212 Gb/s PAM4 per Lane C2M Channels
A Via Length Performance Study Supplement

Rick Rabinovich
January 17, 2023

KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

Supporter

- Ali Ghiasi

200G PAM4 C2M Via Length Effect Study Supplement

Objectives

- Follow up to presentation given on September 21st, 2022
- Study the effect of via length in channel performance
  - ✓ Via lengths = 19/67/93/135 mil
- Evaluated channel performance using COM rev. 3.9 and corresponding new spreadsheets.
- Investigate the effect of Raised Cosine vs. Butterworth filter performance
- Illustrate the paradox when cascading s-parameters of vias and connector models

The intention of this presentation is NOT to:

- ✓ Discuss specific materials
- ✓ Discuss specific equalizations/implementations
- ✓ Discuss specific ASIC footprints
- ✓ Recommend specific receive filters

The intention of this presentation is to:

- ✓ Contribute two additional “optimized” channels based on “actual” channel implementations which includes the ASIC breakout, routing, via transitions, and the latest OSFP model available
  - ➢ Via antipads in PCB inner layers were optimized using HFSS Optimetrix
- ✓ Provide channels with **impairments** that seasoned design engineers will encounter when implementing channels operating at 224 Gb/s per lane.
- ✓ Analyze receiver equalization solutions to pass COM rev. 3.9

200G PAM4 C2M Via Length Effect Study Supplement

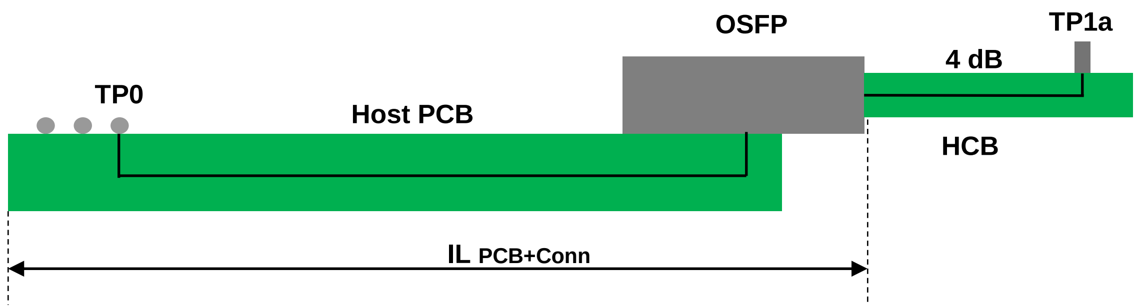
C2M Channel Highlights

- Traditional Topology, i.e., medium PCB material between ASIC and Connector
  - ❖ Short Channel - Ex. NIC card
- Short Host Channel
  - ❖ Well engineered challenging channel
  - ❖ Includes Huray model for copper roughness
- Channel with **IMPAIRMENTS**
  - ❖ ASIC/Connector vias and module finger transition
  - ❖ Layout trace turns
  - ❖ Skew compensation
  - ❖ Full channel crosstalk
- MDI is an OSFP connector model
- Crosstalk source mostly at the connector and footprint
- HCB – Ideal transmission line with IL=4.0 dB @ Nyquist
- COM rev. 3.9 – Includes raise cosine option

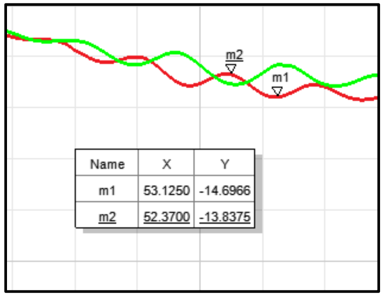
KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

Structure View & Insertion Losses



- **Full Structure:**
  - **Two adjacent channels**
    - ➢ **Matching segmentation meshing (i.e., common minimum element size)**
  - **Connector integrated with PCB**
  - **HCB is ideal transmission line with IL = 4 dB @ Nyquist**
  - **NEXT is evaluated at the ASIC model for more realistic results**
- **Vias = 19/67/93/135 mil long**
- **Blind Vias**
- **Frequency Sweep Range = 10 MHz to 120 GHz**



Reflections Effect

IL @ Nyquist (53.125 GHz)

Parallel Breakout

- $IL_{\text{PCB+Conn}}$ = 8.24/9.32/10.31/8.92 dB
- IL_{HCB} = 4 dB
- $IL_{\text{TP0-to-TP1a}}$ = 12.27/13.32/13.44/12.93 dB

Orthogonal Breakout

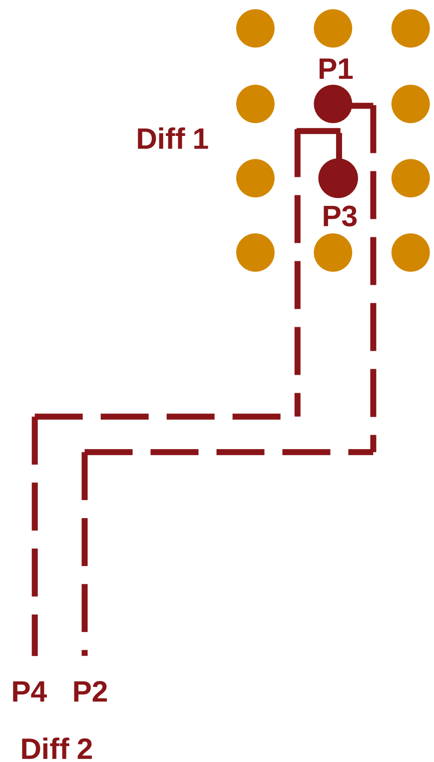
- $IL_{\text{PCB+Conn}}$ = 8.34/10.69/10.14/9.33 dB
- IL_{HCB} = 4 dB
- $IL_{\text{TP0-to-TP1a}}$ = 12.38/14.69/14.17/13.36 dB

KEYSIGHT TECHNOLOGIES

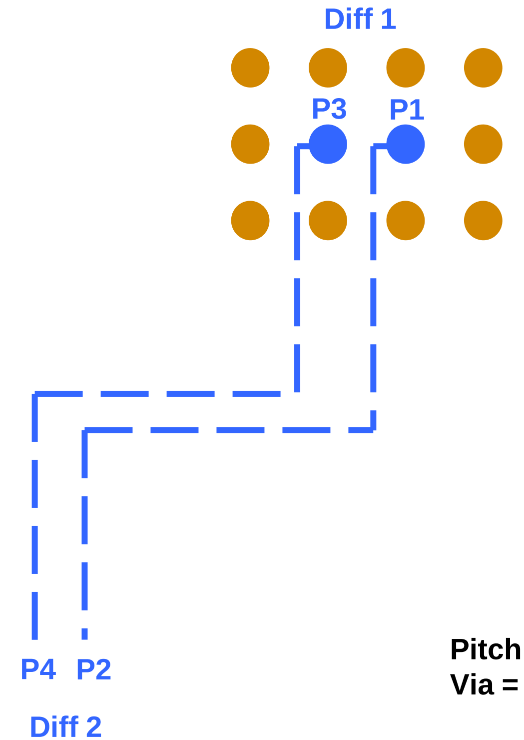
200G PAM4 C2M Via Length Effect Study Supplement

