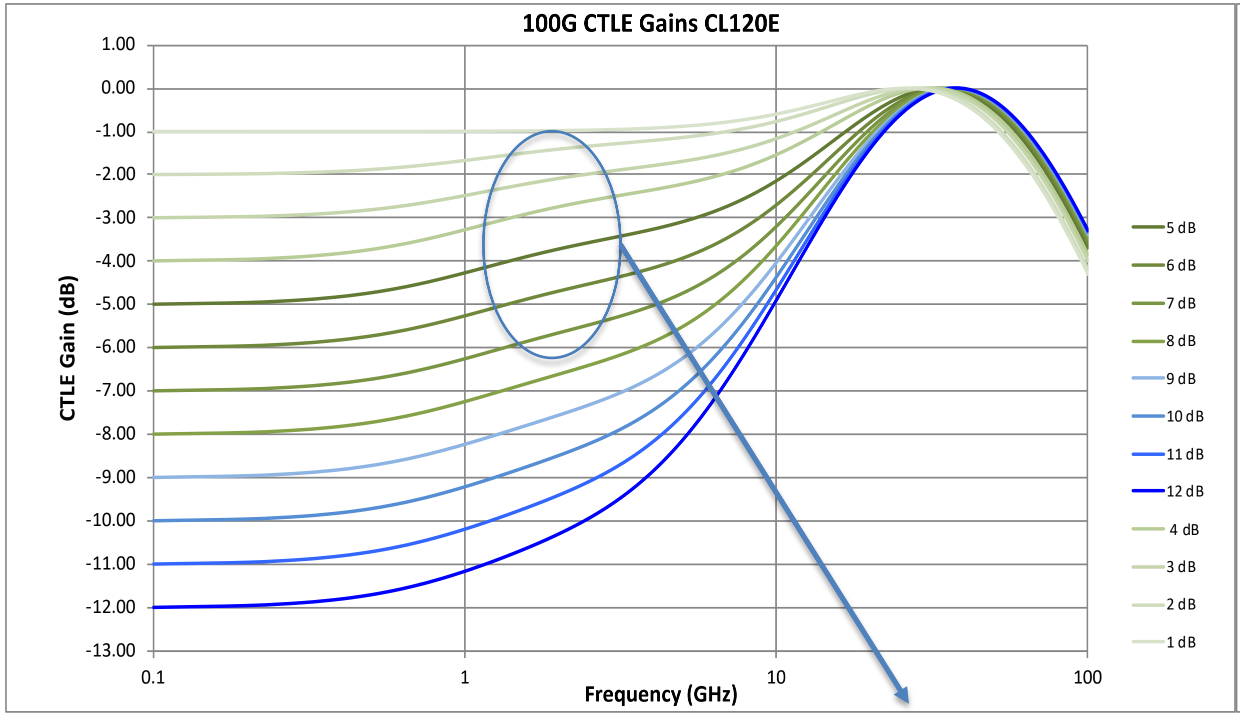
Adjusting CL120D CTLE to Have Improved Performance of CL120E CTLE

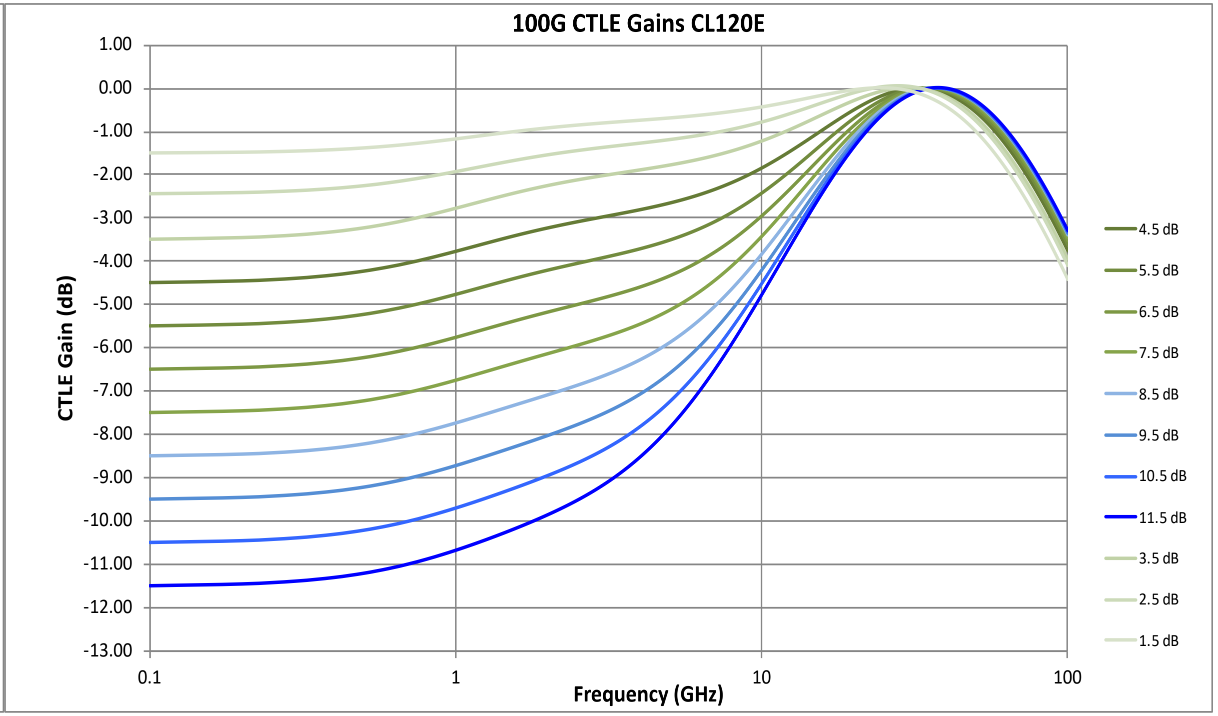
- **CL120D low frequency CTLE gain =g_{DC}+ g_{DC2} CTLE where CL120 low frequency CTLE gain is determine only by high frequency poles/zero**
- **CL120D CTLE can adapted to have response of CL120 by making following changes to equation 93A-22:**
  - Z1 changed from 0.28736*Baudrate to 0.35398*Baudrate
  - P1 changed from 0.4*Baudrate to 0.53082*Baudrate
  - P2 changed from 2*Baudrate to 1*Baudrate
  - f_{LF} unchanged
- **Graph shown is for 9 dB CTLE from CL120E and the adapted CL120D for 7.5 dB g_{DC} with 1.5 dB g_{DC2} with identical response.**



