212 Gb/s PAM4 per Lane C2M Channels Frequency Range and Rx Filter

Rick Rabinovich
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KEYSIGHT TECHNOLOGIES

200G PAM4 C2M Frequency Range and Rx Filter

Supporters/Contributors

Femi Akinwale	Intel
Howard Heck	Intel
Mike Dudek	Marvell
Phil Sun	Credo Semiconductor
Richard Mellitz	SAMTEC

200G PAM4 C2M Frequency Range and Rx Filter

Objectives

- Determine the minimum maximum frequency for s-parameter measurements
  - Investigate the s-parameter frequency range effect on COM results
- Analyze Potential Receive Filter Types

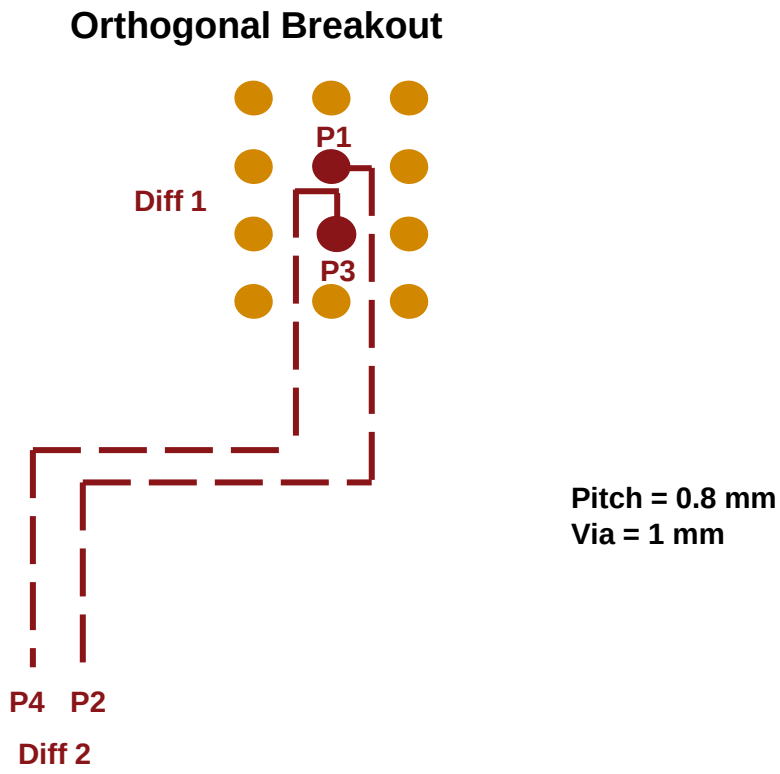
200G PAM4 C2M Frequency Range and Rx Filter

Methodology

- Truncate 120 GHz C2M s-parameter files and check for convergence of EH and VEC
  - 120 GHZ → 90 GHz → 80 GHz → 75 GHz → 70 GHz → 60 GHz
  - Use orthogonal rabinovich_3df_01_2209.zip contribution dated 9/19/2022
- Three types of reference receive filter:
  - Type 1: Butterworth Only with f_r = 0.75 Baud Rate
  - Type 2: Butterworth Only with f_r = 0.55 Baud Rate
  - Type 3: Butterworth + Strong Roll-Off Filter
- Six cases are analyzed:
  - Small Size Package (12 mm) for 19mil/67mil/93mil vias
  - Medium Size Package (30 mm) for 19mil/67mil/93mil vias
- COM Revision COM rev. 4.0
- Working spreadsheet at the end of presentation
  - Tx Package Preset
  - Floating Taps

200G PAM4 C2M Frequency Range and Rx Filter

Orthogonal Breakout Topology



Reference Channels:
https://www.ieee802.org/3/df/public/tools/index.html\rabinovich_3df_01_2209.zip

200G PAM4 C2M Frequency Range and Rx Filter

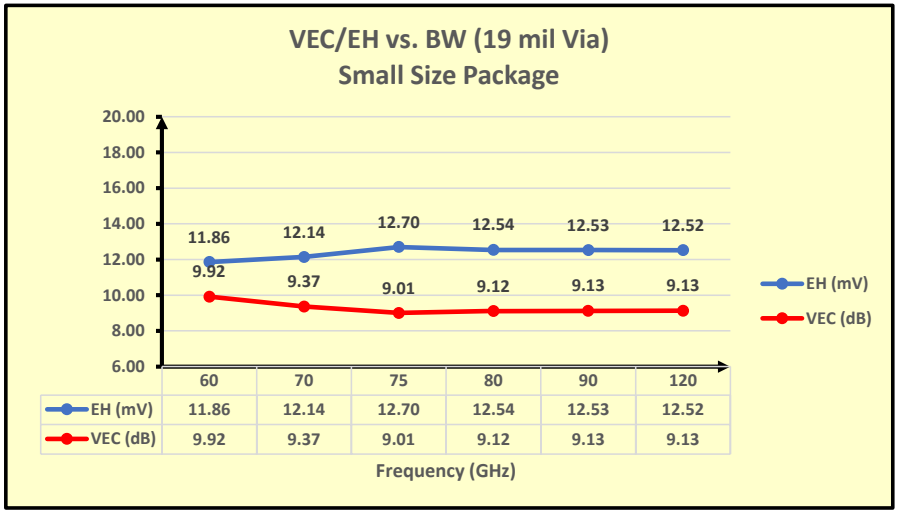
Filter Type 1

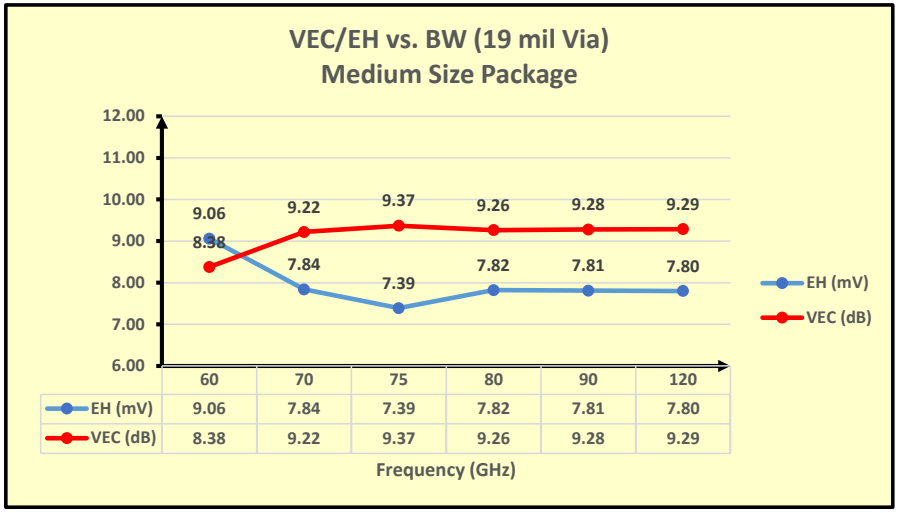
Input Filter: Butterworth Only – f_r = 0.75