Two ASIC breakouts: Orthogonal vs. Parallel

Orthogonal Breakout



Parallel Breakout

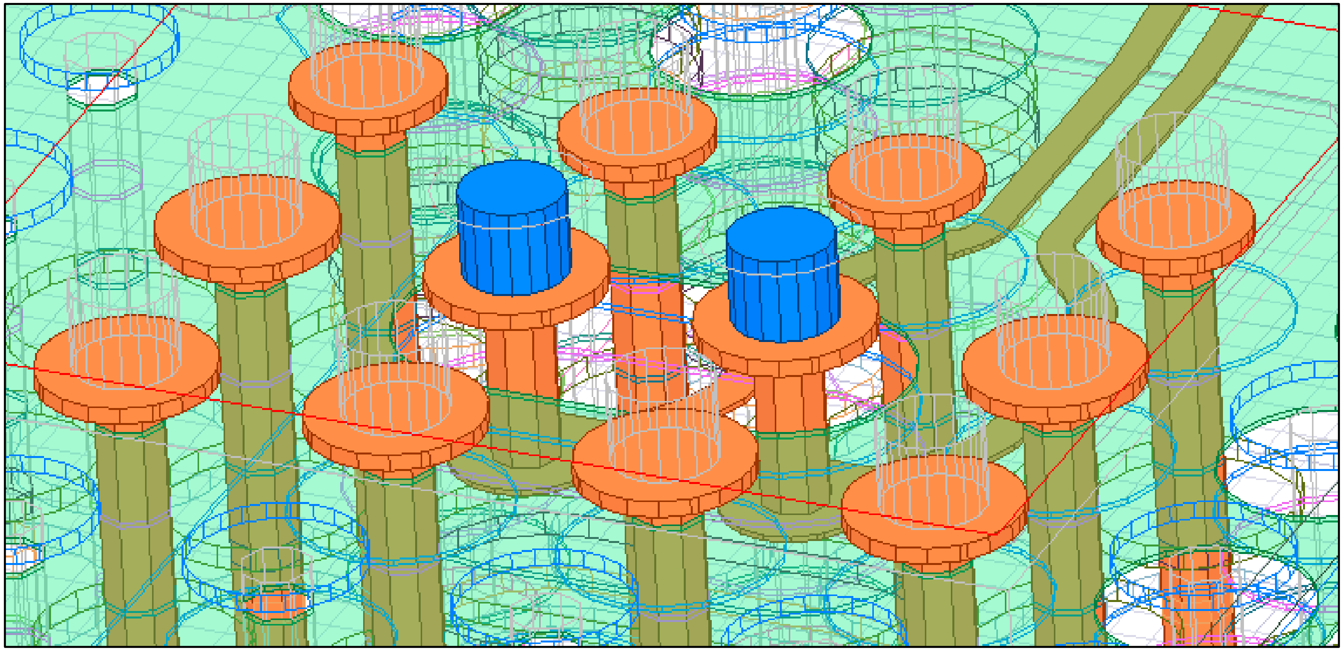


Pitch = 0.8 mm
Via = 1 mm

![KEYSIGHT TECHNOLOGIES]