Converging Toward 100G C2M CTLE

- **The 100G C2M CTLE HF gain adjusted below 9 dB to 12 dB but LF pole (1.2 GHz) and gain (1.5 dB) unchanged**
  - Should consider increasing LF gain to 2 dB, either adjust LF gain to be equal-distance in dB or scale it as ratio of HF gain
  - Other option would be to go with C120D CTLE style having CL120E response with 10 dB HF gain and 2 dB LF gain

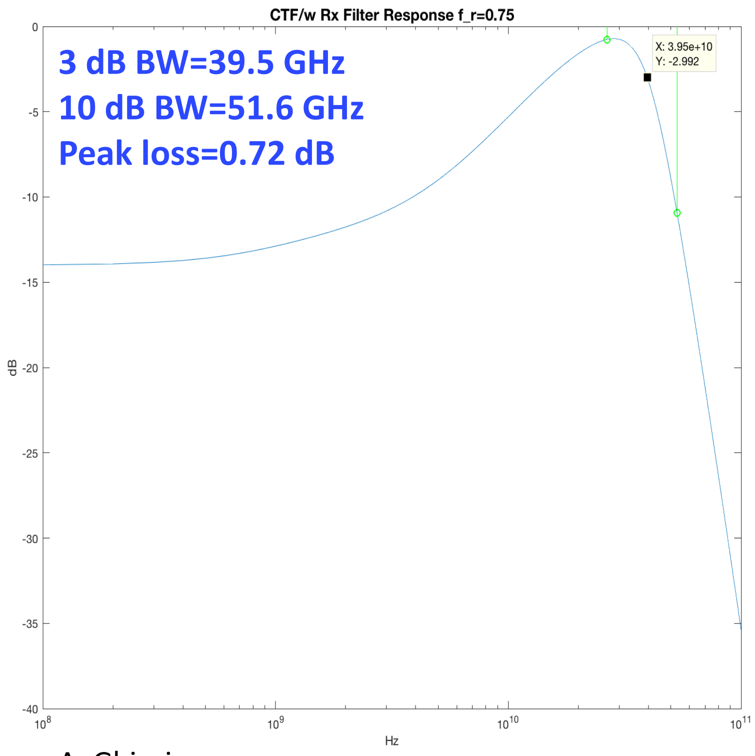


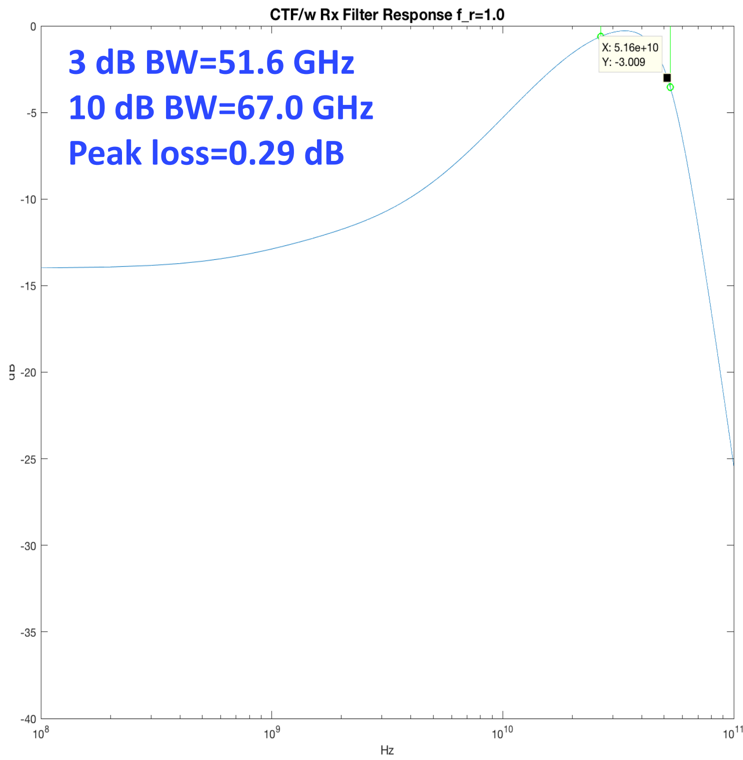


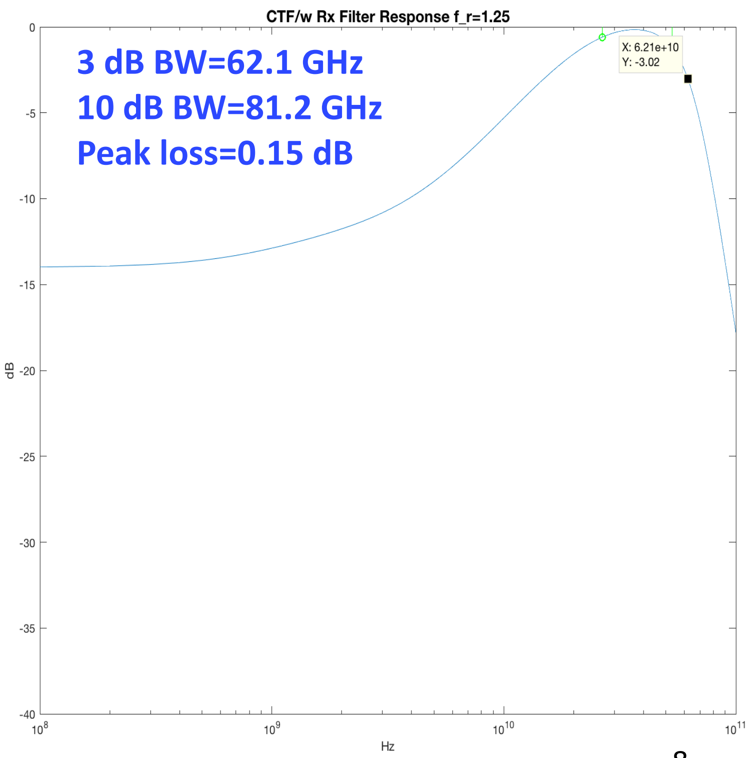
Adjusting LF gain proportionally will smooth this region

Cascaded CTLE and Frontend BW

- **Clause 120E style of CTLE has wider BW with faster roll-off results shown for G_{DC}=-12 dB G_{DC2}=-2 dB**
  - COM simulations here uses F_r=1.0
  - Reducing post CTLE filter BW f_r increases peak loss
  - I can adjust the poles/zeros if preferred to get peak loss=0 dB.