Crosstalk : 2 FEXTs – 1 NEXT

200G PAM4 C2M Frequency Range and Rx Filter

19 Mil Via - VEC/EH vs. Frequency - Butterworth Only





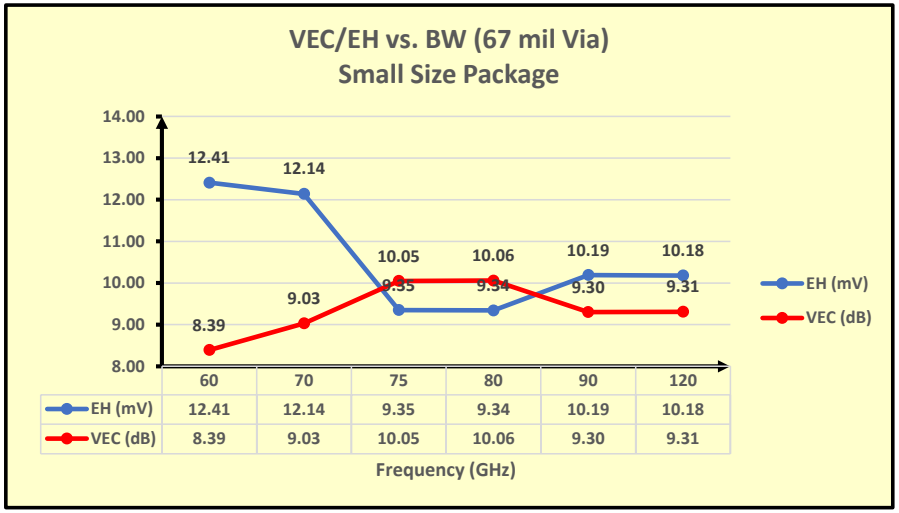
DER = 1e-5

12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	11.86	9.92	-5.27%	8.60%
70	12.14	9.37	-3.04%	2.57%
75	12.70	9.01	1.44%	-1.40%
80	12.54	9.12	0.16%	-0.15%
90	12.53	9.13	0.08%	-0.08%
120	12.52	9.13	0.00%	0.00%

30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	9.06	8.38	16.15%	-9.79%
70	7.84	9.22	0.51%	-0.75%
75	7.39	9.37	-5.26%	0.86%
80	7.82	9.26	0.26%	-0.26%
90	7.81	9.28	0.13%	-0.12%
120	7.80	9.29	0.00%	0.00%

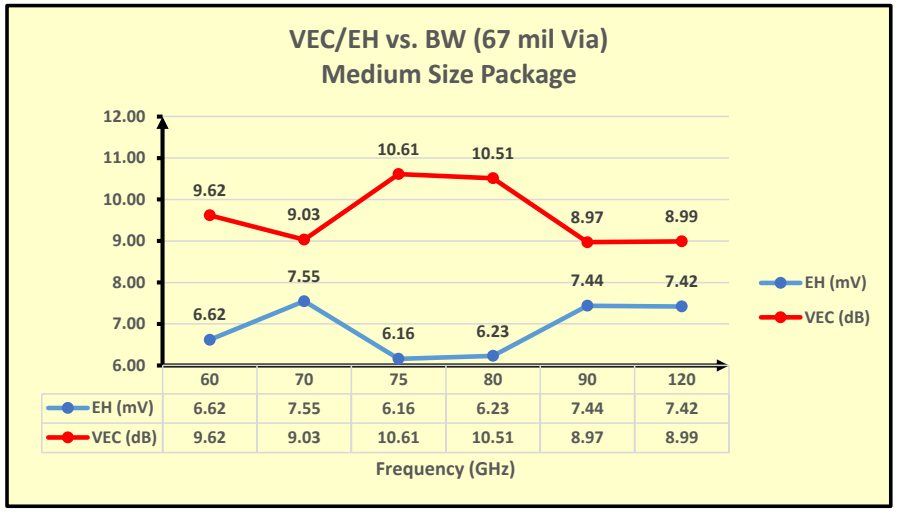
200G PAM4 C2M Frequency Range and Rx Filter

67 Mil Via - VEC/EH vs. Frequency - Butterworth Only



DER = 5e-5

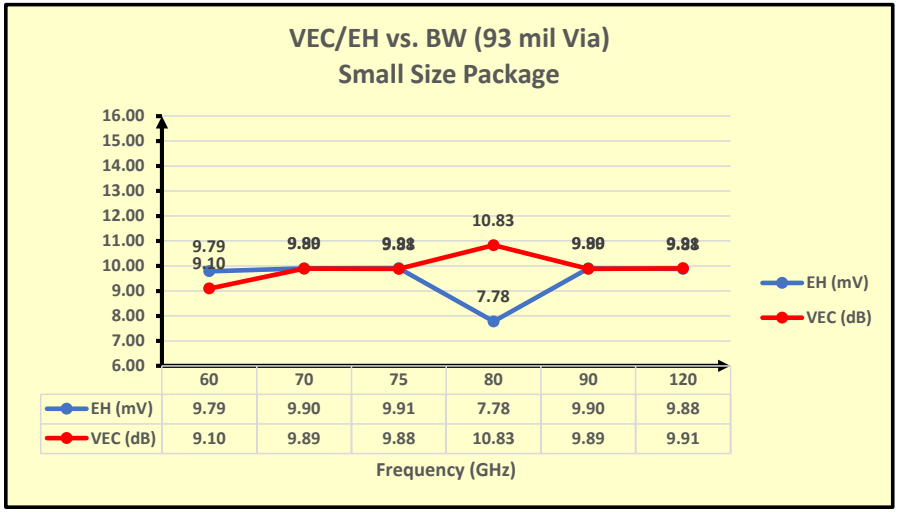
12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	12.41	8.39	21.91%	-9.87%
70	12.14	9.03	19.25%	-3.01%
75	9.35	10.05	-8.15%	7.96%
80	9.34	10.06	-8.25%	8.05%
90	10.19	9.30	0.10%	-0.09%
120	10.18	9.31	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	6.62	9.62	-10.78%	6.96%
70	7.55	9.03	1.75%	0.46%
75	6.16	10.61	-16.98%	17.99%
80	6.23	10.51	-16.04%	16.90%
90	7.44	8.97	0.27%	-0.26%
120	7.42	8.99	0.00%	0.00%