200G PAM4 C2M Via Length Effect Study Supplement

ASIC Ball Model Example

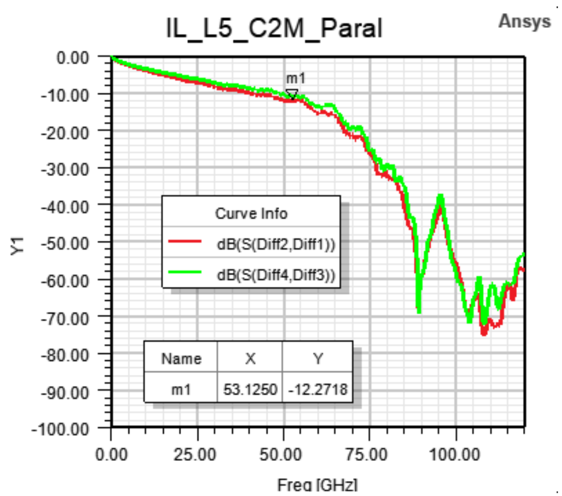


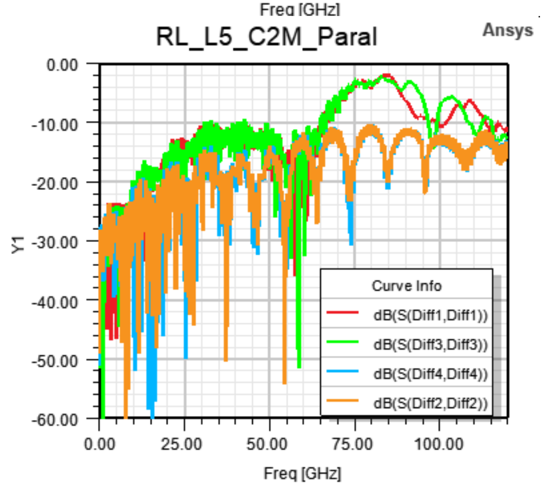
Cp already included in model => Cp=0

200G PAM4 C2M Via Length Effect Study Supplement

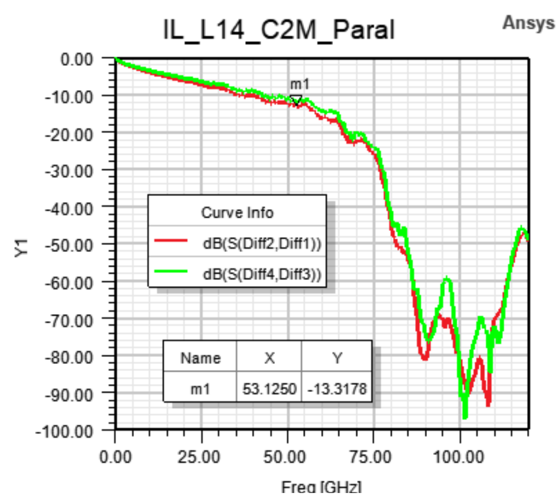
Parallel Breakout - IL/RL Performance

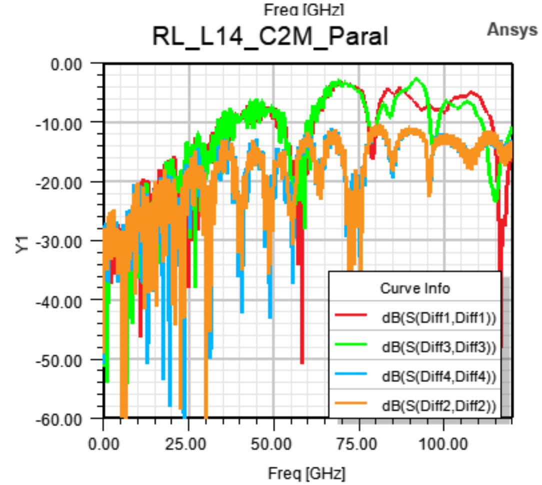
19 mil





67mil



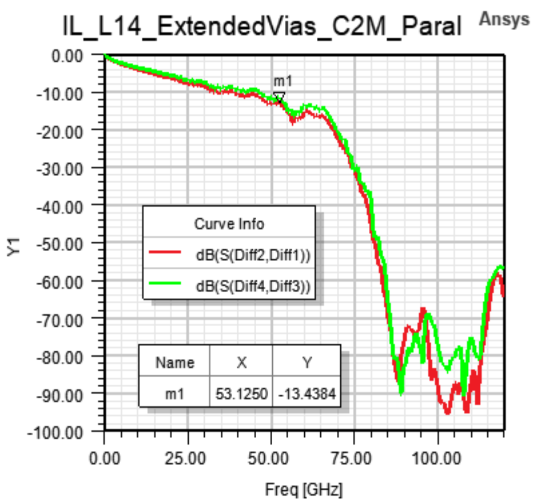


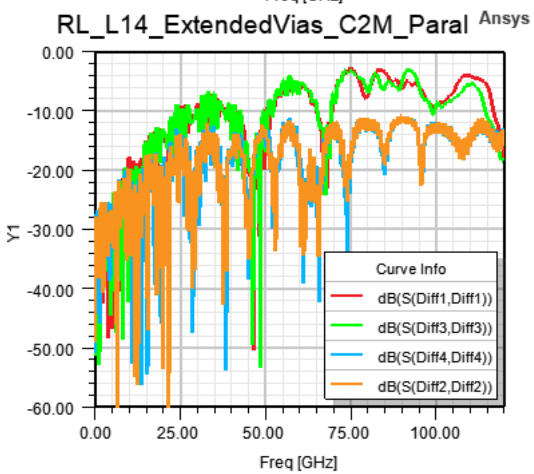
KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

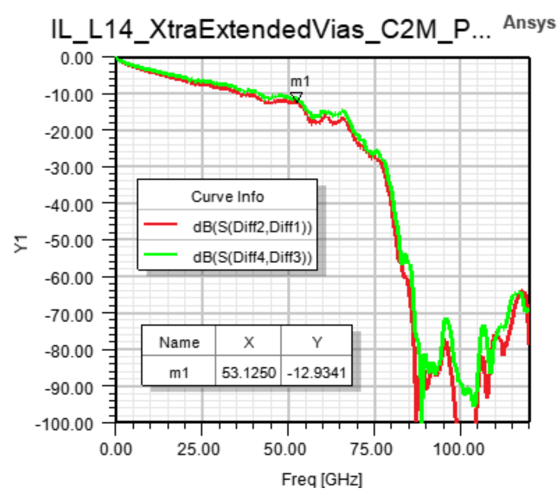
Parallel Breakout - IL/RL Performance

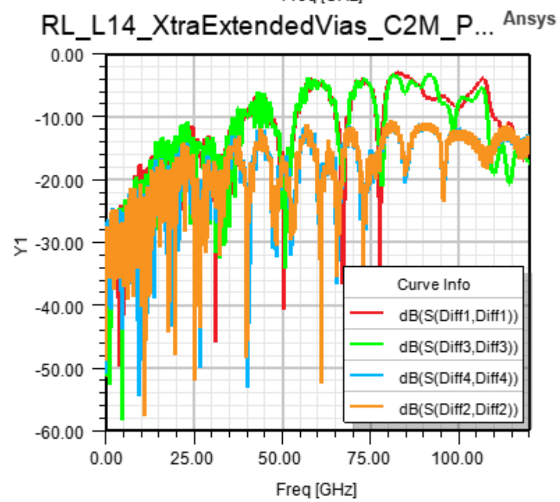
93 mil





135 mil



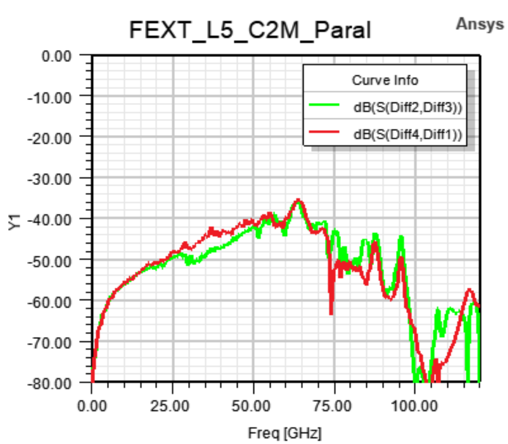


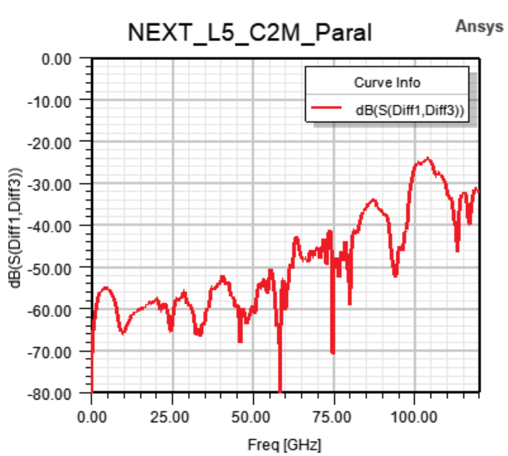
KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

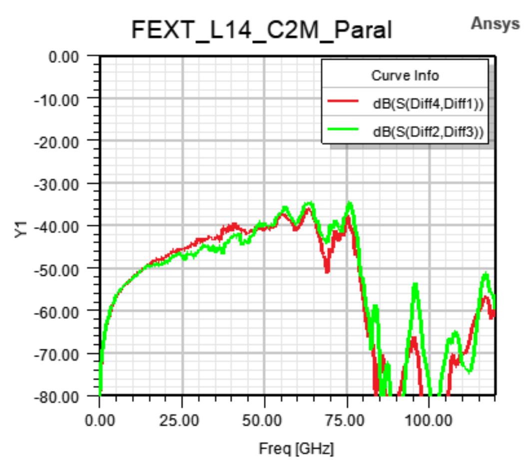
Parallel Breakout - FEXT/NEXT(ASIC) Performance

