Choosing an Optimum CR Equalizer

Ali Ghiasi

Ghiasi Quantum LLC

IEEE 802.3ck Task Force

Waikoloa Meeting

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List of Supporters

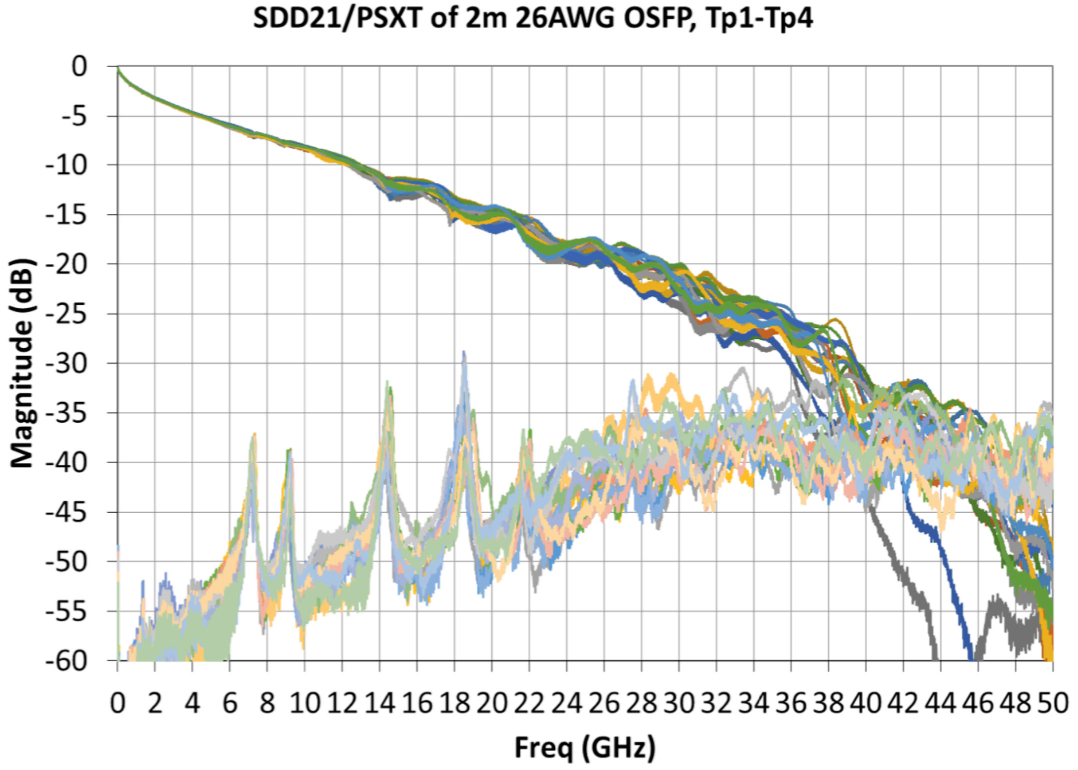
- Athos Kasapi – Cadence
- Upen Kareti – Cisco
- Ali Ghiasi – Ghiasi Qauntum
- Arash Farhoodfar – Inphi
- Ilya Lyubomirsky – Inphi
- Tom Palkert – Molex
- Scott Sommers – Molex
- Geoff Zhang – Xilinx.

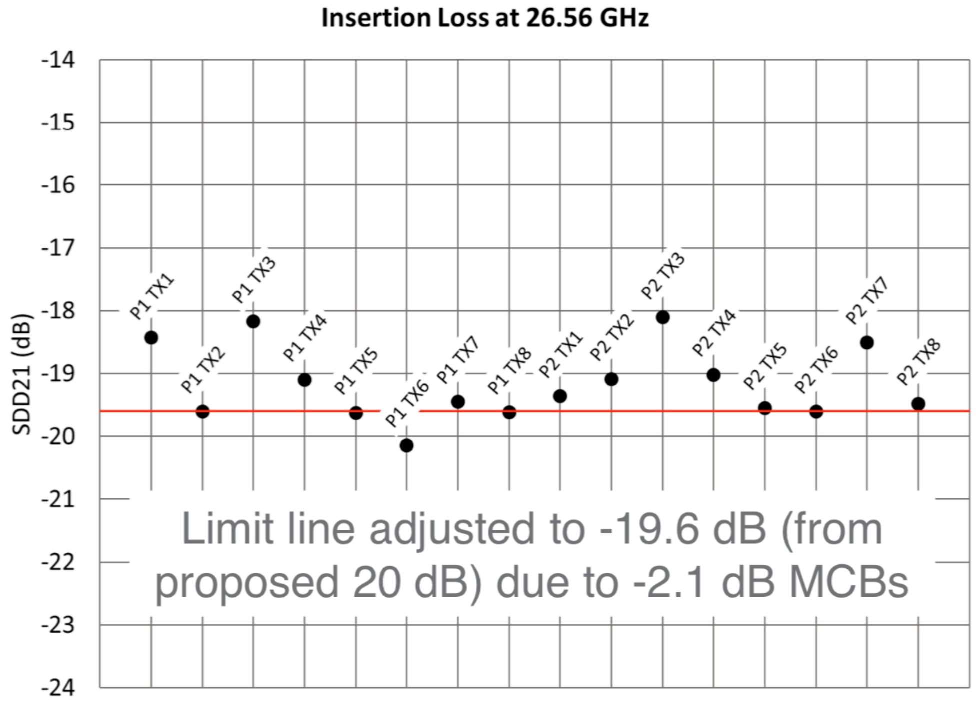
Overview

- **COM Results for 8 TE OSFP 2 m CR cables**
- **Using COM 2.7.5**
  - COM case I [12, 12] mm package
  - COM case II [31, 29] mm package
- **Comparing following equalizer for the 2 m cable**
  - 16 taps fixed DFE
  - 21 taps fixed DFE
  - 24 taps fixed DFE
  - KR EQ 12 fixed DFE + 3 banks of 3 floating DFE with span of 40 UI
- **Tap weights on Lim QSFP-dd end-end CR links**
- **Summary.**

Tracy OSFP 2 m CR Channels

- **Include 7 FEXT and 8 NEXT**
  - http://www.ieee802.org/3/ck/public/19_07/tracy_3ck_01a_0719.pdf





Tracy OSFP 2 m CR COM Results

- **Original reported COM results**
  - Based on COM 2.7.0
  - With 80 tap DFE
  - doesn't consider additional impairment due to via stubs and BGA crosstalk.