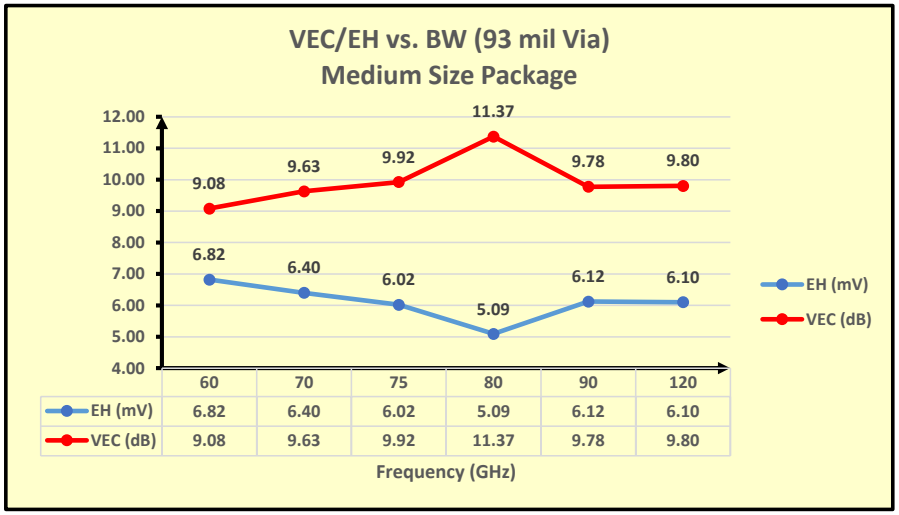
200G PAM4 C2M Frequency Range and Rx Filter

93 Mil Via - VEC/EH vs. Frequency - Butterworth Only



DER = 5e-5

12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	9.79	9.10	-0.91%	-8.15%
70	9.90	9.89	0.20%	-0.13%
75	9.91	9.88	0.30%	-0.23%
80	7.78	10.83	-21.26%	9.32%
90	9.90	9.89	0.20%	-0.17%
120	9.88	9.91	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	6.82	9.08	11.75%	-7.37%
70	6.40	9.63	4.85%	-1.76%
75	6.02	9.92	-1.38%	1.23%
80	5.09	11.37	-16.55%	16.02%
90	6.12	9.78	0.29%	-0.28%
120	6.10	9.80	0.00%	0.00%

200G PAM4 C2M Frequency Range and Rx Filter

Type 1 (Butterworth Only – f_r = 0.75) Conclusion

EH and VEC stabilize at 90 GHz

- S-Parameter setup needs to be at least 90 GHz

Challenge

- Test bench frequency range to be at least 90 GHz
  - Cable/Connector
  - Sensitivity of the overall setup

200G PAM4 C2M Frequency Range and Rx Filter

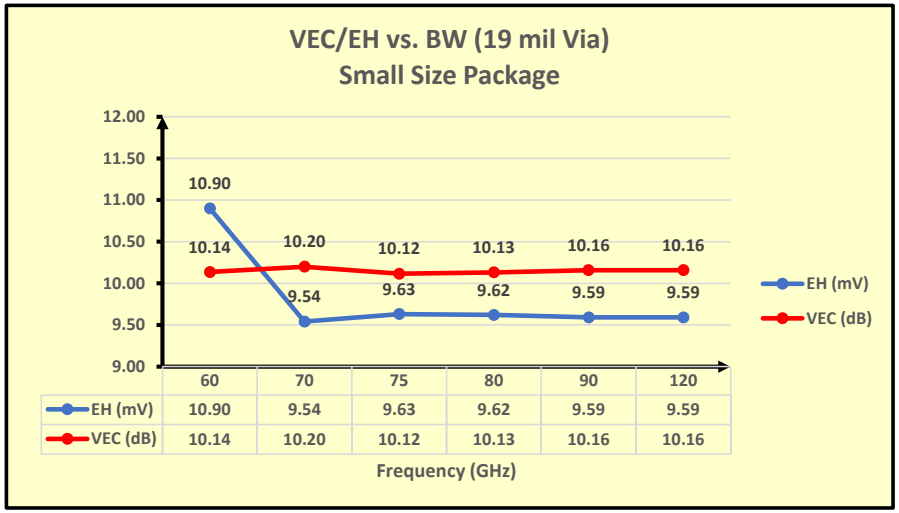
Filter Type 2

Input Filter: Butterworth Only – f_r = 0.55

Crosstalk : 2 FEXTs – 1 NEXT

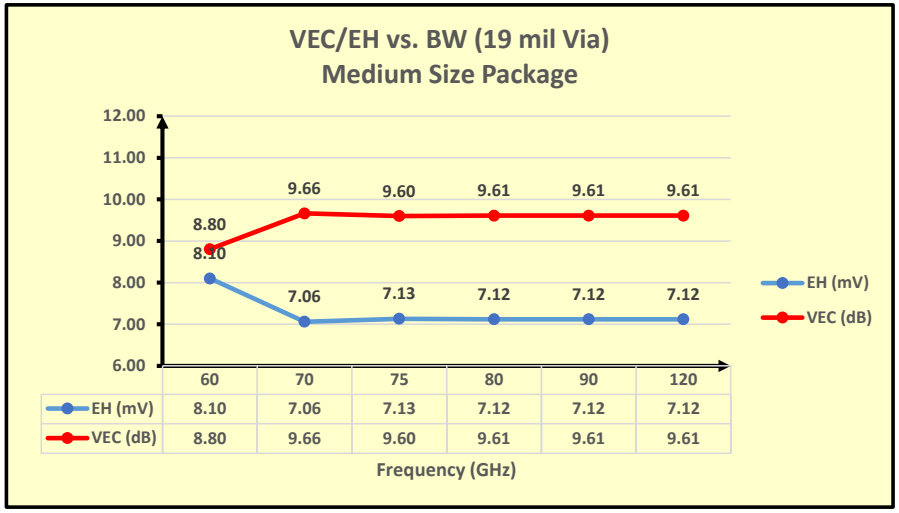
200G PAM4 C2M Frequency Range and Rx Filter