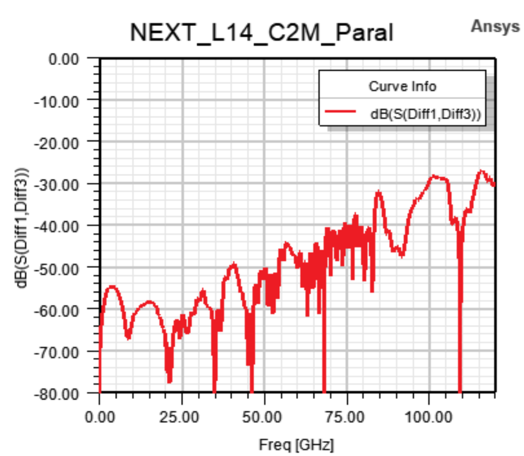
19 mil





67mil



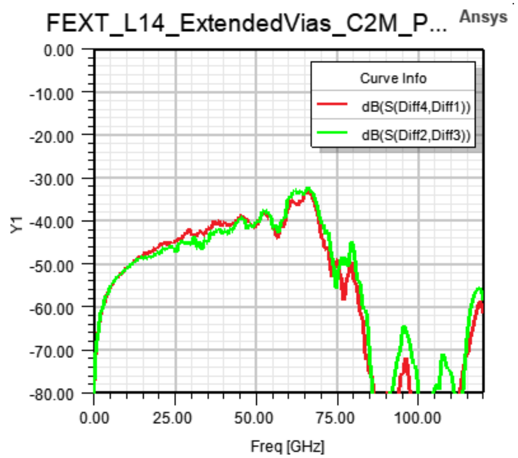


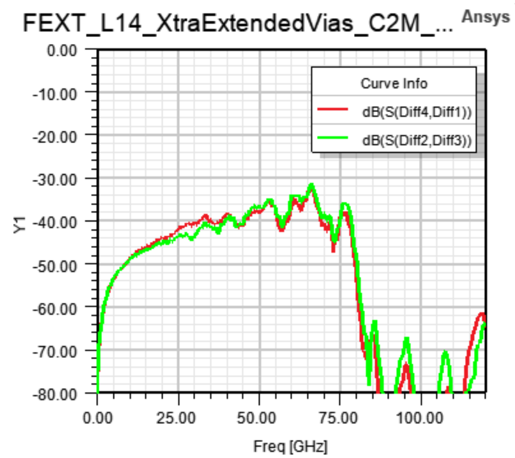
KEYSIGHT TECHNOLOGIES

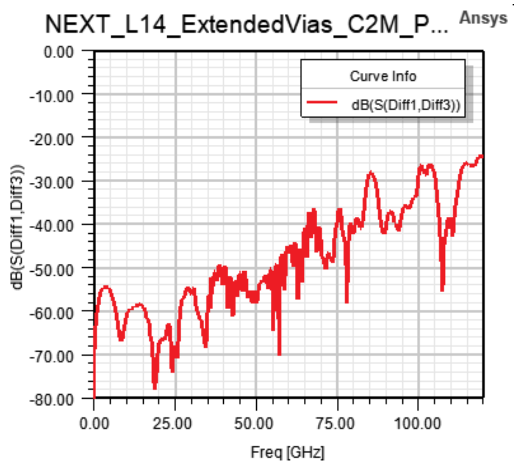
200G PAM4 C2M Via Length Effect Study Supplement

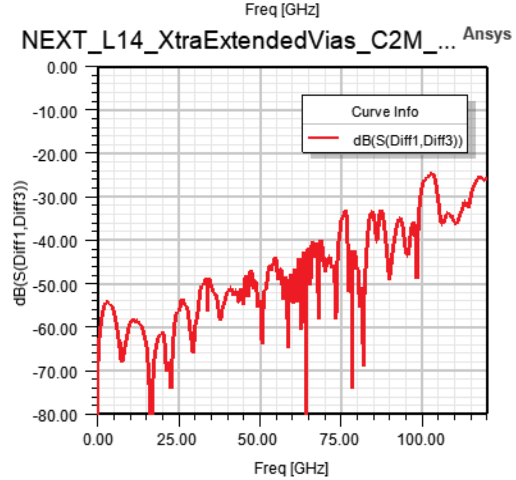
Parallel Breakout - FEXT/NEXT(ASIC) Performance