COM Code 2.41

- **Filter coefficient selected to have CL120E response**
  - http://www.ieee802.org/3/ck/public/tools/tools/mellitz_3ck_adhoc_01_081518_COM2p41.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)	[-0.2:0.02:0]		[min:step:max]
N_b	0	UI	
b_max(1)	0.6		
g_DC	[-14:0.5:-8]	dB	[min:step:max]
f_z	1.8805E+01	GHz	
f_p1	5.3100E+01	GHz	
f_p2	2.8200E+01	GHz	
g_DC_HP	[-2:0.25:-0.5]		[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	0	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	
R_LM	0.95		

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	110	Ohm
z_bp (TX)	151	mm
z_bp (NEXT)	72	mm
z_bp (FEXT)	72	mm
z_bp (RX)	151	mm

COM Results for Cl120D/120E for 5 Tap RX FFE as function of LF HP Poles

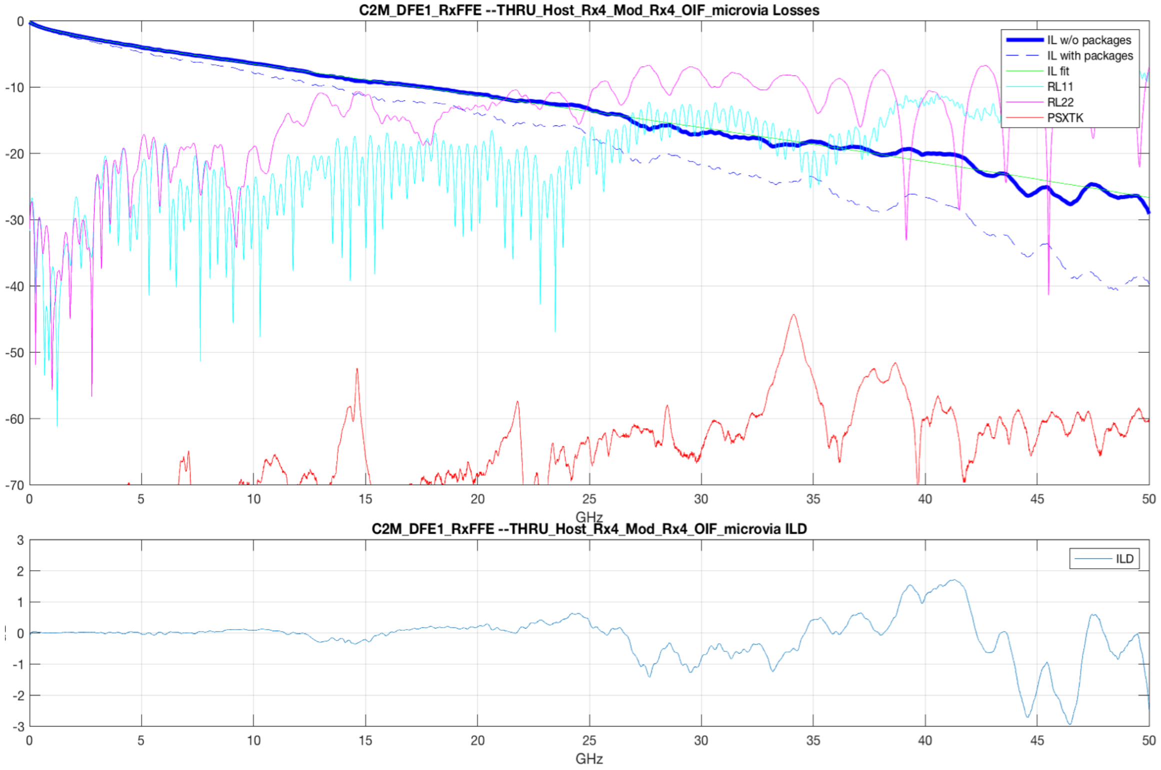
(Both Channels Have total_IL_wpkgs_dB~20 dB, CL120D f_r=0.75 Fbaud, CL120E f_r=Fbaud)