19 Mil Via - VEC/EH vs. Frequency - Butterworth Only



DER = 1e-5

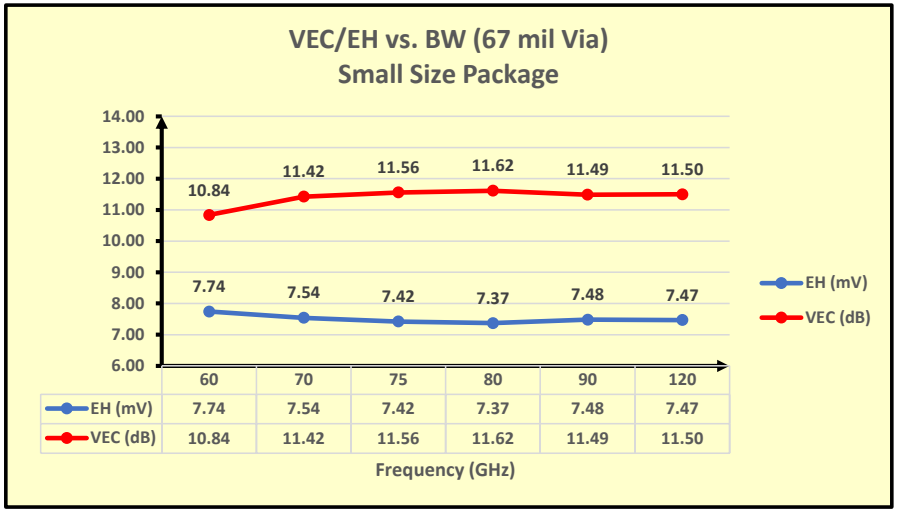
12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	10.90	10.14	13.66%	-0.23%
70	9.54	10.20	-0.52%	0.40%
75	9.63	10.12	0.42%	-0.42%
80	9.62	10.13	0.31%	-0.27%
90	9.59	10.16	0.00%	0.00%
120	9.59	10.16	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	8.10	8.80	13.76%	-8.39%
70	7.06	9.66	-0.84%	0.54%
75	7.13	9.60	0.14%	-0.10%
80	7.12	9.61	0.00%	0.00%
90	7.12	9.61	0.00%	0.00%
120	7.12	9.61	0.00%	0.00%

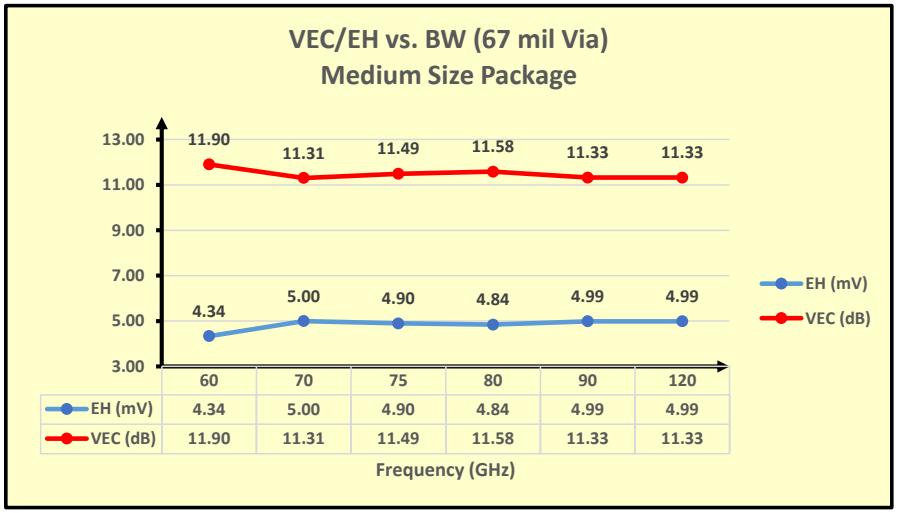
200G PAM4 C2M Frequency Range and Rx Filter

67 Mil Via - VEC/EH vs. Frequency - Butterworth Only



DER = 1e-5

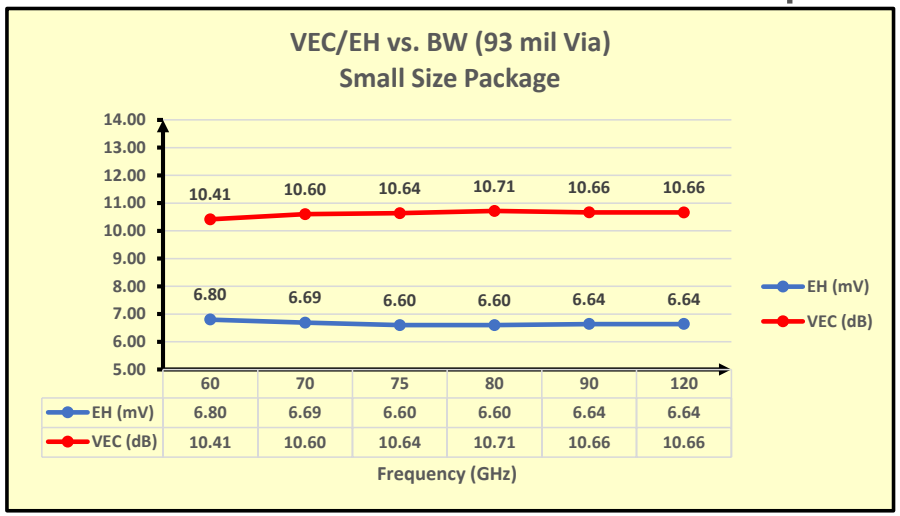
12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	7.74	10.84	3.61%	-5.77%
70	7.54	11.42	0.94%	-0.65%
75	7.42	11.56	-0.67%	0.52%
80	7.37	11.62	-1.34%	1.02%
90	7.48	11.49	0.13%	-0.10%
120	7.47	11.50	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	4.34	11.90	-13.05%	5.10%
70	5.00	11.31	0.24%	-0.14%
75	4.90	11.49	-1.84%	1.42%
80	4.84	11.58	-2.95%	2.29%
90	4.99	11.33	0.00%	0.00%
120	4.99	11.33	0.00%	0.00%

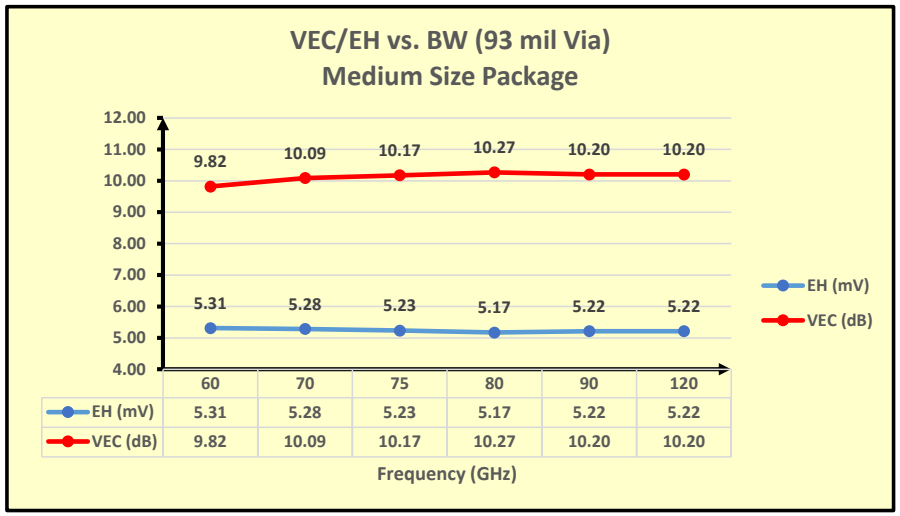
200G PAM4 C2M Frequency Range and Rx Filter