93 mil | 135 mil





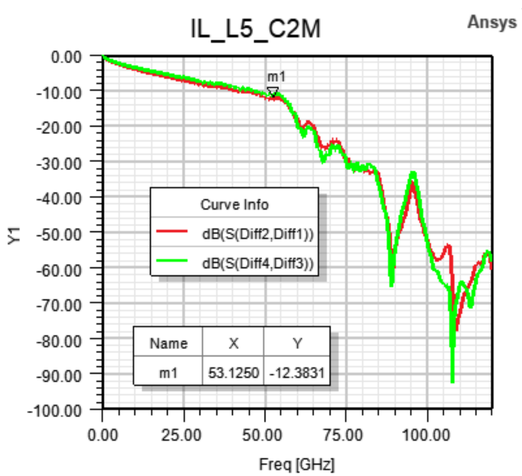


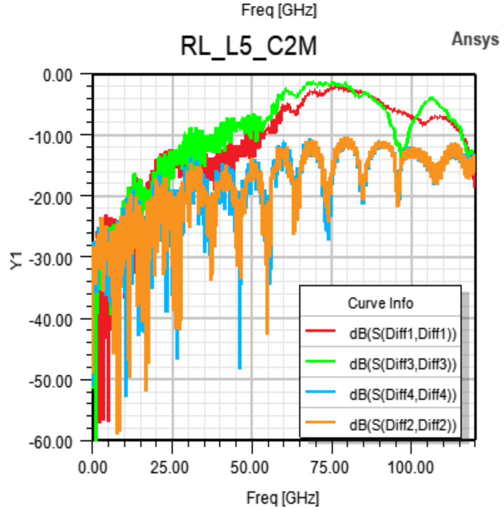


200G PAM4 C2M Via Length Effect Study Supplement

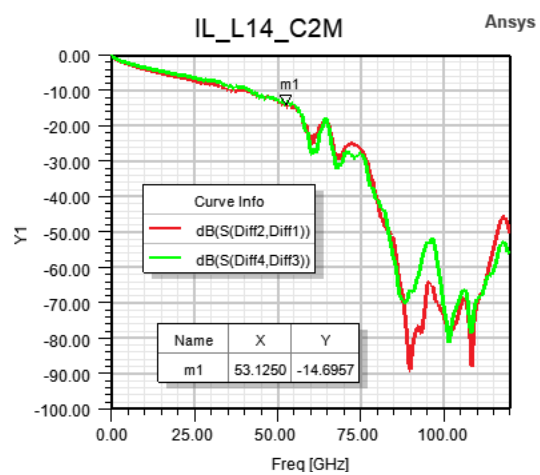
Orthogonal Breakout - IL/RL Performance

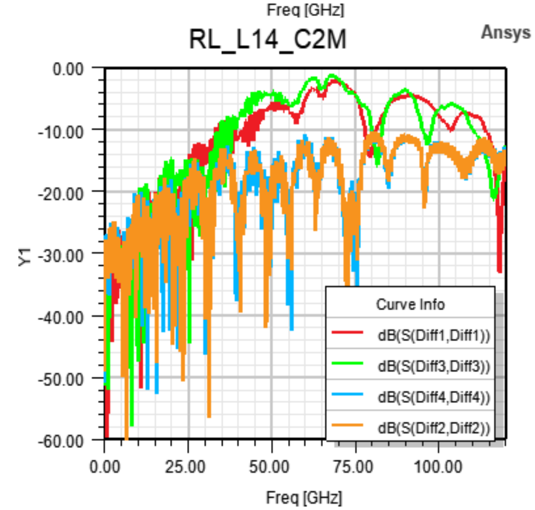
19 mil





67mil



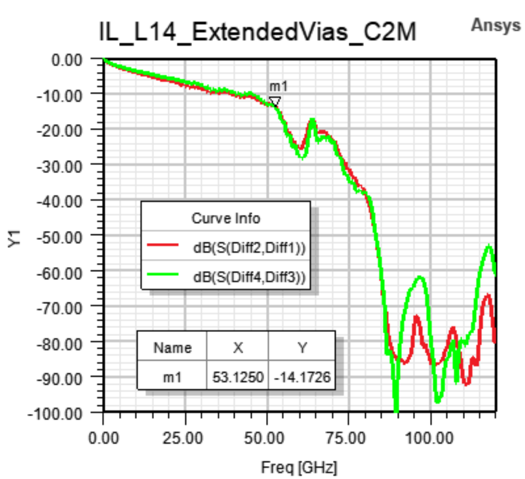


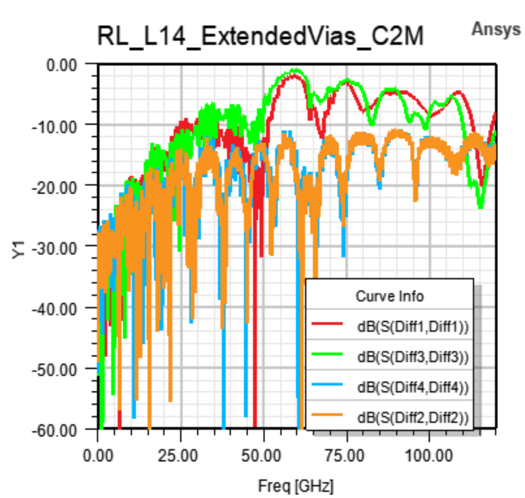
KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

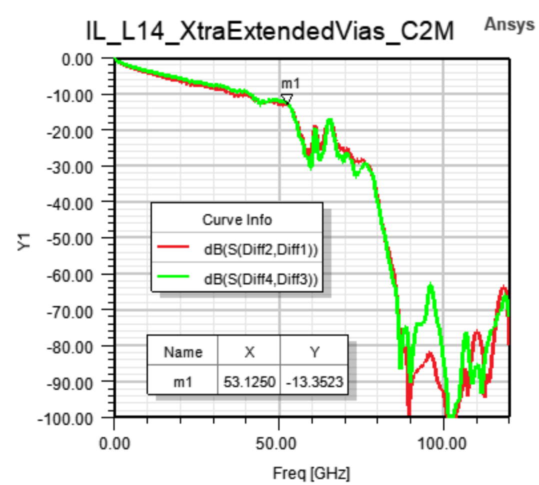
Orthogonal Breakout - IL/RL Performance

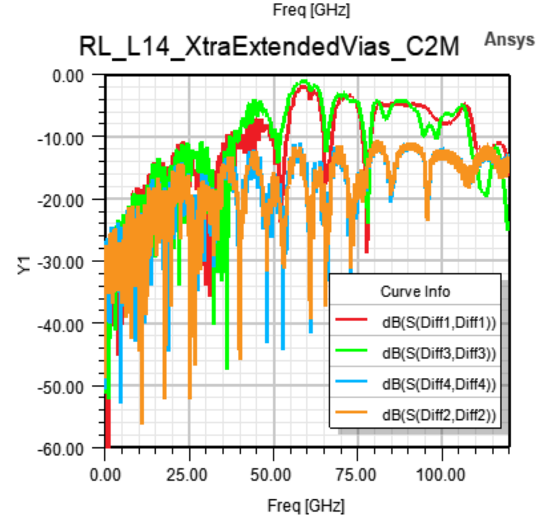
93 mil





135 mil





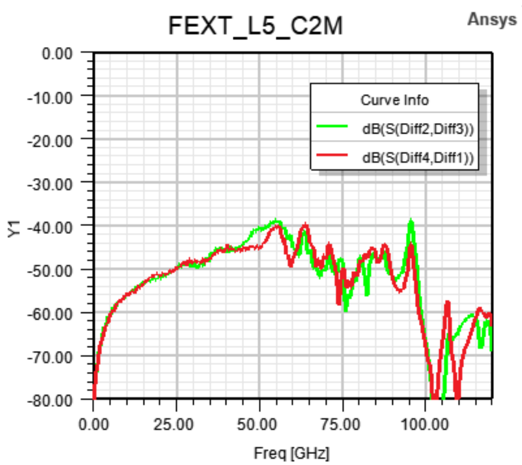
KEYSIGHT TECHNOLOGIES

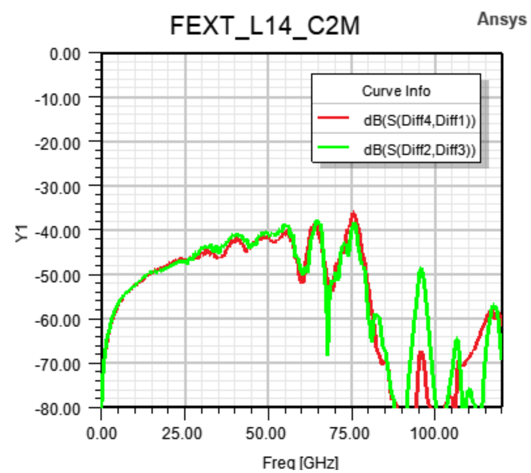
200G PAM4 C2M Via Length Effect Study Supplement

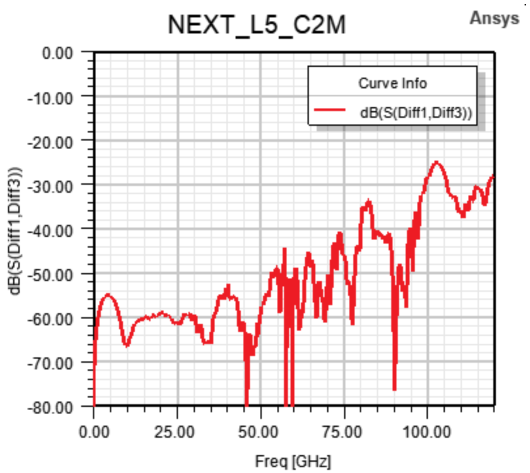
Orthogonal Breakout – FEXT/NEXT(ASIC) Performance