tracy T4 Long Barrel	COM (dB)	EH (mV)	VEC (dB)	ICN (mV)	ILD	CTLE (dB)	G_{DC2} (dB)
CL120E, fH=1.2 GHz	3.32	10.02	9.96	0.54	0.42	-13	-1.5
CL120E, fH=1.8 GHz	3.19	9.67	10.24	0.54	0.42	-13	-1.25
CL120E, fH=2.4 GHz	3.19	9.69	10.25	0.54	0.42	-12.5	-1.75
CL120D, fH=1.2 GHz	3.09	7.67	10.47	0.51	0.39	-14	-1.5
CL120D, fH=1.8 GHz	2.99	7.44	10.71	0.51	0.39	-14	-1.25
CL120D, fH=2.4 GHz	2.96	7.4	10.78	0.51	0.39	-13.5	-1.75
lim 14 dB Channel							
CL120E, fh=1.2 GHz	1.05	4.07	18.91	2.99	0.15	-12.5	-1.75
CL120E, fh=2.4 GHz	0.95	3.73	19.6	2.99	0.15	-12	-2
CL120D, fh=1.2 GHz	1.06	3.43	18.78	2.84	0.13	-13.5	-1.75
CL120D, fh=2.4 GHz	0.98	3.16	19.5	2.87	0.13	-13	-2

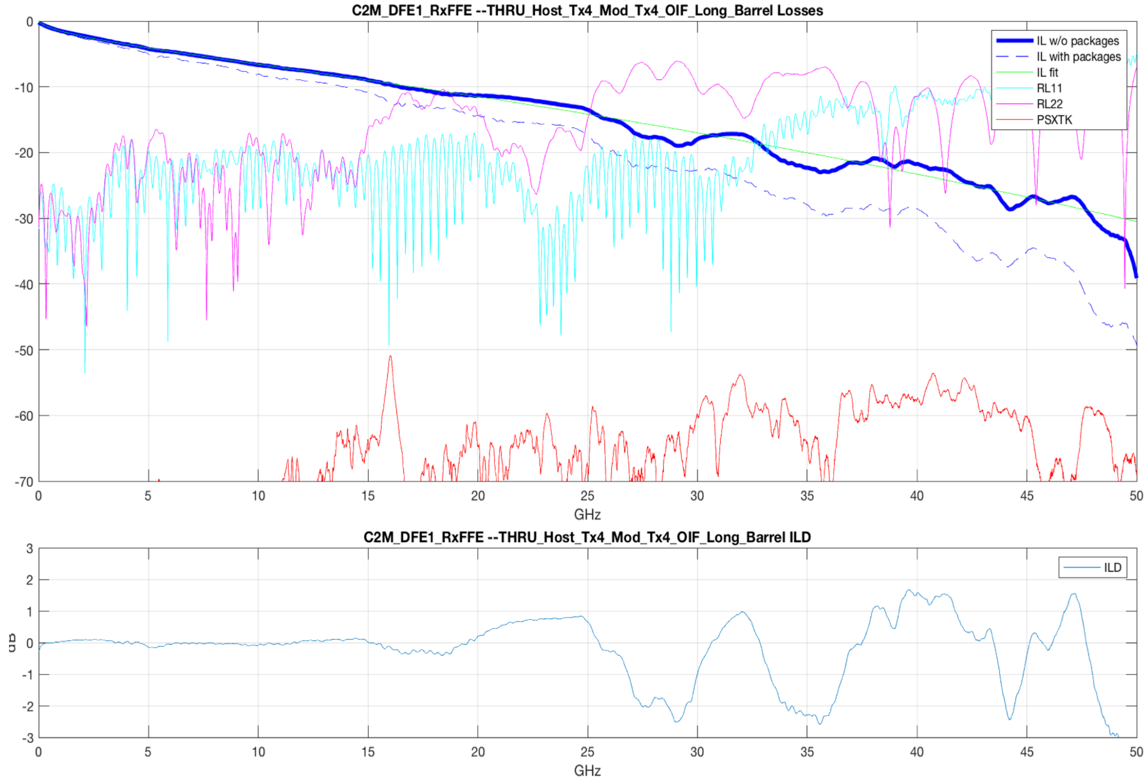
COM Analysis of Tracy Channels

- **COM results for 8.5" OSFP channels with 4 TX FFE and RX CTLE with 5 tap FFE (4 post)**
  - 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)
  - Channel do have somewhat higher ILD/RL but given low crosstalk these channel operates with margin with just 5 tap RX FFE!

Tracy MicroVia, FOM_ILD=0.228, ICN=0.676 mV
COM=4.06 dB, EH=14.04, VEC=8.56 dB
ICR=48 dB, CTLE Gain=-13 dB, G_DC2=-1.5 dB



Tracy LongBarrel, FOM_ILD=0.415, ICN=0.527 mV
COM=3.32 dB, EH=10.02, VEC=9.96 dB
ICR=46 dB, CTLE Gain=-13 dB, G_DC2=-1.5 dB