93 Mil Via - VEC/EH vs. Frequency - Butterworth Only



DER = 5e-5

12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	6.80	10.41	2.41%	-2.32%
70	6.69	10.60	0.75%	-0.56%
75	6.60	10.64	-0.60%	-0.23%
80	6.60	10.71	-0.60%	0.50%
90	6.64	10.66	0.00%	0.00%
120	6.64	10.66	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	5.31	9.82	1.84%	-3.77%
70	5.28	10.09	1.30%	-1.10%
75	5.23	10.17	0.33%	-0.27%
80	5.17	10.27	-0.81%	0.69%
90	5.22	10.20	0.00%	0.00%
120	5.22	10.20	0.00%	0.00%

200G PAM4 C2M Frequency Range and Rx Filter

Type 2 (Butterworth Only – f_r = 0.55) Conclusion

EH and VEC stabilize at 70 GHz

- S-Parameter setup needs to be at least 70-75 GHz

Requirement

- Test bench frequency range to be at least 70-75 GHz
  - Cable/Connector
  - Connectivity of the overall setup

200G PAM4 C2M Frequency Range and Rx Filter

Filter Type 3

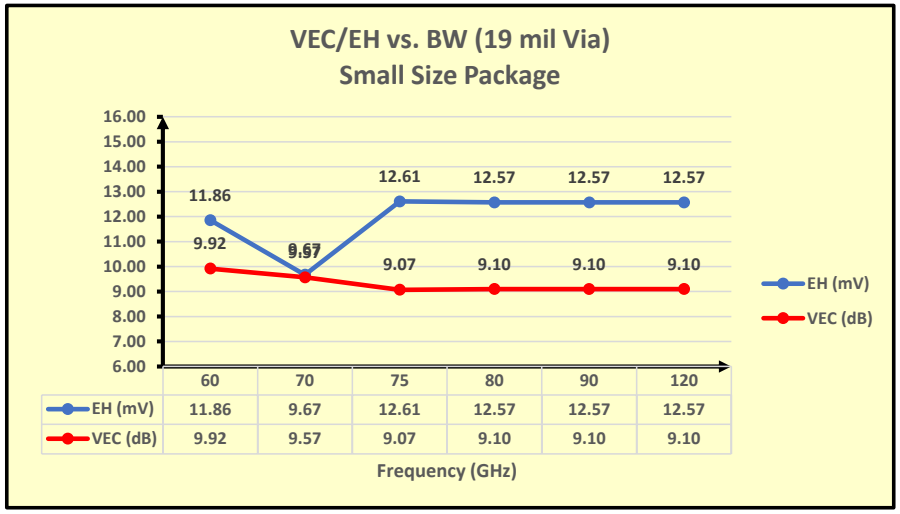
Input Filters: Butterworth (f_r = 0.75) + High Roll-Off Filter

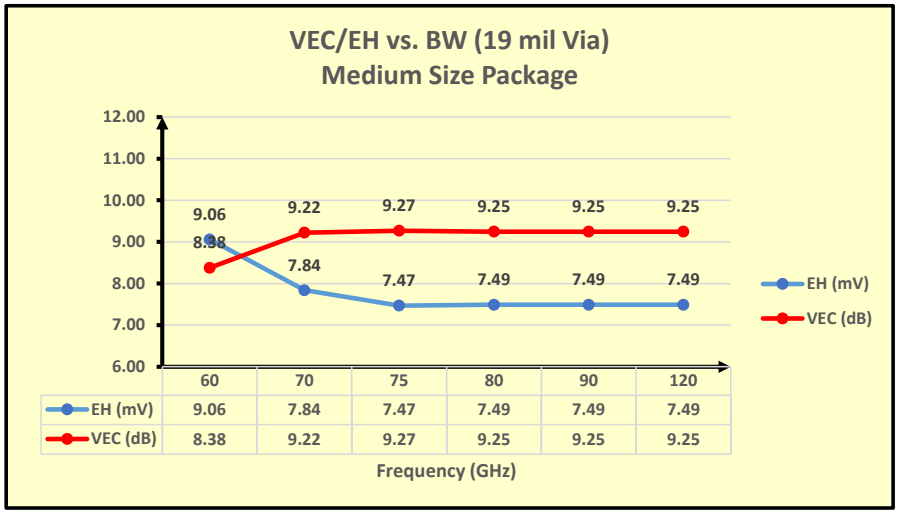
Crosstalk : 2 FEXTs – 1 NEXT

RCos Start: 67 GHz
RCos Stop: 79.7 GHz (1.5 Nyquist)

200G PAM4 C2M Frequency Range and Rx Filter

19 Mil Via - VEC/EH vs. Freq. - BW + High-Roll Off Filter





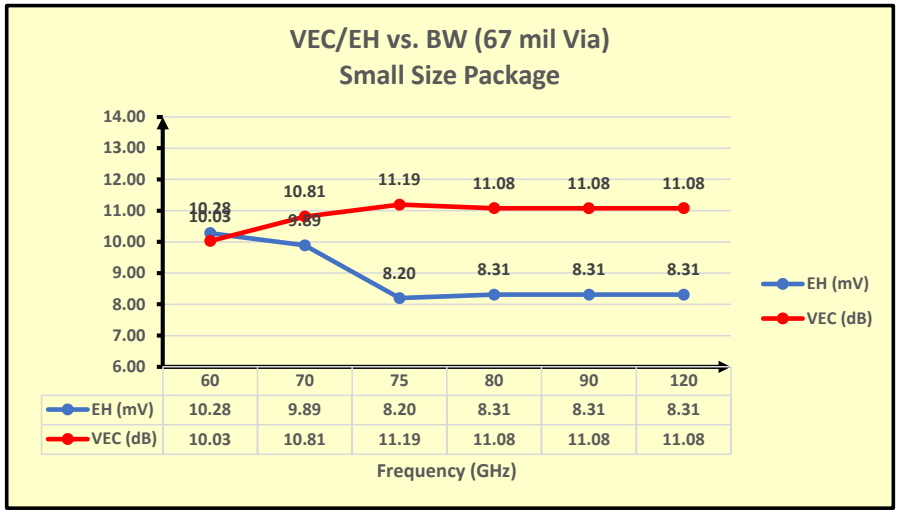
DER = 1e-5

12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	11.86	9.92	-5.65%	9.00%
70	9.67	9.57	-23.07%	5.14%
75	12.61	9.07	0.32%	-0.32%
80	12.57	9.10	0.00%	0.00%
90	12.57	9.10	0.00%	0.00%
120	12.57	9.10	0.00%	0.00%