	IL at 26.56 GHz	COM Case 1	COM Case 2	ERL 11	ERL 22
P1_Tx1	-18.432	4.408	3.363	10.084	9.824
P1_Tx2	-19.602	3.688	2.569	9.040	9.846
P1_Tx3	-18.171	4.731	3.768	10.586	11.172
P1_Tx4	-19.097	4.524	3.453	8.610	9.889
P1_Tx5	-19.622	3.795	2.890	10.955	10.701
P1_Tx6	-20.143	4.237	3.086	9.556	10.383
P1_Tx7	-19.452	3.904	2.938	10.437	8.804
P1_Tx8	-19.619	3.890	2.902	9.314	10.089
P2_Tx1	-19.359	4.867	3.728	10.867	10.949
P2_Tx2	-19.086	4.510	3.440	10.153	10.478
P2_Tx3	-18.107	4.852	3.863	10.533	11.116
P2_Tx4	-19.017	4.408	3.440	9.562	10.100
P2_Tx5	-19.548	3.688	2.865	10.612	9.458
P2_Tx6	-19.607	3.999	3.086	10.604	11.060
P2_Tx7	-18.508	3.768	2.938	10.449	9.696
P2_Tx8	-19.479	3.836	2.950	9.854	10.117

COM 2.7.5 CR Parameters

Table 93A-1 parameters			
Parameter	Setting	Units	Information
f_b	53.125	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1.2e-4 1.2e-4]	nF	[TX RX]
L_s	[0.12, 0.12]	nH	[TX RX]
C_b	[0.3e-4 0.3e-4]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 31; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 29; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 31; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 29; 1.8 1.8]	mm	[test cases]
C_p	[0.87e-4 0.87e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50 50]	Ohm	[TX RX]
A_v	0.415	V	vp/vf=.694
A_fe	0.415	V	vp/vf=.694
A_ne	0.608	V	
L	4		
M	32		
filter and Eq			
f_r	0.75	*fb	
c(0)	0.54		min
c(-1)	[-0.34:0.02:0]		[min:step:max]
c(-2)	[0:0.02:0.12]		[min:step:max]
c(-3)	[-0.06:0.02: 0]		[min:step:max]
c(1)	[-0.2:0.05:0]		[min:step:max]
N_b	16	UI	
b_max(1)	0.85		
b_max(2..N_b)	0.2		
g_DC	[-20:1:0]	dB	[min:step:max]
f_z	21.25	GHz	
f_p1	21.25	GHz	
f_p2	53.125	GHz	
g_DC_HP	[-6:1:0]		[min:step:max]
f_HP_PZ	0.6640625	GHz	

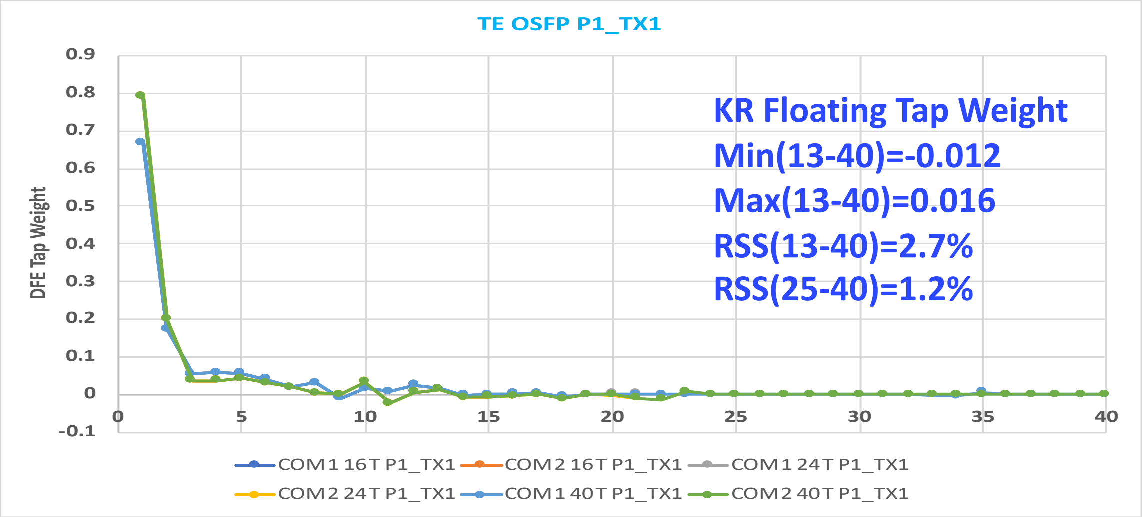
I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\100GEL_CR_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	CR_eval_	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10	dB
DER_0	1.00E-04	
T_r	6.16E-03	ns
FORCE_TR	1	logical
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	3000	
beta_x	2.3407E+09	
rho_x	0.21	
fixture delay time	[0 0]	[port1 port2]
TDR_W_TXPKG	0	
N_bx	12	UI
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	8.37E-09	V^2/GHz
SNR_TX	32.5	dB
R_LM	0.95	