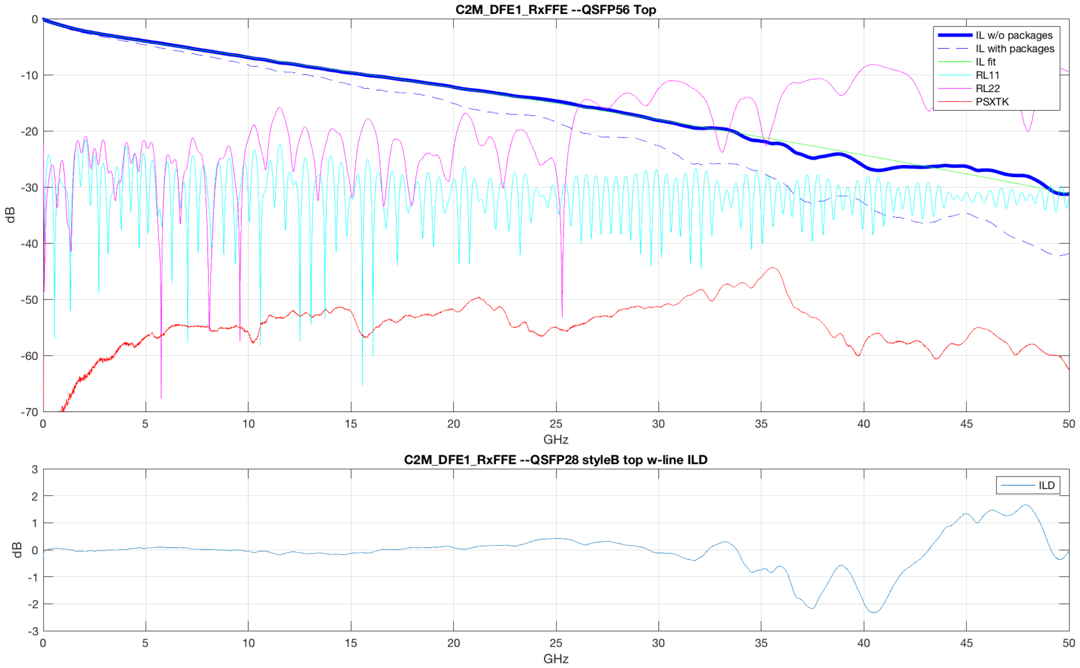


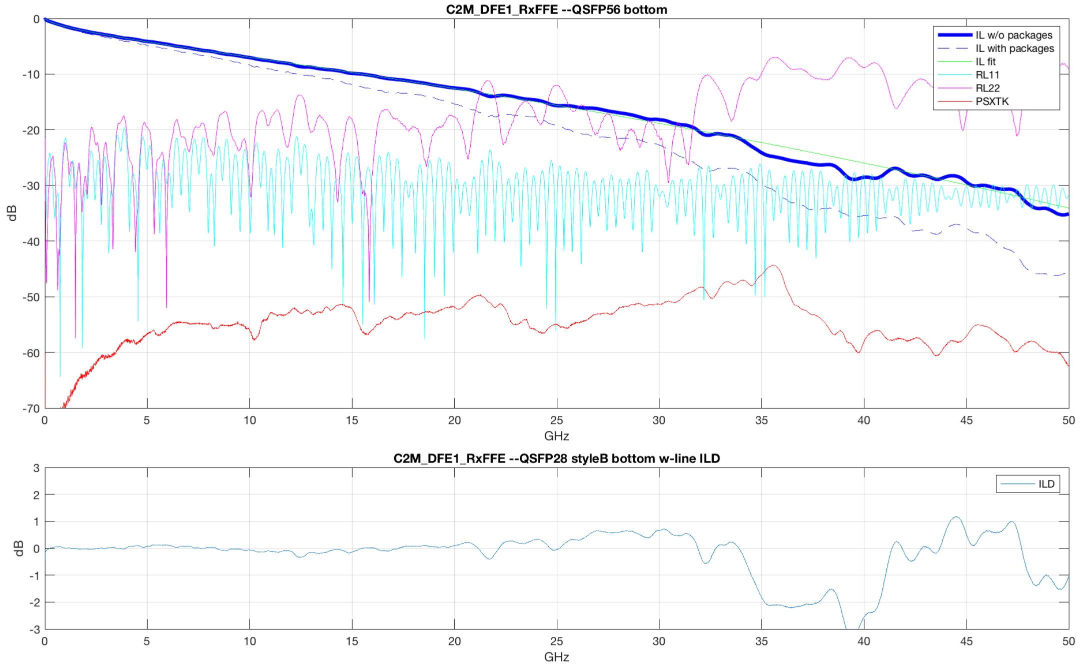
COM Analysis Yamaichi QSFP56 Mated Board

- **130 mm trace added in COM to increase mated board loss to 16 dB**
  - Include 3 FEXT+ worst NEXT
  - Results are for 4 TX FFE and RX CTLE with 5 tap FFE (4 post).

Top Contact, FOM_ILD=0.203, ICN=1.96 mV
COM=4.71 dB, EH=16.11 mV, VEC=7.45 dB
ICR=38.2 dB, CTLE Gain=-11 dB, G_DC2=-2 dB

Bottom Contact, FOM_ILD=0.295, ICN=1.96 mV
COM=4.39 dB, EH=15.9 mV, VEC=8.02 dB
ICR=37.9 dB, CTLE Gain=-8 dB, G_DC2=-2 dB

