

CR/KR Considerations for c(-3) tap

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Supporters

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Outline

- Background and Motivation
- COM analysis with and without Tx c(-3)
- Concerns about Requiring Tx c(-3)
- Benefits of Requiring Tx c(-3)
- Summary
- Proposal

Background and Motivation

- The need for a 3rd pre-cursor tap for CR/KR channels was shown during the Jan 2019 Long Beach meeting [1]
- This tap is included in the Backplane Baseline Proposal introduced at the March 2019 Vancouver meeting [2]
 - Concerns about requiring this tap to be placed at the Tx was discussed, and c(-3) was hence marked a magenta item
- This contribution explores the pros and cons of requiring Tx c(-3)

COM Analysis Setup

- COM 2.60 (parameters are shown at the end of the slide)
- Focused on the 9 selected KR channels [3] and simulated each with 12mm and 32mm package lengths
- Compared impact on COM with and without Tx FIR c(-3) using 3 Reference Rx's
 - 24-tap DFE
 - FFE (3 pre and 12 post) + 1-tap DFE
 - FFE (3 pre and 24 post) + 1-tap DFE

COM Analysis Results: 24-tap DFE

adapted c(-3) values
. -0.02 in 17 of 18 cases

#	Channel	Tx/Rx Package (mm)	c(-3) En/Dis	#DFE	#FFE_pre	#FFE_post	IL_w_Pkg (dB)	C(-3)	C(-2)	C(-1)	C(0)	C(1)	COM (dB)	COM Improvement due to C(-3) (dB)
1	Cable_BKP_28dB_0p575m_more_isi_thru1.s4p	12	Disabled	24	0	0	34.5		0.04	-0.22	0.74	0	4.279	
2		32					42.9	0.06	-0.26	0.68	0	2.674		
3		12	Enabled				34.5	-0.02	0.08	-0.26	0.64	0	4.687	0.408
4		32					42.9	-0.02	0.08	-0.26	0.64	0	3.049	0.375
5	Cable_BKP_16dB_0p575m_more_isi_thru1.s4p	12	Disabled				20.8		0.04	-0.20	0.66	-0.1	5.613	
6		32					28.8	0.04	-0.20	0.66	-0.1	5.005		
7		12	Enabled				20.8	-0.02	0.08	-0.24	0.61	-0.05	6.405	0.792
8		32					28.8	-0.02	0.08	-0.26	0.64	0	5.564	0.559
9	CaBP_BGAVia_Opt2_28dB_THRU.s4p	12	Disabled	31.7		0.04	-0.20	0.76	0	5.900				
10		32		39.3	0.04	-0.20	0.76	0	4.792					
11		12	Enabled	31.7	-0.02	0.08	-0.24	0.66	0	6.055	0.155			
12		32		39.3	0	0.04	-0.20	0.76	0	4.792	0.000			
13	Std_BP_12inch_Meg7_Thru_B56.s4p	12	Disabled	20.9		0.02	-0.22	0.71	-0.05	4.039				
14		32		26.9	0.04	-0.26	0.70	0	4.166					
15		12	Enabled	20.9	-0.02	0.06	-0.26	0.66	0	5.070	1.031			
16		32		26.9	-0.02	0.06	-0.26	0.66	0	5.240	1.074			
17	DPO_4in_Meg7_THRU.s4p	12	Disabled	17.6		0.04	-0.22	0.74	0	5.267				
18		32		23.5	0.04	-0.22	0.74	0	5.539					
19		12	Enabled	17.6	-0.02	0.06	-0.22	0.65	-0.05	5.643	0.376			
20		32		23.5	-0.02	0.06	-0.22	0.65	-0.05	5.978	0.439			
21	OAch4_t.s4p	12	Disabled	33.4		0.04	-0.22	0.74	0	2.963				
22		32		40.5	0.06	-0.26	0.68	0	1.982					
23		12	Enabled	33.4	-0.02	0.08	-0.26	0.64	0	3.466	0.503			
24		32		40.5	-0.02	0.08	-0.26	0.64	0	2.169	0.187			
25	Och4_t.s4p	12	Disabled	33.6		0.08	-0.32	0.60	0	1.442				
26		32		40.9	0.08	-0.32	0.60	0	0.668					
27		12	Enabled	33.6	-0.02	0.10	-0.32	0.56	0	2.103	0.661			
28		32		40.9	-0.02	0.10	-0.32	0.56	0	1.081	0.413			
29	CAch3_b2_t.s4p	12	Disabled	34.0		0.04	-0.22	0.74	0	4.452				
30		32		40.4	0.04	-0.22	0.74	0	3.299					
31		12	Enabled	34.0	-0.02	0.08	-0.26	0.64	0	5.005	0.554			
32		32		40.4	-0.02	0.08	-0.26	0.64	0	3.795	0.496			
33	Bch2_a7p5_7_t.s4p	12	Disabled	34.1		0.08	-0.32	0.60	0	2.147				
34		32		40.8	0.08	-0.32	0.60	0	1.681					
35		12	Enabled	34.1	-0.02	0.10	-0.32	0.56	0	2.817	0.670			
36		32		40.8	-0.02	0.10	-0.32	0.56	0	2.315	0.634			
Average impact on COM due to c(-3) (dB)														0.518