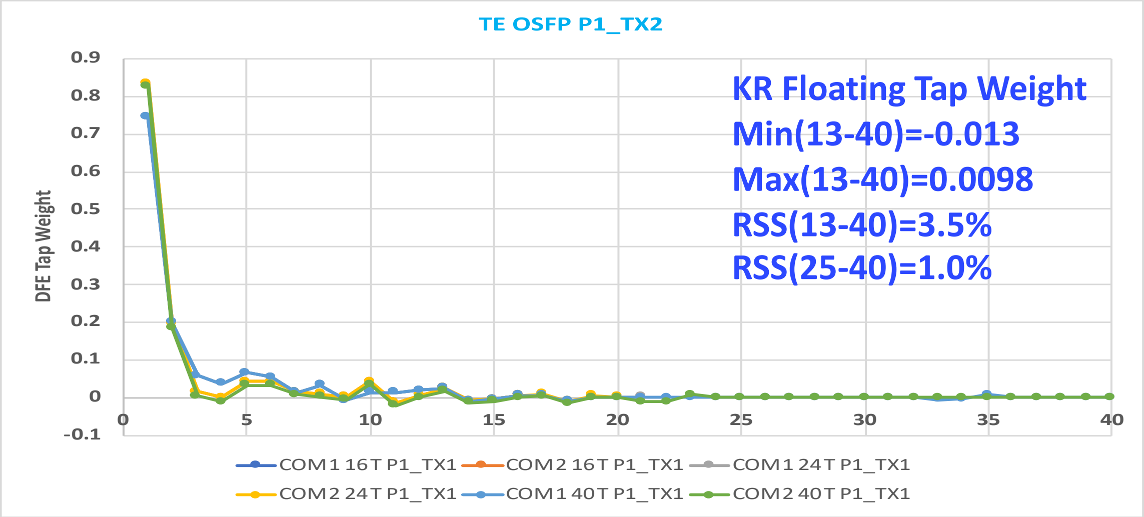
Table 93A–3 parameters		
Parameter	Setting	Units
package_tl_gamma0_a1_a2	[0 0.0009909 0.0002772]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	[87.5 87.5 ; 92.5 92.5]	Ohm
benartsi_3ck_01_0119 & mellitz_3ck_01_0119		
Table 92–12 parameters		
Parameter	Setting	
board_tl_gamma0_a1_a2	*[0 3.8206e-04 9.5909e-05]*	1 dB / in
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	*110.3*	mm
z_bp (NEXT)	*110.3*	mm
z_bp (FEXT)	*110.3*	mm
z_bp (RX)	*110.3*	mm
C_0	[0.29e-4]	nF
C_1	[0.19e-4]	nF
Include PCB	**1**	**logical**
Floating Tap Control		
N_bg	0	0 1 2 or 3 groups
N_bf	3	taps per group
N_f	40	UI span for floating taps
bmaxg	0.2	max DFE value for floating taps
cable assemblies require this for each HCB		
ICN parameters (v2.73)		
f_f	12.919	
f_n	12.919	
f_2	39.844	
A_ft	0.600	
A_nt	**0.600**	
heck_3ck_03b_0319	**Adopted Mar 2019**	
walker_3ck_01d_0719	**Adopted July 2019**	
result of R_d=50		
benartsi_3ck_01a_0719	**require COM 2.72 or later**	
mellitz_3ck_03_0919		
mellitz_3ck_02_0919		
under consideration		