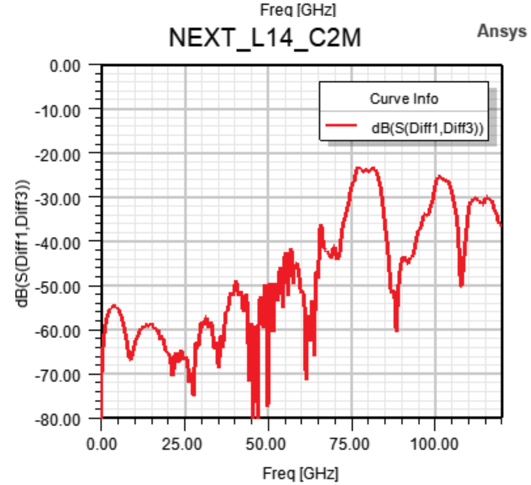
19 mil

67mil







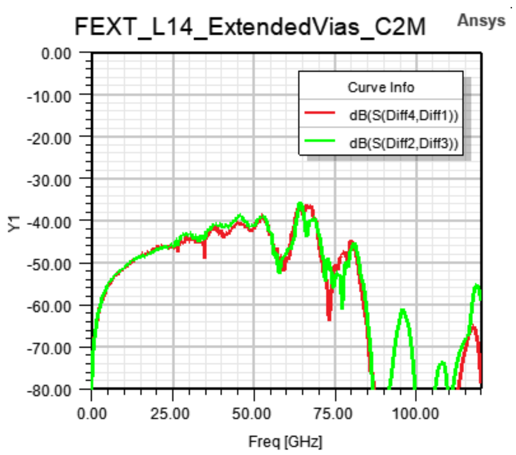


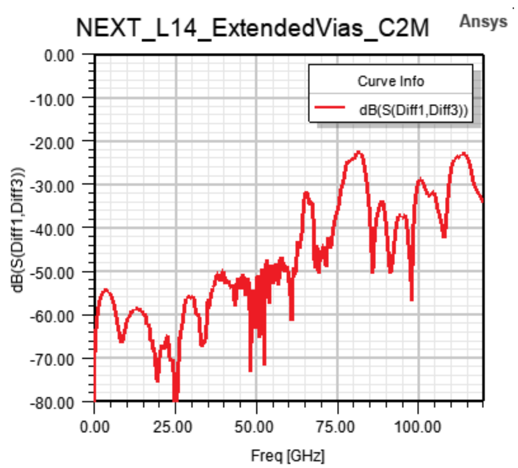
KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

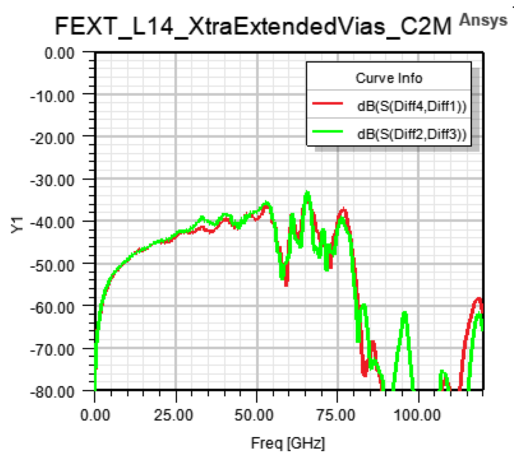
Orthogonal Breakout – FEXT/NEXT(ASIC) Performance

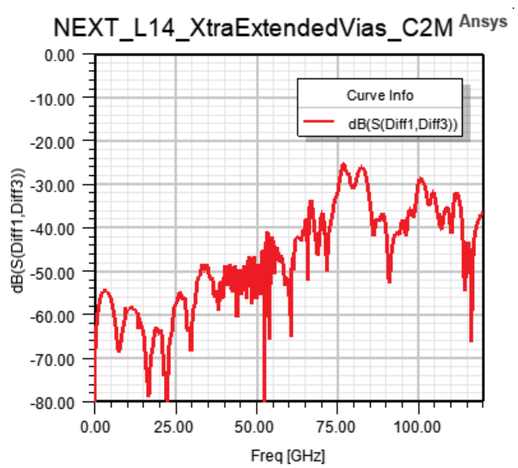
93 mil





135 mil





200G PAM4 C2M Via Length Effect Study Supplement

Structures and COM Configurations

- Four Via Lengths:
  - ✓ 19 mil – 67 mil – 93 mil – 135 mil
- Two Breakouts:
  - ✓ Parallel
  - ✓ Orthogonal
- Medium Package Size = 30 mm
- Two Filters:
  - ✓ Butterworth
  - ✓ Raised Cosine (starts @ 67 GHz, ends @ 79.7 GHz)*
- With PKG_Tx_FFE_Preset*
- Floating Taps:
  - ✓ 6 groups/3 taps per group/120 UI span
- DER = 1e-05 and 5e-5

*** Note: Default values in contributed spreadsheets**

200G PAM4 C2M Via Length Effect Study Supplement

COM Results

2 FEXTs - 1 NEXT - Medium Size Package (30 mm)											
Orthogonal Breakout											
Case #	Via Length	PKG_TX_FFE_Preset	Filter	DER_0	SNR_TX	eta_0	Float. Taps	EH (mV)	VEC (dB)	ERL (dB)	ICN
1	19 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	10.3	8.63	17.6	1.47
2	67 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	8.7	9.88	16.6	2.04
3	93 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	6.7	11.21	15.5	2.27
4	135 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	4.5	13.85	15.5	2.83
5	135 mil	Yes	Rcin+ BW	5.00E-05	32.5	4.10E-09	Yes	6.2	11.14	16.1	2.83

2 FEXTs - 1 NEXT - Medium Size Package (30 mm)											
Paralell Breakout											
Case #	Via Length	PKG_TX_FFE_Preset	Filter	DER_0	SNR_TX	eta_0	Float. Taps	EH (mV)	VEC (dB)	ERL (dB)	ICN
1	19 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	9.5	8.79	17.6	1.79
2	67 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	7.9	10.28	16.6	2.36
3	93 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	6.9	11.15	15.4	2.62
4	135 mil	Yes	Rcin+ BW	1.00E-05	32.5	4.10E-09	Yes	5.6	13.36	15.5	3.25
5	135 mil	Yes	Rcin+ BW	5.00E-05	32.5	4.10E-09	Yes	7.5	10.80	16.1	3.25