30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	9.06	8.38	20.96%	-9.37%
70	7.84	9.22	4.67%	-0.26%
75	7.47	9.27	-0.27%	0.27%
80	7.49	9.25	0.00%	0.00%
90	7.49	9.25	0.00%	0.00%
120	7.49	9.25	0.00%	0.00%

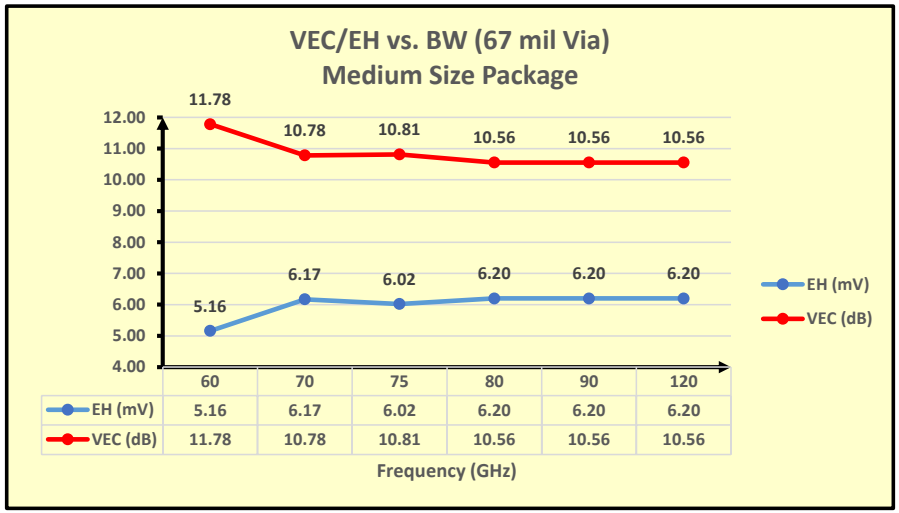
200G PAM4 C2M Frequency Range and Rx Filter

67 Mil Via - VEC/EH vs. Freq. - BW + High-Roll Off Filter



DER = 1e-5

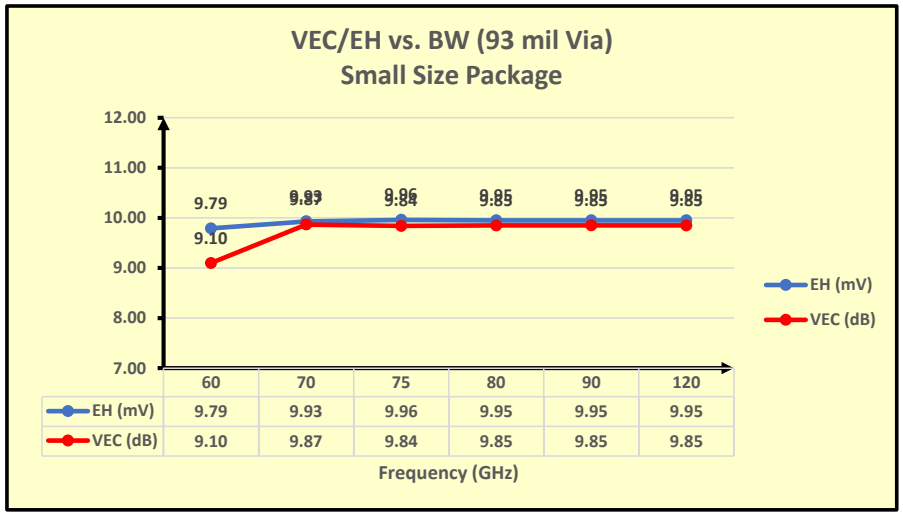
12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	10.28	10.03	23.71%	-9.48%
70	9.89	10.81	19.01%	-2.41%
75	8.20	11.19	-1.32%	1.06%
80	8.31	11.08	0.00%	0.00%
90	8.31	11.08	0.00%	0.00%
120	8.31	11.08	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	5.16	11.78	-16.77%	11.62%
70	6.17	10.78	-0.48%	2.16%
75	6.02	10.81	-2.90%	2.42%
80	6.20	10.56	0.00%	0.00%
90	6.20	10.56	0.00%	0.00%
120	6.20	10.56	0.00%	0.00%

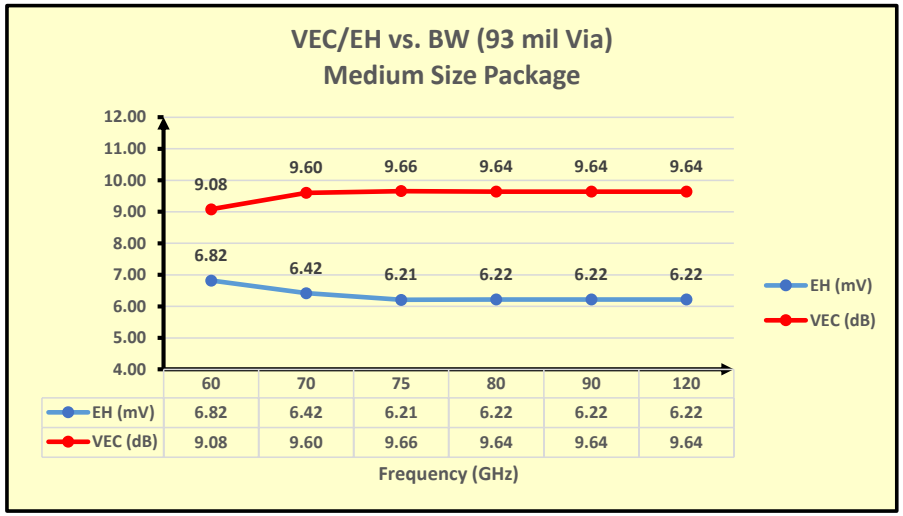
200G PAM4 C2M Frequency Range and Rx Filter

93 Mil Via - VEC/EH vs. Freq. - BW + High-Roll Off Filter



DER = 5e-5

12 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	9.79	9.10	-1.61%	-7.62%
70	9.93	9.87	-0.20%	0.19%
75	9.96	9.84	0.10%	-0.08%
80	9.95	9.85	0.00%	0.00%
90	9.95	9.85	0.00%	0.00%
120	9.95	9.85	0.00%	0.00%