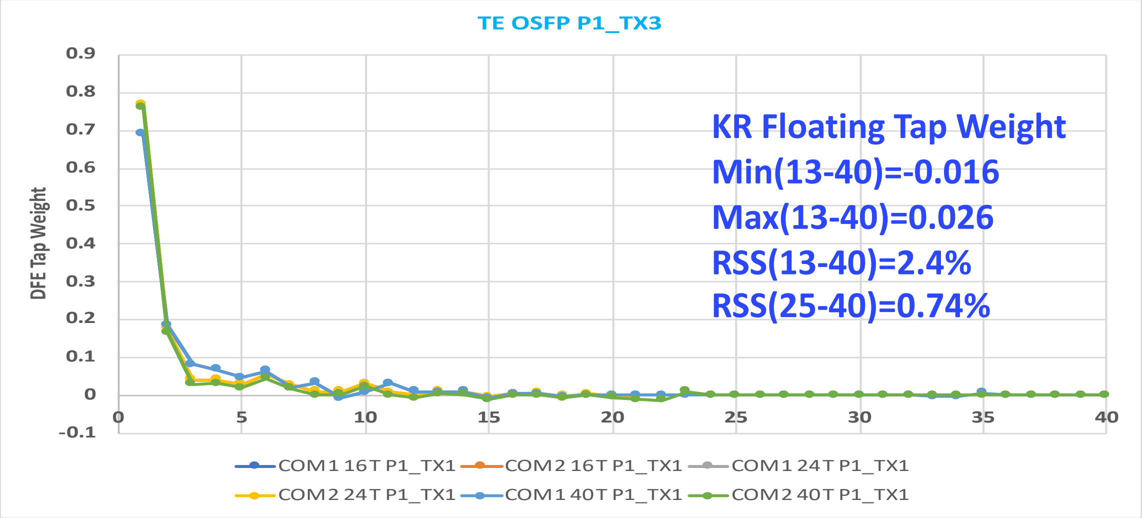
COM Summary of Tracy CR Channels

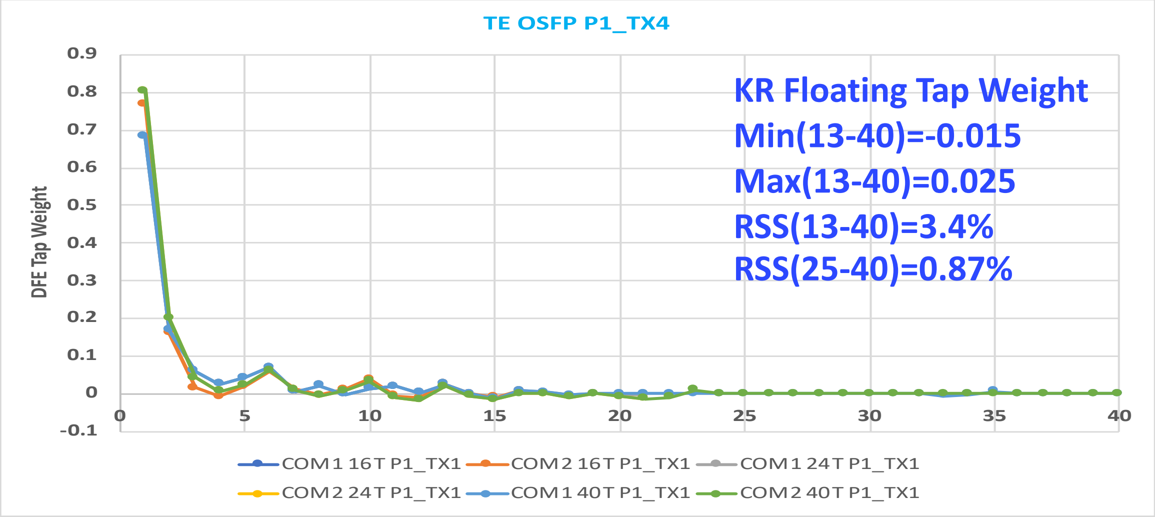
Tracy OSFP Cables	Fitted IL at 26.56 GHz (dB)	Total IL w PKG at 26.55 GHz (dB)	ERL11 (dB)	ERL22 (dB)	FOM ILD	ICN (mV)	COM Case I	COM Case II
P1_Tx1 Fixed 24T C0, C1=0	19.3 dB	39.4 dB	10.1	9.8	0.35	2.97	4.63	3.84
P1_TX1 Fixed 16T	19.3	39.4	10.1	9.8	0.35	3.0	3.90	2.95
P1_TX1 Fixed 24T	19.3	39.4	10.1	9.8	0.35	3.0	3.97	3.26
P1_Tx1 Float 40T	19.3	39.4	10.1	9.8	0.35	3.0	4.0	3.26
P1_Tx2 Fixed 24T C0, C1=0	20.7	40.6	9.0	9.8	0.5	4.0	3.76	2.99
P1_Tx2 Fixed 16T	20.7	40.6	9.0	9.8	0.5	4.0	3.12	2.21
P1_Tx2 Fixed 24T	20.7	40.6	9.0	9.8	0.5	4.0	3.25	2.52
P1_Tx2 Float 40T	20.7	40.6	9.0	9.8	0.5	4.0	3.3	2.52
P1_Tx3 Fixed 24T C0, C1=0	18.6	37.9	10.6	11.1	0.5	3.3	4.88	4.15
P1_Tx3 Fixed 16T	18.6	38.7	10.6	11.1	0.5	3.3	4.32	3.39
P1_Tx3 Fixed 24T	18.6	38.7	10.6	11.1	0.5	3.3	4.37	3.69
P1_Tx3 Float 40T	18.6	38.7	10.6	11.1	0.5	3.3	4.41	3.66
P1_Tx4 Fixed 24T C0, C1=0	19.3	39.2	8.6	9.9	0.39	3.06	4.66	3.76
P1_Tx4 Fixed 16T	19.3	39.2	8.6	9.9	0.39	3.06	3.92	2.91
P1_Tx4 Fixed 24T	19.3	39.2	8.6	9.9	0.39	3.06	3.97	3.22
P1_Tx4 Float 40T	19.3	39.2	8.6	9.9	0.39	3.06	4.01	3.22