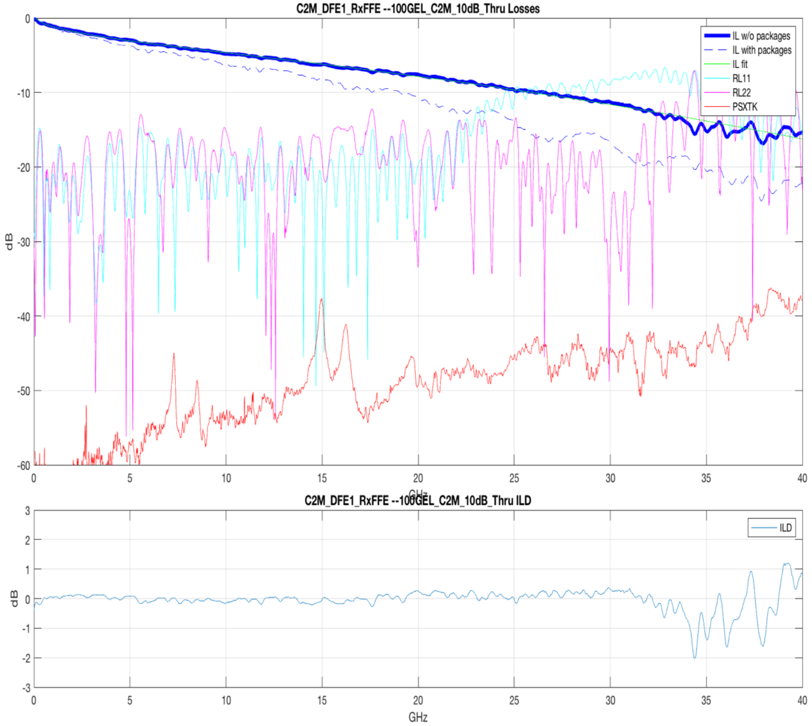




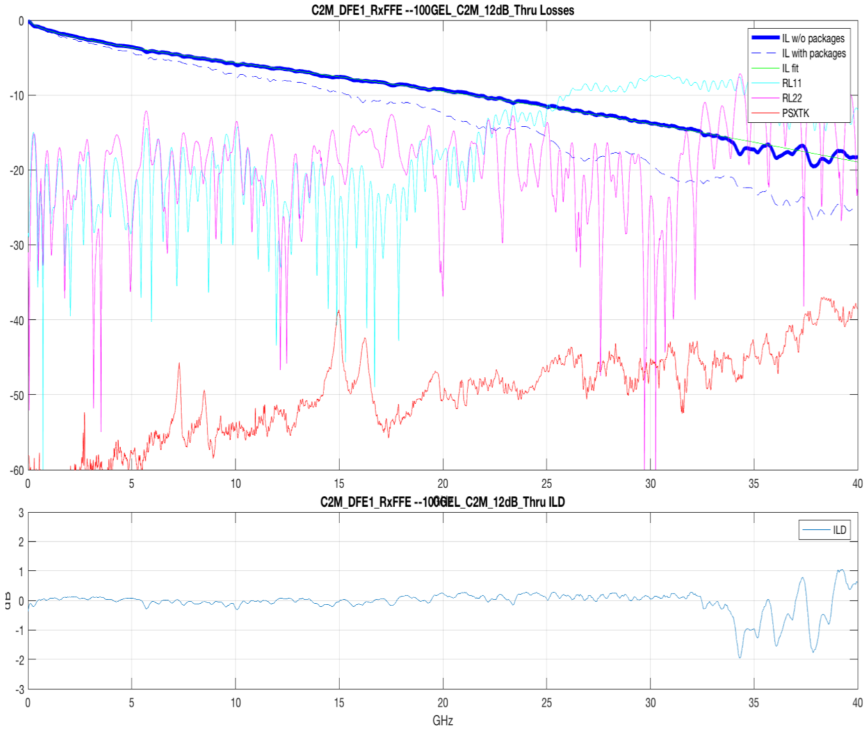
COM Analysis Lim Channels

- **COM results for QSFP56 channels with 4 TX FFE and RX CTLE with 5 tap FFE (4 post)**
  - http://www.ieee802.org/3/ck/public/tools/c2m/lim_3ck_01_0718.zip
  - Channels have excellent ILD/RL but due to crosstalk even 10 dB channel fails with 5 tap RX FFE!
  - Lim simulations show that 5 tap FFE can work but the improvement possibly due to more aggressive package model than assumed here
    - See http://www.ieee802.org/3/ck/public/18_07/lim_3ck_01b_0718.pdf

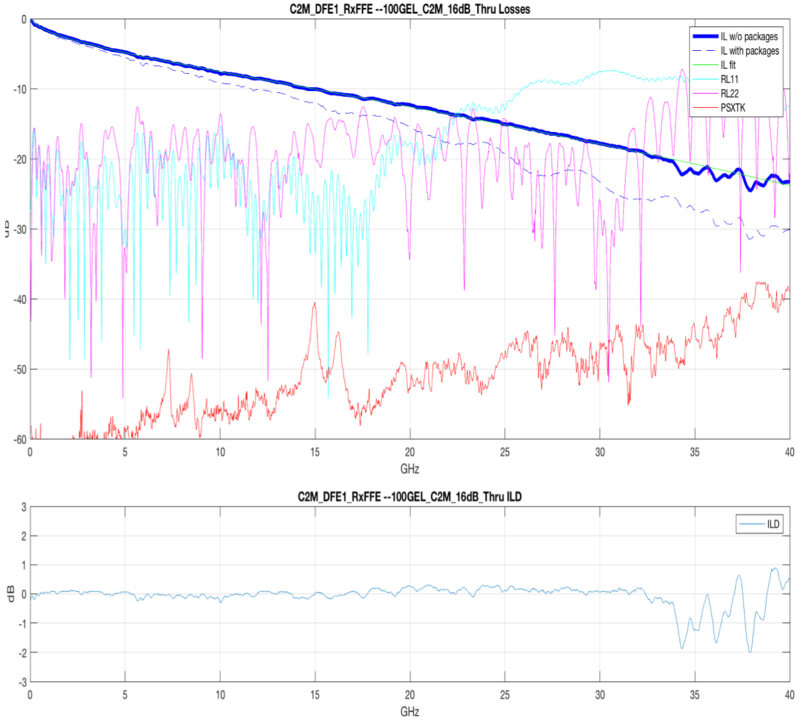
Lim 10 dB, FOM_ILD=0.145, ICN=3.65 mV
COM=2.11 dB, EH=12.06, VEC=13.3 dB
ICR=34 dB, CTLE Gain=-8 dB, G_DC2=-1.5 dB