30 mm				
Frequency	EH (mV)	VEC (dB)	EH (%)	VEC(%)
60	6.82	9.08	9.68%	-5.83%
70	6.42	9.60	3.23%	-0.41%
75	6.21	9.66	-0.14%	0.13%
80	6.22	9.64	0.00%	0.00%
90	6.22	9.64	0.00%	0.00%
120	6.22	9.64	0.00%	0.00%

200G PAM4 C2M Frequency Range and Rx Filter

Type 3 (Butterworth (f_r = 0.75) + High Roll-Off Filter) Conclusion

- Bound the overall receiver input frequency bandwidth by adding a strong roll-off filter

- Example
  - COM Revision 4.0
    - ➢ Raised Cosine: F_{start} = 67 GHz → F_{stop} = 79.7 GHz (= 1.5*Nyquist)
      - ➢ S-Parameter frequency range needs to be at least 75 GHz

200G PAM4 C2M Frequency Range and Rx Filter

Summary (1)

Defined and Analyze 3 filter types:

- Type 1: Butterworth Filter Only (f_r = 0.75 Baud Rate):
  - VEC and EH converge at ≥ 90 GHz
  - Higher DER may be required

- Type 2: Butterworth Filter Only (f_r = 0.55 Baud Rate):
  - VEC and EH converge at ≥ 70-75 GHz
  - Lower DER: Relaxes C2M FEC budget

- Type 3 : Add a Strong Roll-Off Filter (1) in series with Butterworth Filter (f_r = 0.75 Baud Rate)
  - Strong roll-off filter
    - Example: Fstop = 80 GHz (1.5*Nyquist ?)
    - VEC and EH converge at ≥ 75 GHz
  - Lower DER: Relaxes C2M FEC budget

(1) No specific filter is promoted even though raise cosine is used as an example.

200G PAM4 C2M Frequency Range and Rx Filter

Summary (2)

Trade-off between Convenience vs. Accuracy (EH and VEC stabilize Error ≤ 5%)

We need to define the receive filter type before we can specify the s-parameter frequency range:

- Type 1: Butterworth Filter Only (f_r = 0.75 Baud Rate) => S-Param (f) ≥ 90 GHz
- Type 2: Butterworth Filter Only (f_r = 0.55 Baud Rate) => S-Param (f) ≥ 70-75 GHz
- Type 3: Butterworth Filter (f_r = 0.75 Baud Rate) + Strong Roll-Off Filter => S-Param (f) ≥ 75 GHz

Small Size Package (VEC Error %)									
Frequency	Type 1			Type 2			Type 3		
	19 mil	67 mil	93 mil	19 mil	67 mil	93 mil	19 mil	67 mil	93 mil
60	8.60	(9.87)	(8.15)	(0.23)	(5.77)	(2.32)	9.00	(9.48)	(7.62)
70	2.57	(3.01)	(0.13)	(0.40)	(0.65)	(0.56)	5.14	(2.41)	0.19
75	(1.40)	7.96	(0.23)	(0.42)	0.52	(0.23)	(0.32)	1.06	(0.08)
80	(0.15)	8.05	9.32	(0.27)	1.02	0.50	0.00	0.00	0.00
90	(0.08)	(0.09)	(0.17)	0.00	(0.10)	0.00	0.00	0.00	0.00
120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Medium Size Package (VEC Error %)									
Frequency	Type 1			Type 2			Type 3		
	19 mil	67 mil	93 mil	19 mil	67 mil	93 mil	19 mil	67 mil	93 mil
60	(9.79)	6.96	(7.37)	(8.39)	5.10	(3.77)	(9.37)	11.62	(5.83)
70	(0.75)	0.46	(1.76)	0.54	(0.14)	(1.10)	(0.26)	2.16	(0.41)
75	0.86	17.99	1.23	(0.10)	1.42	(0.27)	0.27	2.42	0.13
80	(0.26)	16.90	16.02	0.00	2.29	0.69	0.00	0.00	0.00
90	(0.12)	(0.26)	(0.28)	0.00	0.00	0.00	0.00	0.00	0.00
120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

➢ Type 1 requires frequency range to be at least 90 GHz

200G PAM4 C2M Frequency Range and Rx Filter

Summary (3)

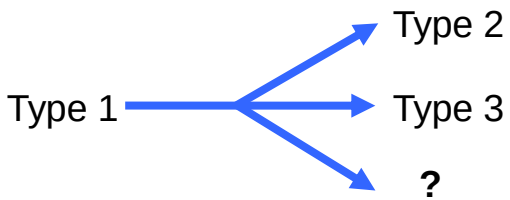
We need to define the receive filter type before we can specify the s-parameter frequency range:

- Type 1: Butterworth Filter Only (f_r = 0.75 Baud Rate) => S-Param (f) ≥ 90 GHz
- Type 2: Butterworth Filter Only (f_r = 0.55 Baud Rate) => S-Param (f) ≥ 70-75 GHz
- Type 3: Butterworth Filter (f_r = 0.75 Baud Rate) + Strong Roll-Off Filter => S-Param (f) ≥ 75 GHz

		Stable Values					
		EH			VEC		
Cases	DER	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
19 mil Via - 12 mm	1.00E-05	12.52	9.59	12.57	9.13	10.16	9.10
19 mil Via - 30 mm	1.00E-05	7.80	7.12	7.49	9.29	9.61	9.25
67 mil Via - 12 mm	5.00E-05	10.18			9.31		
67 mil Via - 12 mm	1.00E-05		7.47	8.31		11.50	11.08
67 mil Via - 30 mm	5.00E-05	7.42			8.99		
67 mil Via - 30 mm	1.00E-05		4.99	6.20		11.33	10.56
93 mil Via - 12 mm	5.00E-05	9.88	6.64	9.95	9.91	10.66	9.85
93 mil Via - 30 mm	5.00E-05	6.10	5.22	6.22	9.80	10.20	9.64

Observations:

1. Type 1 requires frequency range to be at least 90 GHz
2. Type 1 requires higher DER
3. Type 3 has better EH and VEC than Type 2
4. Type 3 would require defining a “strong roll-off” filter