DFE Tail Taps Weights





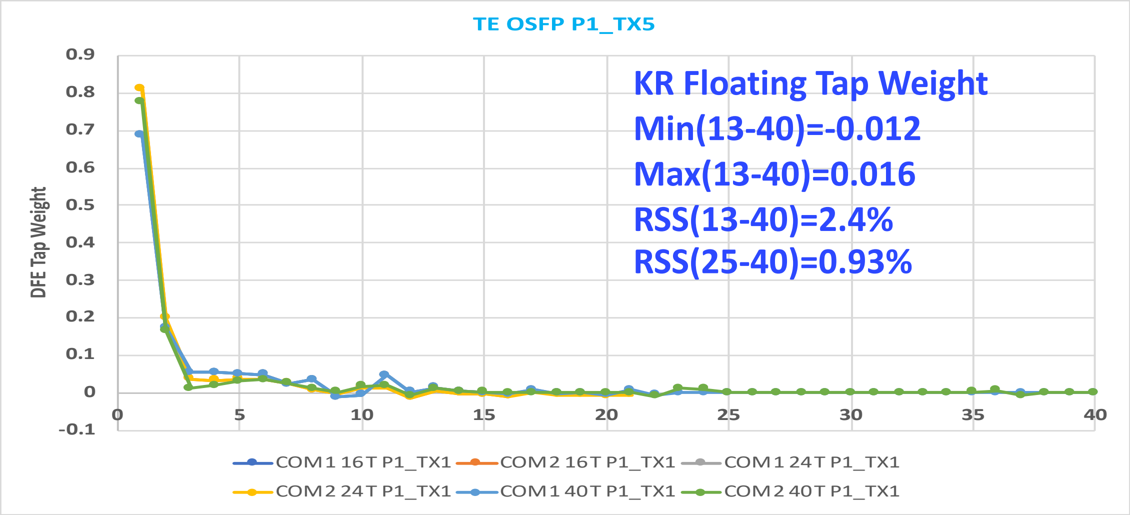


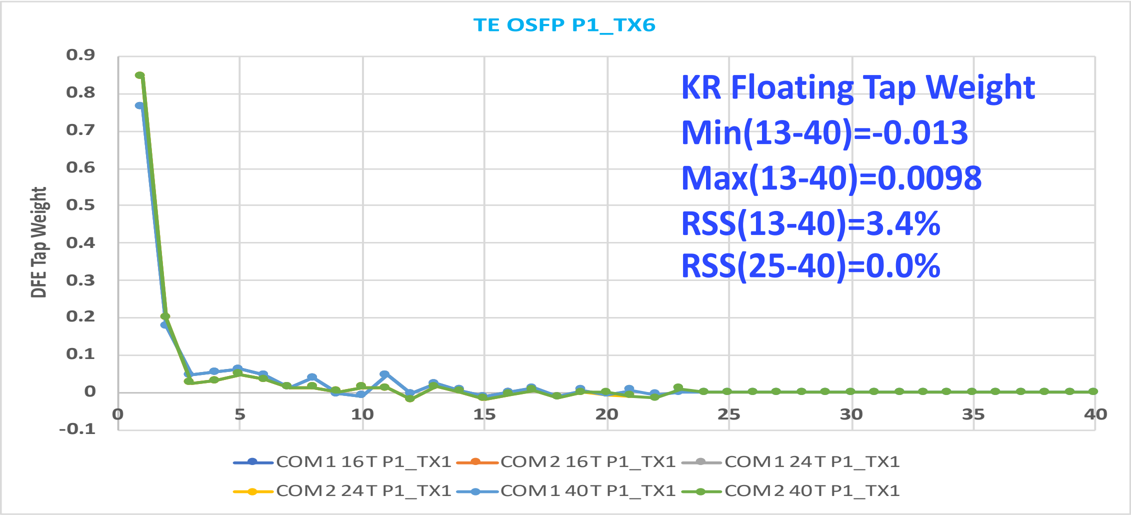


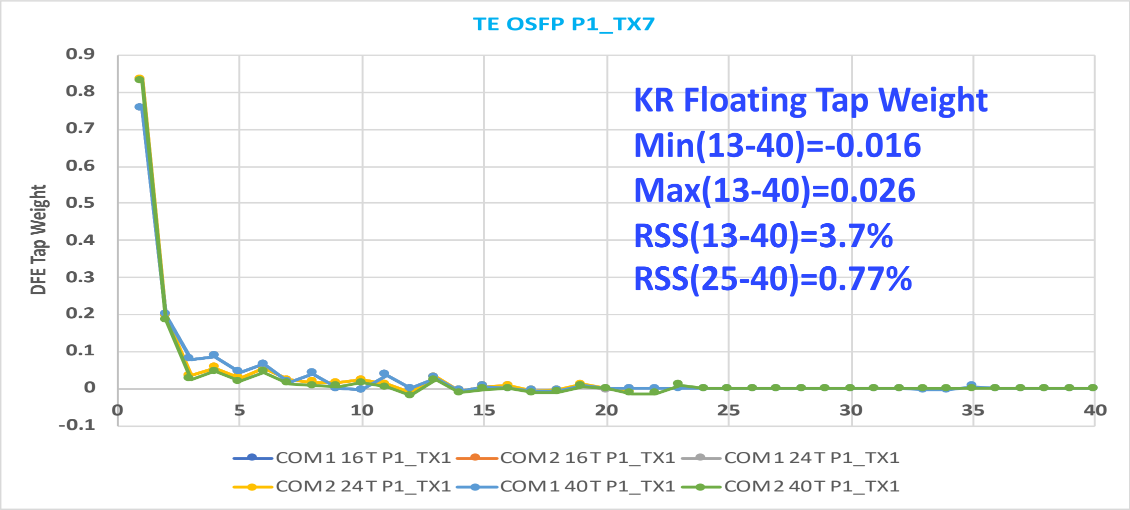
COM Summary of Tracy CR Channels

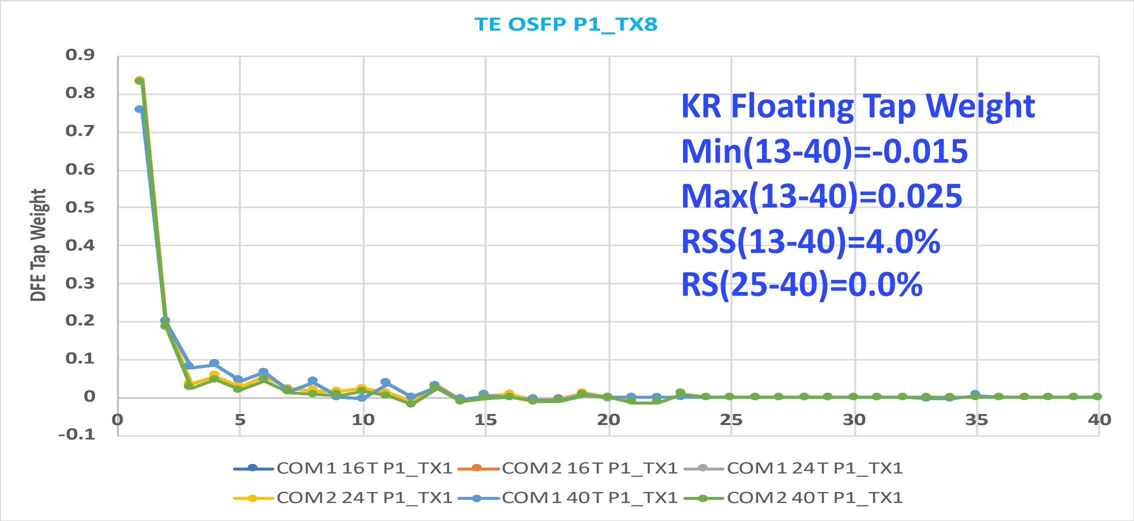
ID	Fitted IL at 26.56 GHz (dB)	Total IL w PKG at 26.55 GHz (dB)	ERL11 (dB)	ERL22 (dB)	FOM ILD	ICN (mV)	COM Case I	COM Case II
P1_Tx5 Fixed 16T	19.8 dB	35.3 dB	10.9	10.7	0.33	3.9	3.27	2.53
P1_Tx5 Fixed 21T	19.8 dB	35.3 dB	10.9	10.7	0.33	3.9	3.4	2.62
P1_Tx5 Fixed 24T	19.8 dB	35.3 dB	10.9	10.7	0.33	3.9	3.4	2.81
P1_Tx5 Float 40T	19.8 dB	35.3 dB	10.9	10.7	0.33	3.9	3.4	2.76
P1_Tx6 Fixed 16T	20.6	41.9	9.6	10.4	0.42	3.3	3.48	2.63
P1_Tx6 Fixed 21T	20.6	41.9	9.6	10.4	0.42	3.3	3.80	2.83
P1_Tx6 Fixed 24T	20.6	41.9	9.6	10.4	0.42	3.3	3.82	3.04
P1_Tx6 Float 40T	20.6	41.9	9.6	10.4	0.42	3.3	3.82	2.99
P1_Tx7 Fixed 16T	19.7	40.6	10.4	8.8	0.41	4.1	3.38	2.57
P1_Tx7 Fixed 21T	19.7	40.6	10.4	8.8	0.41	4.1	3.49	2.73
P1_Tx7 Fixed 24T	19.7	40.6	10.4	8.8	0.41	4.1	3.53	2.93
P1_Tx7 Float 40T	19.7	40.6	10.4	8.8	0.41	4.1	3.49	2.87
P1_Tx8 Fixed 16T	19.7	40.4	9.3	10.1	0.54	4.0	3.35	2.48
P1_Tx8 Fixed 21T	19.7	40.4	9.3	10.1	0.54	4.0	3.49	2.62
P1_Tx8 Fixed 24T	19.7	40.4	9.3	10.1	0.54	4.0	3.53	2.87
P1_Tx8 Float 40T	19.7	40.4	9.3	10.1	0.54	4.0	3.49	2.76