ave. impact on COM due to c(-3)

COM Analysis Results: FFE (3 pre and 12 post) + 1-tap DFE

adapted c(-3) values
 . Mostly 0
 . -0.02 in 1 of 18 cases

#	Channel	Tx/Rx Pacakge (mm)	c(-3) En/Dis	#DFE	#FFE_pre	#FFE_post	IL_w_Pkg (dB)	C(-3)	C(-2)	C(-1)	C(0)	C(1)	COM (dB)	COM Improvement due to C(-3) (dB)						
1	Cable_BKP_28dB_0p575m_more_isi_thru1.s4p	12	Disabled	1	3	12	34.5	0.04	-0.28	0.68	0	4.568								
2		32					42.9	0	-0.24	0.76	0	1.852								
3		12	Enabled				34.5	0	-0.28	0.68	0	4.568	0.000							
4		32					42.9	0	-0.28	0.68	0	1.852	0.000							
5	Cable_BKP_16dB_0p575m_more_isi_thru1.s4p	12	Disabled				1	3	12	20.8	0.1	-0.3	0.6	0	5.082					
6		32								28.8	0.04	-0.26	0.7	0	3.427					
7		12	Enabled							20.8	0	-0.3	0.6	0	5.082	0.000				
8		32								28.8	0	-0.26	0.7	0	3.427	0.000				
9	CaBP_BGAVia_Opt2_28dB_THRU.s4p	12	Disabled							1	3	12	31.7	0.02	-0.24	0.74	0	6.393		
10		32											39.3	0	-0.22	0.78	0	4.152		
11		12	Enabled										31.7	0	-0.24	0.74	0	6.393	0.000	
12		32											39.3	0	-0.22	0.78	0	4.152	0.000	
13	Std_BP_12inch_Meg7_Thru_B56.s4p	12	Disabled	1	3	12							20.9	0.1	-0.3	0.6	0	4.701		
14		32											26.9	0	-0.2	0.6	-0.2	3.220		
15		12	Enabled										20.9	-0.02	0.12	-0.3	0.56	0	4.795	0.094
16		32											26.9	0	-0.2	0.6	-0.2	3.220	0.000	
17	DPO_4in_Meg7_THRU.s4p	12	Disabled				1	3	12				17.6	0.06	-0.28	0.66	0	4.813		
18		32											23.5	0.06	-0.28	0.66	0	3.403		
19		12	Enabled										17.6	0	-0.28	0.66	0	4.813	0.000	
20		32											23.5	0	-0.28	0.66	0	3.403	0.000	
21	OAch4_t.s4p	12	Disabled							1	3	12	33.4	0.04	-0.28	0.68	0	3.466		
22		32											40.5	0.02	-0.28	0.7	0	1.639		
23		12	Enabled										33.4	0	-0.28	0.68	0	3.466	0.000	
24		32											40.5	0	-0.28	0.7	0	1.639	0.000	
25	Och4_t.s4p	12	Disabled	1	3	12							33.6	0.08	-0.34	0.58	0	2.476		
26		32											40.9	0.08	-0.34	0.58	0	0.687		
27		12	Enabled										33.6	0	-0.34	0.58	0	2.476	0.000	
28		32											40.9	0	-0.34	0.58	0	0.687	0.000	
29	CAch3_b2_t.s4p	12	Disabled				1	3	12				34.0	0.04	-0.28	0.68	0	5.067		
30		32											40.4	0.02	-0.26	0.72	0	2.627		
31		12	Enabled										34.0	0	-0.28	0.68	0	5.067	0.000	
32		32											40.4	0	-0.26	0.72	0	2.627	0.000	
33	Bch2_a7p5_7_t.s4p	12	Disabled							1	3	12	34.1	0.08	-0.34	0.58	0	2.180		
34		32											40.8	0.02	-0.3	0.68	0	1.240		
35		12	Enabled										34.1	0	-0.34	0.58	0	2.180	0.000	
36		32											40.8	0	-0.3	0.68	0	1.240	0.000	
Average impact on COM due to c(-3) (dB)													0.005							