*** Pass: VECmax = 12 ; ERLmin = 10**

200G PAM4 C2M Via Length Effect Study Supplement

COM Results Highlights

Longer vias require additional equalization features regardless of the ASIC breakout style:

- Stronger filter in addition to traditional Butterworth
  - Raised Cosine or equivalent
- Reduce receiver intrinsic noise
- Higher SNR
- Stronger FEC (segmented?) to account for higher DER
- Floating DFE taps or equivalent

200G PAM4 C2M Via Length Effect Study Supplement

Modeling Paradox – Via + Connector ≠ Via and Connector

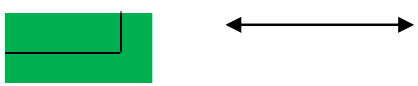
Cascading s-parameters from different sources has risks:

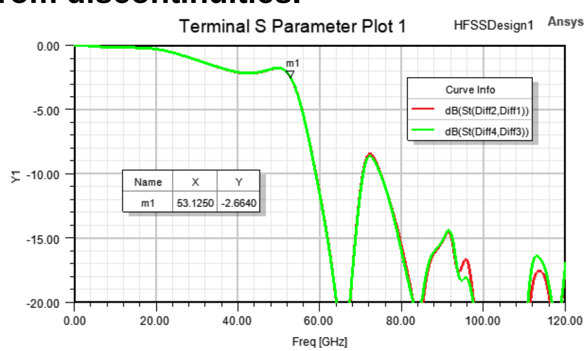
- **Actual x-talk is lost by interconnecting non-TEM boundaries.**
- **Cascading s-parameters from different sources**
  - ✓ **Missing interconnect structure pieces and phase information**
  - ✓ **Double counting of transitions and creating phase distortion**
- **Unaccounted meshing mismatch**

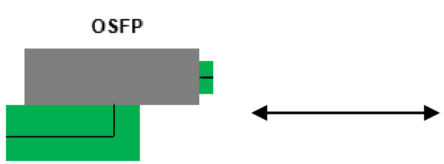
➢ **Build channel model with a "holistic" approach**

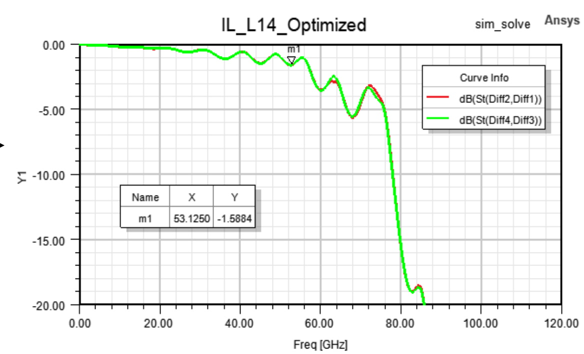
- ❖ **Channel model should <u>NOT</u> be just an aggregate of s-parameter structures**
- ❖ **Channel should be segmented with wave ports along uniform transmission lines several wavelengths away from discontinuities.**

Example:









KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

Summary

“Equal Distribution of *PAIN*” to make C2M a viable interface

Longer PCB via solutions are feasible but:

1. **Need to optimize via transitions**
   - **Cancel via capacitive and inductive effects**
   - **Optimize connector to module PCB transition**

2. **Stronger FEC to support higher DER**
   - **Segmented FEC (?)**

3. **Enhanced Receiver Equalization (compared to P802.3ck):**
   - **Stronger filter**
   - **Higher SNR**
   - **Include floating taps option or equivalent**
   - **Reduce intrinsic chip noise**

➢ **Channel Modeling: Take a holistic approach**

Q & A

KEYSIGHT TECHNOLOGIES

Additional Data

200G PAM4 C2M Via Length Effect Study Supplement

Working Spreadsheet

	A	B	C	D
1	Table 93A-1 parameters			
2	**Parameter**	**Setting**	**Units**	**Information**
3	f_b	106.25	GBd	
4	f_min	0.05	GHz	
5	Delta_f	0.01	GHz	
6	C_d	[0.4e-4 0.9e-4 1.1e-4 ;0 0 0]	nF	[TX RX]
7	L_s	[.12 .15 .14; 0 0 0]	nH	[TX RX]
8	C_b	[.3e-4 0]	nF	[TX RX]
9	z_p select	[1 2 3]		[test cases to run]
10	z_p (TX)	[12 30 45; 1 1 1 ; 0.1 0.1 0.1 ; 0.58 0.58 0.58]	mm	[test cases]
11	z_p (NEXT)	[0 0 0; 0 0 0;0 0 0 ;0 0 0]	mm	[test cases]
12	z_p (FEXT)	[12 30 45; 1 1 1 ; 0.1 0.1 0.1 ; 0.58 0.58 0.58]	mm	[test cases]
13	z_p (RX)	[0 0 0; 0 0 0;0 0 0 ;0 0 0]	mm	[test cases]
14	PKG_Tx_FFE_preset	[-0.140 1; -0.182 1; -0.231 1]		
15	C_p	0	nF	[TX RX]
16	R_0	50	Ohm	
17	R_d	[45 50]	Ohm	[TX RX]
18	A_v	0.387	V	vp/vf=
19	A_fe	0.387	V	vp/vf=
20	A_ne	0.608	V	
21	L	4		
22	M	32		
23	filter and Eq			
24	f_r	0.75	*fb	
25	c(0)	0.65		min
26	c(-1)	[-0.2:0.02:0]		[min:step:max]
27	c(-2)	[0:.02:0.1]		[min:step:max]
28	c(-3)	[-0.1:.02:0]		[min:step:max]
29	c(1)	[-0.2:0.02:0]		[min:step:max]
30	N_b	8	UI	
31	b_max(1)	0.85		As/dffe1
32	b_max(2..N_b)	0.15		As/dfe2..N_b
33	b_min(1)	0		As/dffe1
34	b_min(2..N_b)	-0.15		As/dfe2..N_b
35	g_DC	[-13:1:0]	dB	[min:step:max]
36	f_z	42.5	GHz	
37	f_p1	42.5	GHz	
38	f_p2	106.25	GHz	
39	g_DC_HP	[-6:1:0]		[min:step:max]
40	f_HP_PZ	1.0625	GHz	
41	Butterworth	1	logical	include in fr
42	Raised_Cosine	1	logical	include in fr
43	RC_Start	6.70E+10	Hz	start freq for RCos
44	RC_end	7.97E+10	Hz	end freq for RCos
45				
46	Impulse response truncation threshold	0.0001		
47				