DFE Tail Taps Weights









Lim End-End CR Links

- **Lim end-end CR link include BGA break out, BGA via/stub, and connector via/stub**
  - Summary of COM analysis for two CR end-end links with KR adopted 40 tap span equalizer is given below and presented in Sept 2019 interim lim_3ck_01a_0919 .

DUT	COM case 1 (dB)	COM case 2 (dB)	ERL11 (dB)	ERL22 (dB)	FOM_{ILD} (dBrms)	ICN (mV)	IL@26G b2b/d2d (dB)
Channel 3a (QSFPDD, new pair, worst case)	3.80	2.90	16.82	17.57	0.48	1.16	28.4/40.9
Channel 3b (QSFPDD, legacy pair, worst case)	3.84	3.16	18.33	18.91	0.58	1.21	28.3/41.1

COM script version 2.70
- **Die termination C: Cd 120fF / Ls 120pH/ Cb 30fF**
- **24 fixed DFE taps**

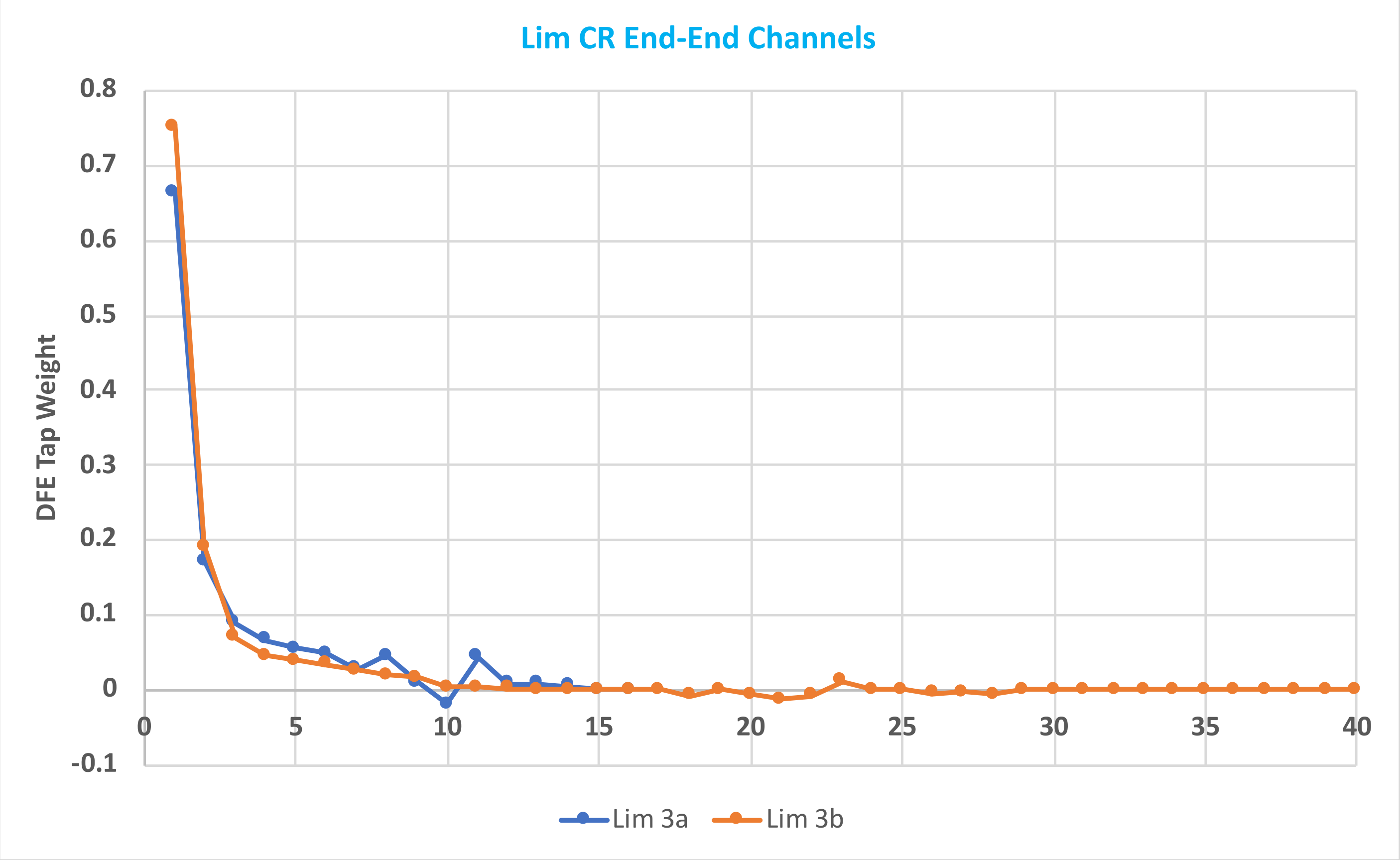
Case 1: z_p (TX) = 12 mm; z_p (RX) = 12 mm
Case 2: z_p (TX) = 31 mm; z_p (RX) = 29 mm

Lim CR End-End Links

- **Lim CR end-end s-parameters are not available publicly at this point but some results were presented in gustlin_3ck_adhoc_100219 and lim_3ck_01a_0919**
  - Lim results are in line with TE OSFP cable measured data with additional impairment per COM 2.7.5.