Q & A

Additional Data

200G PAM4 C2M Frequency Range and Rx Filter

Working Spreadsheet

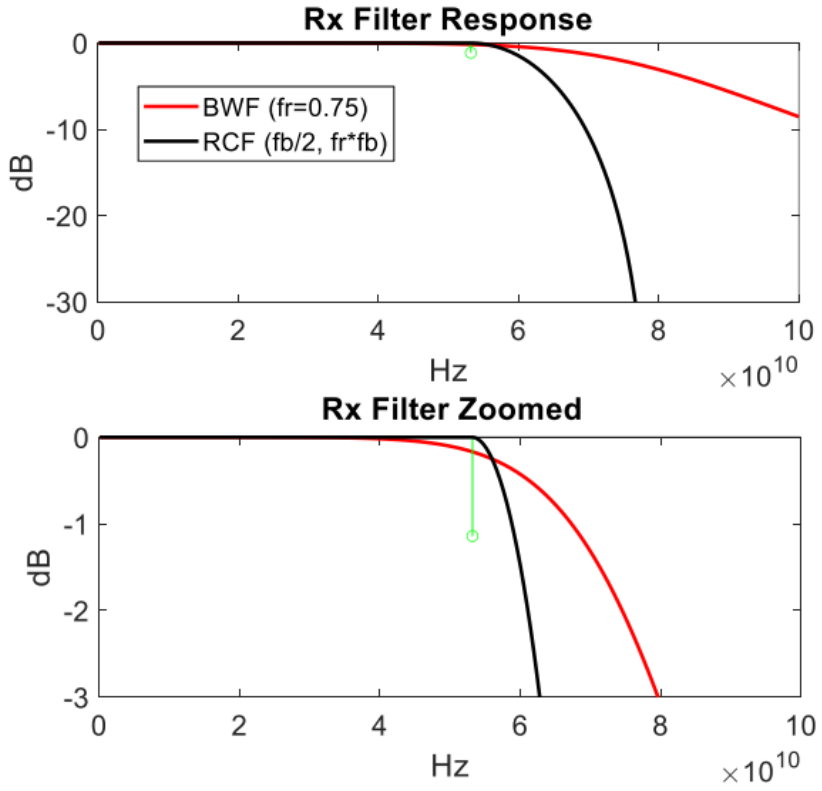
Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	106.25	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[0.4e-4 0.9e-4 1.1e-4 ;0 0 0]	nF	[TX RX]
L_s	[.12 .15 .14; 0 0 0]	nH	[TX RX]
C_b	[.3e-4 0]	nF	[TX RX]
z_p select	[1 2 3]		[test cases to run]
z_p (TX)	[12 30 45; 1 1 1 ; 1 1 1 ; 0.58 0.58 0.58]	mm	[test cases]
z_p (NEXT)	[0 0 0; 0 0 0;0 0 0 ;0 0 0]	mm	[test cases]
z_p (FEXT)	[12 30 45; 1 1 1 ; 1 1 1 ; 0.58 0.58 0.58]	mm	[test cases]
z_p (RX)	[0 0 0; 0 0 0;0 0 0 ;0 0 0]	mm	[test cases]
PKG_Tx_FFE_preset	[-0.140 1; -0.182 1; -0.231 1]		
C_p	0	nF	[TX RX]
R_0	50	Ohm	
R_d	[45 50]	Ohm	[TX RX]
A_v	0.387	V	vp/vf=
A_fe	0.387	V	vp/vf=
A_ne	0.608	V	
L	4		
M	32		
filter and Eq			
f_r	0.75	*fb	
c(0)	0.65		min
c(-1)	[-0.2:0.02:0]		[min:step:max]
c(-2)	[0:.02:0.1]		[min:step:max]
c(-3)	[-0.1:.02:0]		[min:step:max]
c(1)	[-0.2:0.02:0]		[min:step:max]
N_b	8	UI	
b_max(1)	0.85		As/dffe1
b_max(2..N_b)	0.15		As/dfe2..N_b
b_min(1)	0		As/dffe1
b_min(2..N_b)	-0.15		As/dfe2..N_b
g_DC	[-13:1:0]	dB	[min:step:max]
f_z	42.5	GHz	
f_p1	42.5	GHz	
f_p2	106.25	GHz	
g_DC_HP	[-6:1:0]		[min:step:max]
f_HP_PZ	1.0625	GHz	
Butterworth	1	logical	include in fr
Raised_Cosine	0	logical	include in fr
RC_Start	6.70E+10	Hz	start freq for RCos
RC_end	7.97E+10	Hz	end freq for RCos
MLSE	0		
Impulse response truncation threshold	0.0001		

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\c2m_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 2 3 4]	
RUNTAG	l_Rcos_Txpe_TP1a_COM_model	
COM_CONTRIBUTION	0	logical
Operational		
ERL Pass threshold	10	dB
VEC Pass threshold	12	db
EH_min	0	Value
DER_0	1.00E-05	
T_r	6.12E-03	ns
FORCE_TR	1	logical
Min_VEO_Test	0	mV
PMD_type	C2M	
T_O	50	mUI
samples_for_C2M	100	amples/UI
EW	1	
TDR and ERL options		
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.01	ns
N	1000	
TDR_Butterworth	1	logical
beta_x	0	
rho_x	0.618	
TDR_W_TXPKG	1	
N_bx	8	UI
fixture delay time	[0 0.2e-9]	
Tukey_Window	1	
Noise, jitter		
sigma_RJ	0.01	UI
A_DD	0.02	UI
eta_0	4.10E-09	V^2/GHz
SNR_TX	32.5	dB
R_LM	0.95	
11-2022 BenArtsi pkg		
highlighted are under re-consideration		
mli_3df_02_220316		

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 0.0008455 0.000340225]	
package_tl_tau	0.00644805	ns/mm
package_Z_c	[92 92 ; 70 70; 80 80; 100 100]	Ohm
Parameter	**Setting**	
board_tl_gamma0_a1_a2	*[0 6.44084e-4 3.6036e-05]*	1.5 db/in @ 56G
board_tl_tau	*5.790E-03*	ns/mm
board_Z_c	100	Ohm
z_bp (TX)	*125*	mm
z_bp (NEXT)	*0*	mm
z_bp (FEXT)	*125*	mm
z_bp (RX)	*0*	mm
C_0	[0.2e-4 0]	nF
C_1	[0.2e-4 0]	nF
Include PCB	**0**	**logical**
Seletions (rectangle, gaussian,dual_rayleigh,triangle		
Histogram_Window_Weight	gaussian	selection
Qr	*0.02*	UI
ICN parameters		
f_v	0.278	Fb
f_f	0.278	Fb
f_n	0.278	Fb
f_2	79.688	GHz
A_ft	0.450	V
A_nt	0.450	V
Floating Tap Control		
N_bg	6	0 1 2 or 3 groups
N_bf	3	taps per group
N_f	120	UI span for floating tap
bmaxg	0.2	max DFE value for floa
B_float_RSS_MAX	0.1	rss tail tap limit
N_tail_start	9	(UI) start of tail taps li
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V

200G PAM4 C2M Frequency Range and Rx Filter

IL Comparison Between Butterworth and Raise Cosine Filters



*** Source: Mellitz_3df_elec_01_220621.pdf**