Lim 12 dB, FOM_ILD=0.143, ICN=3.26 mV
COM=1.26 dB, EH=5.56, VEC=17.4 dB
ICR=33 dB, CTLE Gain=-11.5 dB, G_DC2=-1.75 dB



Lim 16 dB, FOM_ILD=0.149, ICN=2.78 mV
COM=0.503 dB, EH=1.8 mV, VEC=25.0 dB
ICR=30 dB, CTLE Gain=-11.5 dB, G_DC2=-2 dB

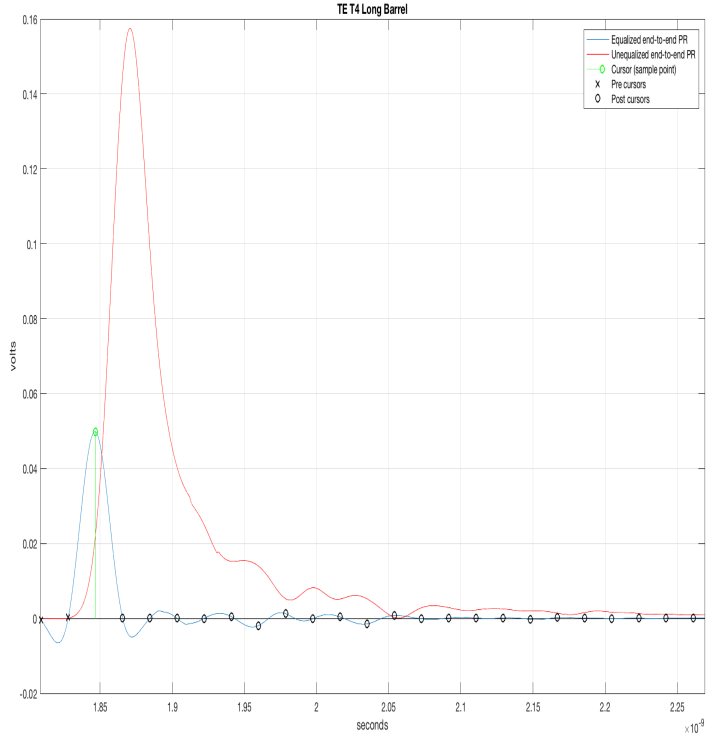


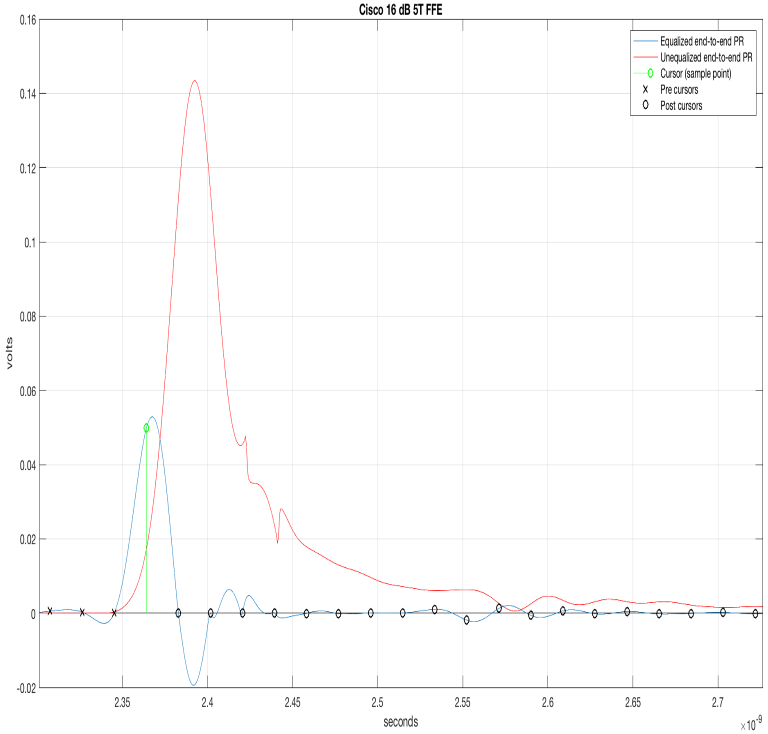
COM Margin with Different Equalizer

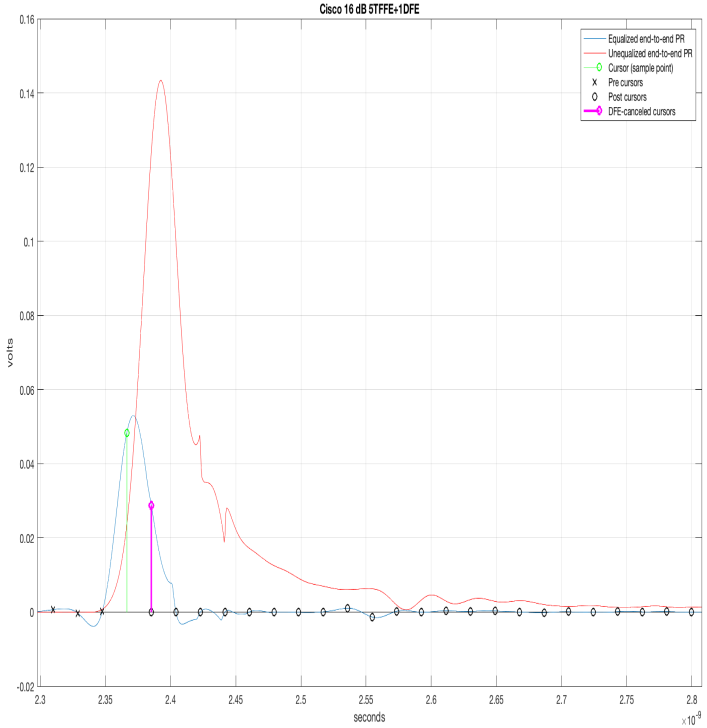
Lim 16 dB Channel	COM (dB)	EH (mV)	VEC (dB)	ICN (mV)	ICR	Peak ISI XTK Int. @BER (mV)
CTLE+5 Tap RX FFE	0.50	1.8	25.01	2.78	30	12.5
CTLE+6 Tap RX FFE	0.51	1.78	24.85	2.78	30	12.1
CTLE+8 Tap RX FFE	0.58	1.92	23.8	2.78	30	11.7
CTLE+10 Tap RX FFE	0.87	2.25	22.55	2.78	30	11.5
CTLE+12 Tap RX FFE	1.88	5.8	14.19	2.78	30	9.8
CTLE+5 Tap FFE, 1FEXT	2.60	8.35	11.6	1.38	40	8.35
CTLE+5 Tap FFE+1DFE, 1FEXT	4.30	11.95	8.2	1.38	40	6.22
CTLE+5 Tap FFE+1DFE, 2FEXT	4.27	11.88	8.22	1.52	38	6.77
CTLE+5 Tap FFE+1DFE, 3FEXT	4.17	11.68	8.37	1.78	37	6.43
CTLE+5 Tap FFE+1DFE, 3FEXT 1NEXT	4.09	11.5	8.5	1.97	35	6.58
CTLE+5 Tap FFE+1DFE, 3FEXT 2NEXT	3.05	9.07	10.57	2.24	33	8.2
CTLE+5 Tap FFE+1DFE	2.07	6.5	13.4	2.78	30	9.32
Lim 10 dB Channel						
CTLE+5 Tap RX FFE	2.11	12.06	13.3	3.65	34	17.9
CTLE+6 Tap RX FFE	2.11	12.06	13.03	3.65	34	17.8
CTLE+8 Tap RX FFE	2.13	12.16	13.3	3.64	34	17.8
CTLE+10 Tap RX FFE	2.33	11.1	12.55	3.65	34	14.8
CTLE+12 Tap RX FFE	4.01	18.9	8.6	3.65	34	11.98
CTLE+5 Tap RX FFE+1DFE	3.3	17.9	9.9	3.65	34	14.76

More Insight Into Performance Difference Between Tracy vs Lim Channels

- **One would expect Lim channels to perform quite well having better ILD than TE**
  - Lim channels have unusually high NEXT and some anomaly in pulse response possibly indicative of cascading effects
  - As shown below Tracy Long Barrel has nice post equalized pulse with just 5T FFE, 5T FFE is inadequate for Lim 16 dB channel, 5T FFE+1 DFE does nice job cancelling negative post-cursor but due to ICR of only ~30 dB the COM is only 2.1 dB!







Summary