ave. impact on COM due to c(-3)

COM Analysis Results: FFE (3 pre and 24 post) + 1-tap DFE

adapted c(-3) values
 . Mostly 0
 . -0.02 in 3 of 18 cases

#	Channel	Tx/Rx Package (mm)	c(-3) En/Dis	#DFE	#FFE_pre	#FFE_post	IL_w_Pkg (dB)	C(-3)	C(-2)	C(-1)	C(0)	C(1)	COM (dB)	COM Improvement due to C(-3) (dB)
1	Cable_BKP_28dB_0p575m_more_isi_thru1.s4p	12	Disabled	1	3	24	34.5	0	0.04	-0.28	0.68	0	4.990	
2		32	Disabled				42.9	0	0	-0.24	0.76	0	3.453	
3		12	Enabled				34.5	0	0.04	-0.28	0.68	0	4.990	0.000
4		32	Enabled				42.9	0	0	-0.24	0.76	0	3.453	0.000
5	Cable_BKP_16dB_0p575m_more_isi_thru1.s4p	12	Disabled				20.8	0	0.06	-0.28	0.66	0	6.286	
6		32	Disabled				28.8	0	0.08	-0.3	0.62	0	5.883	
7		12	Enabled				20.8	0	0.06	-0.28	0.66	0	6.286	0.000
8		32	Enabled				28.8	0	0.08	-0.3	0.62	0	5.883	0.000
9	CaBP_BGAVia_Opt2_28dB_THRU.s4p	12	Disabled				31.7	0	0.02	-0.24	0.74	0	6.503	
10		32	Disabled				39.3	0	0	-0.24	0.76	0	5.114	
11		12	Enabled				31.7	0	0.02	-0.24	0.74	0	6.503	0.000
12		32	Enabled				39.3	0	0	-0.24	0.76	0	5.114	0.000
13	Std_BP_12inch_Meg7_Thru_B56.s4p	12	Disabled				20.9	0	0.12	-0.28	0.6	0	4.821	
14		32	Disabled				26.9	0	0.02	-0.3	0.58	0	5.272	
15		12	Enabled				20.9	-0.02	0.12	-0.3	0.66	0	4.884	0.063
16		32	Enabled				26.9	-0.02	0.12	-0.3	0.56	0	5.256	-0.016
17	DPO_4in_Meg7_THRU.s4p	12	Disabled				17.6	0	0.06	-0.28	0.66	0	5.337	
18		32	Disabled				23.5	0	0.06	-0.28	0.66	0	5.503	
19		12	Enabled				17.6	0	0.06	-0.28	0.66	0	5.337	0.000
20		32	Enabled				23.5	0	0.06	-0.28	0.66	0	5.503	0.000
21	OAch4_t.s4p	12	Disabled				33.4	0	0.04	-0.28	0.68	0	3.622	
22		32	Disabled				40.5	0	0.02	-0.28	0.7	0	2.453	
23		12	Enabled				33.4	0	0.04	-0.28	0.68	0	3.622	0.000
24		32	Enabled				40.5	0	0.02	-0.28	0.7	0	2.453	0.000
25	Och4_t.s4p	12	Disabled				33.6	0	0.08	-0.34	0.58	0	2.686	
26		32	Disabled				40.9	0	0.08	-0.34	0.58	0	1.442	
27		12	Enabled				33.6	0	0.08	-0.34	0.58	0	2.686	0.000
28		32	Enabled				40.9	0	0.08	-0.34	0.58	0	1.442	0.000
29	CAch3_b2_t.s4p	12	Disabled				34.0	0	0.04	-0.28	0.68	0	5.272	
30		32	Disabled				40.4	0	0.02	-0.28	0.7	0	3.945	
31		12	Enabled				34.0	0	0.04	-0.28	0.68	0	5.272	0.000
32		32	Enabled				40.4	0	0.02	-0.28	0.7	0	3.945	0.000
33	Bch2_a7p5_7_t.s4p	12	Disabled				34.1	0	0.08	-0.34	0.58	0	3.286	
34		32	Disabled				40.8	0	0.08	-0.34	0.58	0	2.639	
35		12	Enabled				34.1	-0.02	0.1	-0.34	0.54	0	3.299	0.013
36		32	Enabled				40.8	0	0.08	-0.34	0.58	0	2.639	0.000
Average impact on COM due to c(-3) (dB)													0.003	