Lim Channel 3a (short package)
KR Floating Tap Weight
COM Case I/II=3.80
Min(13-40)=-0.008
Max(13-40)=0.044
RSS(13-40)=4.7%
RSS(24-40)=0.61%

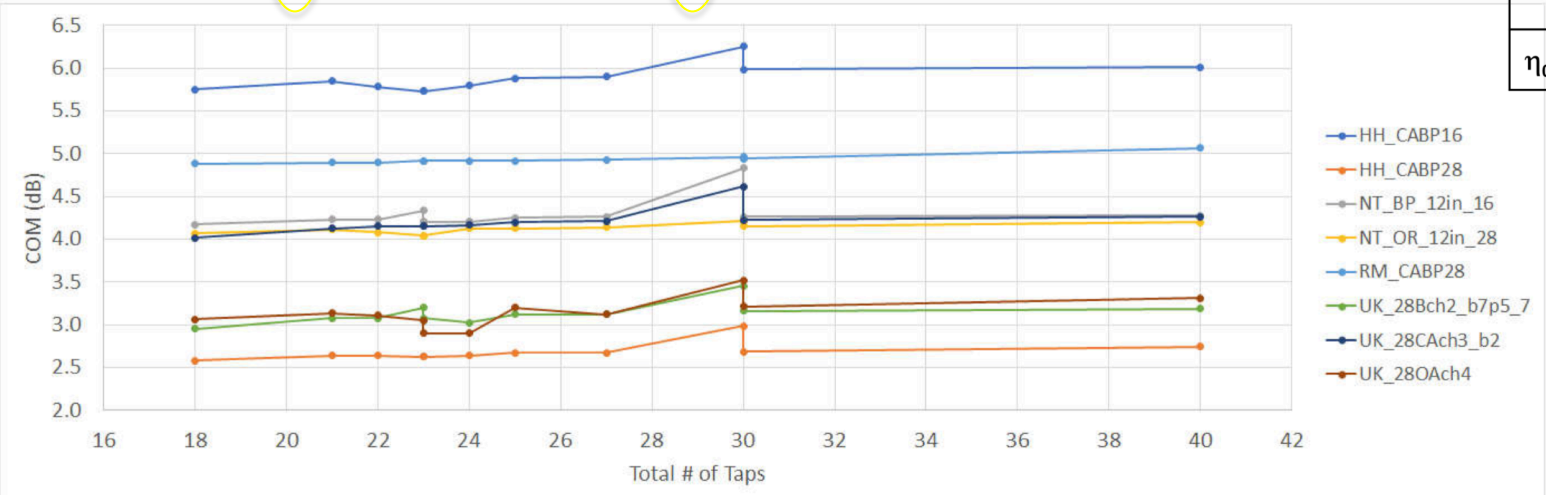
Lim Channel 3a (long package)
KR Floating Tap Weight
COM Case I/II=2.9
Min(13-40)=-0.012
Max(13-40)=0.012
RSS(13-40)=2.3%
RSS(25-40)=0.83%



How Does 40 UI Span Equalizer with floating taps Compare to 24T?

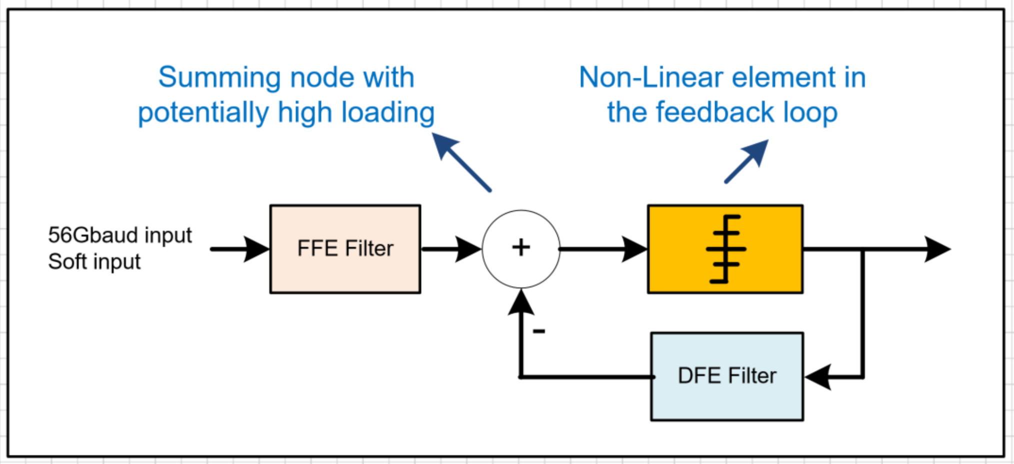
- **On 8 critical KR channels heck_3ck_01b_0719 the 24T fixed DFE performed slightly better or about same as 12 tap DFE + 3x3 banks with 40 UI span**
  - The only exception was Kareti1 where 40T span equalizer had 0.2 dB higher COM.