	F	G	H
1	I/O control		
2	DIAGNOSTICS	1	logical
3	DISPLAY_WINDOW	1	logical
4	CSV_REPORT	1	logical
5	RESULT_DIR	.\results\c2m_{date}\	
6	SAVE_FIGURES	0	logical
7	Port Order	[1 2 3 4]	
8	RUNTAG	l_Rcos_Txpe_TP1a_COM_model	
9	COM_CONTRIBUTION	0	logical
10	Operational		
11	ERL Pass threshold	10	dB
12	VEC Pass threshold	12	db
13	EH_min	0	Value
14	DER_0	5.00E-05	
15	T_r	4.71E-03	ns
16	FORCE_TR	1	logical
17	Min_VEO_Test	0	mV
18	PMD_type	C2M	
19	T_O	50	mUI
20	samples_for_C2M	100	amples/UI
21	EW	1	
22	TDR and ERL options		
23	TDR	1	logical
24	ERL	1	logical
25	ERL_ONLY	0	logical
26	TR_TDR	0.01	ns
27	N	1000	
28	TDR_Butterworth	1	logical
29	beta_x	0	
30	rho_x	0.618	
31	TDR_W_TXPKG	1	
32	N_bx	8	UI
33	fixture delay time	[0 0.2e-9]	
34	Tukey_Window	1	
35	Noise, jitter		
36	sigma_RJ	0.01	UI
37	A_DD	0.02	UI
38	eta_0	4.10E-09	V^2/GHz
39	SNR_TX	32.5	dB
40	R_LM	0.95	
41	11-2022 BenArtsi pkg		
42	highlighted are under re-consideration		
43	mli_3df_02_220316		

	J	K	L
1	Table 93A–3 parameters		
2	**Parameter**	**Setting**	**Units**
3	package_tl_gamma0_a1_a2	[0 0.0008455 0.000340225]	
4	package_tl_tau	0.00644805	ns/mm
5	package_Z_c	[92 92 ; 70 70; 80 80; 100 100]	Ohm
6			
7	**Parameter**	**Setting**	
8	board_tl_gamma0_a1_a2	*[0 6.44084e-4 3.6036e-05]*	1.5 db/in @ 56G
9	board_tl_tau	*5.790E-03*	ns/mm
10	board_Z_c	100	Ohm
11	z_bp (TX)	*125*	mm
12	z_bp (NEXT)	*0*	mm
13	z_bp (FEXT)	*125*	mm
14	z_bp (RX)	*0*	mm
15	C_0	[0.2e-4 0]	nF
16	C_1	[0.2e-4 0]	nF
17	**Include PCB**	**0**	**logical**
18			
19			
20	Seletions (rectangle, gaussian,dual_rayleigh,triangle		
21	Histogram_Window_Weight	gaussian	selection
22	Qr	*0.02*	UI
23			
24			
25	ICN parameters		
26	f_v	0.278	Fb
27	f_f	0.278	Fb
28	f_n	0.278	Fb
29	f_2	79.688	GHz
30	A_ft	0.450	V
31	**A_nt**	0.450	V
32			
33	Floating Tap Control		
34	N_bg	6	0 1 2 or 3 groups
35	N_bf	3	taps per group
36	N_f	120	UI span for floating taps
37	bmaxg	0.2	max DFE value for floating taps
38	B_float_RSS_MAX	0.1	rss tail tap limit
39	N_tail_start	9	(UI) start of tail taps limit
40			
41	Receiver testing		
42	RX_CALIBRATION	0	logical
43	Sigma BBN step	5.00E-03	V

KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Via Length Effect Study Supplement

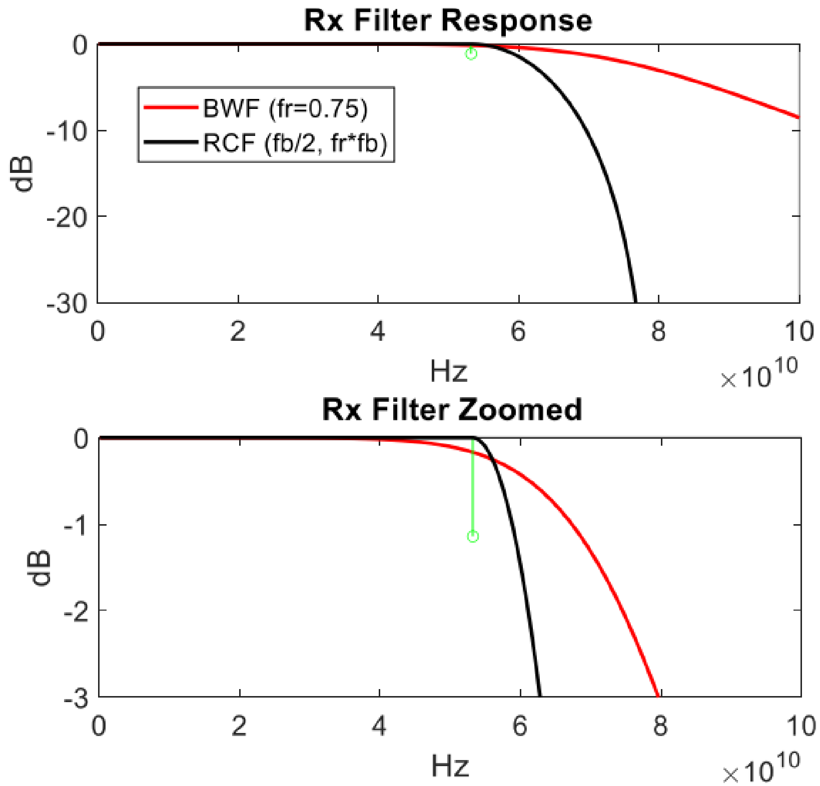
Channel Contributions*

- Rabinovich_C2M_200G_Paral_19mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Paral_19mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Paral_19mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Paral_67mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Paral_67mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Paral_67mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Paral_93mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Paral_93mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Paral_93mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Paral_135mil_011723_FEXT.s4p
- Rabinovich_C2M_200G_Paral_135mil_011723 _NEXT.s4p
- Rabinovich_C2M_200G_Paral_135mil_011723 _Thru.s4p
- Rabinovich_C2M_200G_Ortho_19mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Ortho_19mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Ortho_19mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Ortho_67mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Ortho_67mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Ortho_67mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Ortho_93mil_092122_FEXT.s4p**
- Rabinovich_C2M_200G_Ortho_93mil_092122_NEXT.s4p**
- Rabinovich_C2M_200G_Ortho_93mil_092122_Thru.s4p**
- Rabinovich_C2M_200G_Ortho_135mil_011723 _FEXT.s4p
- Rabinovich_C2M_200G_Ortho_135mil_011723 _NEXT.s4p
- Rabinovich_C2M_200G_Ortho_135mil_011723 _Thru.s4p

* Note: Use Port Order = [1 2 3 4]
** Note: Released on 9/21/22

200G PAM4 C2M Via Length Effect Study Supplement

IL Comparison Between Butterworth and Raise Cosine Filters



*** Source: Mellitz_3df_elec_01_220621.pdf**

KEYSIGHT TECHNOLOGIES