Additional c(-3) tap in Tx FIR can also hurt COM

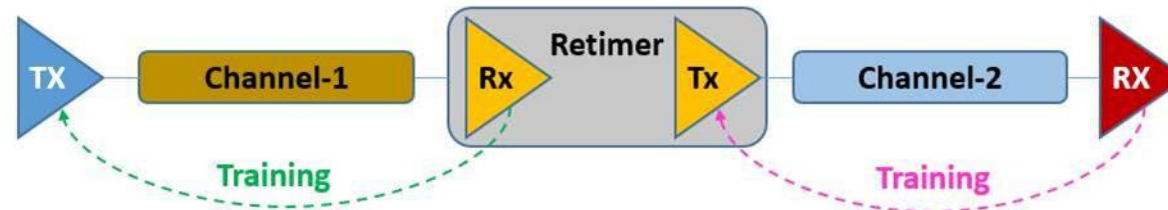
ave. impact on COM due to c(-3)

COM Analysis Results

- COM improvement with DFE-only reference receiver is 0.518dB
 - $c(-3)$ adapted to 0 in 1 out of 18 cases and to -0.02, in 17 out of 18 cases
- Due to overlapped taps of FFE receivers [1], COM improvement due to Tx FIR $c(-3)$ is very small
 - Average COM improvement for FFE(3 pre + 12 post) + 1-tap DFE is 0.005dB
 - $c(-3)$ adapted to 0 in 17 out of 18 cases and to -0.02 in 1 out of 18 cases
 - Average COM improvement for FFE (3 pre + 24 post) + 1-tap DFE is 0.003dB. In one case, COM degraded due to Tx FIR $c(-3)$
 - $c(-3)$ adapted to 0 in 15 out of 18 cases and to -0.02 in 3 out of 18 cases
- Conclusion
 - If the reference receiver includes a 3rd pre-cursor tap, it is not needed in the Tx
 - Tuning $c(-3)$ causes adjustment in other taps, $c(-2:1)$, and this can hurt COM
- Please note: $c(-3)$ can converge to different values depending on $c(-3)$ step size and number of DFE/FFE taps [6]

Concerns about Requiring c(-3) at Tx

- If c(-3) is required at Tx, it would be tuned by Rx during link training
 - In order for Rx to have enough information to train the Tx c(-3) tap, the Rx would need to know the pulse response at these locations, so the power is already spent on the Rx side
 - For a DAC-base implementation, cost of adding c(-3) at Tx is smaller. However, for an analog-based implementation, adding one tap degrades termination and return loss performance
 - Current link_inhibit timer for 56G PAM4 CR/KR is 3.2s max [5]. This timer will likely need to increase with the addition of c(-3), and this time would be spent every time a cable is plugged into a port. What is the max time acceptable by system vendors?
 - Many 112G CR/KR applications may need one (or even two) retimers. Trainings have to happen at the same time, and the longer it takes, the higher the risk of not reaching a global optimal



Concerns about Requiring $c(-3)$ at Tx

- Continuous adaptation of $c(-3)$ at Rx provides better coverage for voltage and temperature changes
 - [4] reported $\sim 0.3\text{dB/m}$ IL difference in copper cable due to 20degC change (25C to 45C). Assuming 2m cable and 60C change from startup to steady state operation, IL difference $\sim 1.8\text{dB}$
 - Tx cursor outputs also varies over voltage and temperature