	18	21	22	23	23	24	25	27	30	30	40	Total Taps
	12	12	16	20	20	24	16	24	24	24	40	# Fixed Taps
	2	3	2	1	1	0	3	1	2	2	0	# Banks
	40	40	40	80	40	-	40	40	80	40	40	Float Span (UI)
Heck2	5.747	5.8486	5.7807	5.7302	5.7302	5.7977	5.8827	5.8998	6.2494	5.9808	6.0119	HH_CABP16
Heck1	2.5802	2.6389	2.6389	2.6271	2.6271	2.6389	2.6743	2.6743	2.9871	2.6861	2.7454	HH_CABP28
Tracy2	4.1681	4.2273	4.2273	4.3349	4.2035	4.2035	4.2511	4.263	4.8299	4.263	4.2749	NT_BP_12in_16
Tracy1	4.0685	4.1102	4.0824	4.0408	4.0408	4.1242	4.1242	4.1382	4.2084	4.1522	4.1943	NT_OR_12in_28
Mellitz1	4.8825	4.8978	4.8978	4.913	4.913	4.913	4.913	4.9283	4.959	4.9437	5.0673	RM_CABP28
Kareti5	2.9504	3.0733	3.0733	3.1979	3.0733	3.0239	3.1229	3.1229	3.4526	3.1603	3.1853	UK_28Bch2_b7p5_7
Kareti3	4.0132	4.1242	4.1522	4.1522	4.1522	4.1662	4.1943	4.2084	4.6125	4.2225	4.265	UK_28CAch3_b2
Kareti1	3.0609	3.1353	3.1105	3.0485	2.9017	2.9017	3.1979	3.1229	3.5175	3.2104	3.3116	UK_28OAch4
	×	?	×	×	×	×	✓	×	✓✓	✓	✓✓	



Taps/Bank		3
Termination	C_d	120fF
	L_s	120pH
	C_b	30fF
Package trace	Tx	31mm
	Rx	29mm
η_0		0.82×10^{-8} V²/GHz

Why 40 UI Floating Span Equalizer is not Free



- **Analog or digital DFE**
  - DFE is a feedback back loop structure with slicer acting as a non-linear element in the feedback
  - Due to the non-linearity in the feedback loop, it is not easy to unroll a 56GBaud PAM4 DFE
  - Various "Look Ahead" techniques are used to lower the operating frequency of the physical implementation DFE.
    - In the Analog domain, 1 step look ahead results in 28GHz and two steps look ahead results in 14GHz
    - Each look ahead will result in roughly 4X the complexity of the resulting circuit due to 4-leves of PAM4
    - Another critical issue is the loading at input of the slicer summing nodes for wide span DFE implementation
  - In digital domain, more systematic look ahead is used to lower the operating frequency to 1GHz-2GHz range, resulting in unrolling factor of 32X to 64X.

Why 40 UI Floating Span Equalizer is not Free

- **Analog FFE**
  - High speed baud-rate or sub-baud-rate FFE can be implemented in Analog using a variety of techniques
  - For all analog FFE implementations, care should be taken to not introduce non-linearity as well as excess loading of a high-frequency summing node before the slicer
- **Digital FFE**
  - Generally standard linear filter unrolling schemes is used to reduce the implementation operating frequency to around 1GHz-2GHz and the area/power of the FFE is proportional to the filter span

Large span equalizers are not free!

- FFE operates on soft data, where FFE power increases linearly with span.
  - For analog implementation, the FFE complexity increases with span due to non-linearity and summing node loading
- DFE operates on hard data however due to non-linearity in the feedback path, unrolling is very expensive
  - DFE power is proportional to the span for large DFE (with say > 8 taps)
  - Just like analog FFE the analog DFE implementation summing node loading with increase span can be an issue
- FFE and DFE power is linearly proportional to the span and increasing span with floating tap is not free
  - For a typical SerDes the RX FFE/DFE is about 50% of the overall power
  - Doubling the equalizer span could increase SerDes power by as much as 30%!

Choosing an Optimized "Power/Performance" Equalizer for CR

- **Option A:**
  - 24 taps fixed DFE offer better performance and lower power than walker_3ck_01d_0719 for CR links studied
    - The 24T DFE can also support 28.5 dB channels
- **Option B:**
  - Go with KR equalizer with 12T DFE+3x3 banks with 40UI span per walker_3ck_01d_0719 with additional tap constrains could be an option
    - Limit RSS floating taps [13-40] < 7% and [25-40] ≤ 3.0% covers worst of KR and CR channels we have seen offers the option for lower power and can be the common equalizer for KR and CR:
      - RSS floating taps [13-40]<4.0% and [25-40]<1.2% for TE OSFP CR channels
      - RSS floating taps [13-40]<4.7% and [25-40]<0.83% for Lim CR channels
      - RSS floating taps [13-40]<4.5% and [25-40]<2.5% for Kareti KR channels.

Summary

- **COM 2.7.5 include penalty associated with BGA ball field crosstalk and long vias**
  - The penalty associated with long vias is ~0.5-0.8 dB
  - The results indicate 19.5 dB CR channel can be supported on cables with improved ICN and ILD
  - Lim CR end-end QSFP-dd links behave similar to TE OSFP CR cables with additional impairments per COM 2.7.5
- **Comparing 4 types of equalizer studied for CR**
  - 16 taps DFE is not adequate for 2 m CR
  - 21 taps DFE is slightly inferior to adopted KR equalizer with floating but with total of 21 taps
  - Adopted KR equalizer is significantly better than 16 tap equalizer but not as good as 24 taps fixed DFE
  - The KR 12T+3 banks of 3 floating DFE taps with a span of 40 UI KR is not an optimum equalizer for CR given that tail taps beyond 24 UI are mostly zeros
- **Adopted KR equalizer will have power penalty for CR applications as most of tails taps >24 UI are zero**
  - Option A: go with a more optimum lower power 24 taps fixed DFE
  - Option B: go with KR equalizer but with following tap constrain where RSS floating taps [13-40] ≤ 7.0% and [25-40] ≤ 3.0%
    - Option B allow trading between shorter span equalizer with improved noise to reduce overall power – and be GREEN
- **End-end CR analysis with COM 2.7.5 supports increasing ball-ball CR loss to 28.5 dB in support of 2 m Cu cable.**