- **Given the performance advantage of CL120E CTLE for C2M need to use this style of filter but need to extend CTLE gain range**
  - Increase CTLE HF gain from 9 dB to 14 dB
  - Increase CTLE LF gain from 1.5 dB to 2 dB
- **If the group prefers style of CL120D where g_{DC} and g_{DC2} controls the HF and LF CTLE zeros those coefficient have been provided here but if the group prefers poles/zeros up to 14 dB I can provide them**
  - Regarding LF filter gain my suggestion is
    - Up to 2 dB zero LF gain
    - From 3 dB to 14 dB increase LF gain by 0.25 dB at every 1 dB increment for max of 2 dB
- **Initial results with 14 dB CTLE and 5T FFE are very promising for Tracy channel and Yamaichi QSFP56**
  - Lim 16 dB channels badly fails even for 12T FFE due to low ICR even 5T FFE+1T FFE marginally fails
  - Due to high crosstalk/Low ICR even Lim 10 dB channel would require 12 + Tap FFE or 5Tap FFE+1T DFE
  - For some unknow reason Lim data with Yamaichi QSFP56 connector cascaded with additional host trace COM/VEC/EH are much worse than using just Yamaichi QSFP56 mated board with added trace in COM
- **If we have to equalize >2.5 mV ICN or channels with ICR<35 dB the equalizer required would be outside power envelope for C2M, where the best solution would be 5 Tap FFE+1 Tap DFE or more taps**
  - Results are based on COM 2.4.1 which still work in progress with some of COM parameters used here could be in question
  - High crosstalk/low ICR channels given our power envelope reasonably should only be supported for an IL< 10 dB
- **As demonstrated here 4T TX FFE with an RX CTLE+5T FFE is sufficient for reasonably well constructed boards such as Tracy OSFP and Yamaichi boards both with ~16 dB loss**
- **As demonstrated here two nice channel on the surface with similar IL but with drastically different COM results, which reinforces the need for channel compliance tool**
  - Separately trying to limit ICN vs loss, return loss, and ILD will result in over constraining the channel!