Benefit of Requiring c(-3) at Tx

- May allow for lower cost Receiver implementations in the future

Summary

- A 3rd pre-cursor tap is needed at 112G
 - If DFE-only reference receiver is used, COM shows ~0.52dB improvement with the addition of c(-3) at Tx
 - If the reference receiver includes a 3rd pre-cursor tap, c(-3) is not needed in the Tx. In some cases, c(-3) can degrade COM performance
- Requiring c(-3) at Tx increases link training time and may not be sufficient given variation in channel insertion loss due to voltage and temperature changes
- Requiring c(-3) at Tx may allow for lower cost Rx implementation in the future

Proposal

- Tx c(-3) should be used in COM since it is a DFE-only approach
- Baseline should not mandate real implementation to use Tx c(-3), including link training

References

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(http://www.ieee802.org/3/ck/public/19_01/sun_3ck_03a_0119.pdf)
2. Baseline Proposal for 100, 200 and 400 Gb/s Backplane (Update), Howard Heck
(http://www.ieee802.org/3/ck/public/19_03/heck_3ck_03b_0319.pdf)
3. Summary of System Discussion of Backplane Channels, Beth Kochuparambil
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4. QSFP-DD 2m Cable Channels, Tom Palkert
(http://www.ieee802.org/3/ck/public/19_03/palkert_3ck_01a_0319.pdf)
5. IEEE 802.3cd-2018, section 73.10.2
6. KR/CR Simulation Results with COM Tool 2.57, Phil Sun
(http://www.ieee802.org/3/ck/public/19_01/sun_3ck_02a_0119.zip)

Additional slides

COM Parameter Example: 24-tap DFE with c(-3)

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	[1.1e-4 1.1e-4]	nF	[TX RX]
z_p select	[12]		[test cases to run]
z_p (TX)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 32; 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	0.413	V	vp/vf=.694
A_fe	0.413	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	24	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	
ffe_pre_tap_len	0	UI	
ffe_post_tap_len	0	UI	
ffe_tap_step_size	0		
ffe_main_cursor_min	0.7		
ffe_pre_tap1_max	0.3		
ffe_post_tap1_max	0.3		
ffe_tapn_max	0.125		
ffe_backoff	0		

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	CR_eval	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10.5	dB
DER_0	1.00E-04	
T_r	6.16E-03	ns
FORCE_TR	1	logical
Include PCB	0	logical
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	1.70E+09	
rho_x	0.25	
fixture delay time	0	enter sec
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	8.20E-09	V^2/GHz
SNR_TX	33	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
Table 92-12 parameters		
Parameter	Setting	Units
board_tl_gamma0_a1_a2	[0 3.8206e-04 9.5909e-05]	
board_tl_tau	5.790E-03	ns/mm
board_Z_c	90	Ohm
z_bp (TX)	119	mm
z_bp (NEXT)	119	mm
z_bp (FEXT)	119	mm
z_bp (RX)	119	mm

Parameters modified for FFE + 1-tap DFE simulations

COM Parameter Example: 24-tap DFE w/o c(-3)

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	[1.1e-4 1.1e-4]	nF	[TX RX]
z_p select	[12]		[test cases to run]
z_p (TX)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[12 32; 1.8 1.8]	mm	[test cases]
z_p (RX)	[12 32; 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	0.413	V	vp/vf=.694
A_fe	0.413	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]		[min:step:max]
c(1)	[-0.2:0.05:0]		[min:step:max]
N_b	24	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	
ffe_pre_tap_len	0	UI	
ffe_post_tap_len	0	UI	
ffe_tap_step_size	0		
ffe_main_cursor_min	0.7		
ffe_pre_tap1_max	0.3		
ffe_post_tap1_max	0.3		
ffe_tapn_max	0.125		
ffe_backoff	0		

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	CR_eval	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10.5	dB
DER_0	1.00E-04	
T_r	6.16E-03	ns
FORCE_TR	1	logical
Include PCB	0	logical
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	1.70E+09	
rho_x	0.25	
fixture delay time	0	enter sec
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	8.20E-09	V^2/GHz
SNR_TX	33	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
Table 92-12 parameters		
Parameter	Setting	Units
board_tl_gamma0_a1_a2	[0 3.8206e-04 9.5909e-05]	
board_tl_tau	5.790E-03	ns/mm
board_Z_c	90	Ohm
z_bp (TX)	119	mm
z_bp (NEXT)	119	mm
z_bp (FEXT)	119	mm
z_bp (RX)	119	mm

Parameters modified for FFE + 1-tap DFE simulations

Thank you!