Equalizer range and resolution

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Assertions

- The 3rd pre-cursor tap $c(-3)$ is not needed for chip-to-chip interfaces
- It has no impact on channel compliance for the specified package test cases
- It can improve performance for other combinations of package lengths but an additional post-cursor tap is more direct and effective
- Equalizer coefficient and gain ranges are over-provisioned for chip-to-chip interfaces
- This results in wasted search time and the possibility that unexpected channels will meet the COM requirements
- Step sizes for most transmitter equalizer coefficients are smaller than necessary
- This presentation includes data to justify these assertions

Analysis (see results in appendices)

- Begin with the parameters proposed in sun_3ck_adhoc_01_030420
  - Including $f_{LF} = f_b / 40$
- Look at channel L4 and R4 sensitivity to package length without $c(-3)$
- Compare performance of $c(-3)$ to one additional post-cursor tap
- Look at performance sensitivity to $c(-3)$ value
- Look at sensitivity to transmitter equalizer coefficient step size similar to ran_3ck_adhoc_01_030420
- Constrain transmitter and receiver equalizer ranges to be only slightly larger that what is needed
- Compute COM for the available chip-to-chip channels

Proposed changes to Table 120F–5

Parameter	Symbol	Value	Units
Transmitter equalizer, minimum cursor coefficient	$c(0)$	0.6 ~~0.54~~	—
Transmitter equalizer, 1st pre-cursor coefficient Minimum value Maximum value Step size	$c(-1)$	 −0.25 ~~−0.34~~ 0 0.025	—
Transmitter equalizer, 2nd pre-cursor coefficient Minimum value Maximum value Step size	$c(-2)$	 0 0.1 ~~0.12~~ 0.025	—
~~Transmitter equalizer, 3rd pre-cursor coefficient~~ ~~Minimum value~~ ~~Maximum value~~ ~~Step size~~	~~$c(-3)$~~	 ~~−0.06~~ ~~0~~ ~~0.02~~	~~—~~
Transmitter equalizer, post-cursor coefficient Minimum value Maximum value Step size	$c(1)$	 −0.25 ~~−0.1~~ 0 0.025	—

Proposed changes to Table 120F–5, continued

Parameter	Symbol	Value	Units
Continuous time filter, DC gain Minimum value Maximum value Step size	g_{DC}	 <u>−15</u> ~~−20~~ 0 1	dB
Continuous time filter, DC gain 2 Minimum value Maximum value Step size	g_{DC2}	 <u>−5</u> ~~−6~~ 0 1	dB
Continuous time filter, zero frequency for $g_{DC} = 0$	f_z	f_b / 2.5	GHz
Continuous time filter, pole frequencies	f_{p1} f_{p2}	f_b / 2.5 f_b	GHz GHz
Continuous time filter, low-frequency pole/zero	f_{LF}	<u>f_b / 40</u> ~~f_b / 80~~	GHz
Decision feedback equalizer (DFE) length	N_b	<u>6</u> ~~TBD~~	—
Normalized DFE coefficient magnitude limit n = 1 ~~to N_b~~ <u>n = 2 to N_b</u>	$b_{max}(n)$	 <u>0.85</u> ~~TBD~~ <u>0.2</u>	—

Proposed changes to Table 120F–1

Parameter	Reference	Value	Units
Output waveform			
abs. step size for all taps (min.)	136.9.3.1.4	0.005	—
abs. step size for all taps (max.)~~*c*(–1), *c*(–2), and *c*(–3) (max.)~~	136.9.3.1.4	0.025	—
~~abs. step size for *c*(1) (max.)~~	~~136.9.3.1.4~~	~~0.05~~	~~—~~
~~value at min. state for *c*(–3) (max.)~~	~~136.9.3.1.4~~	~~−0.06~~	~~—~~
value at max. state for *c*(–2) (min.)	136.9.3.1.4	−0.1 ~~−0.12~~	—
value at min. state for *c*(–1) (max.)	136.9.3.1.4	−0.25 ~~−0.34~~	—
value at min. state for *c*(1) (max.)	136.9.3.1.4	−0.25 ~~−0.1~~	—

Summary and conclusions

- For chip-to-chip interfaces, an additional post-cursor tap would be more valuable than an additional pre-cursor tap
- Channels meet the requirements with significant margin without either
- However, package test cases seem to be relatively benign
- Worst-case length combination is channel-dependent which frustrates attempts to find good test cases
- Presentation proposes updates to the draft based on these observations
- It is likely that further refinements will be necessary

Appendix A

Channel information and COM parameter values

Channel information (sorted by insertion loss)

Label	IL, dB at 26.6 GHz	Reference
R1	10.2	Impaired_C2C_10dB_P1_to_P2 from rabinovich_3ck_informal_08162019.zip, 4x FEXT and 0x NEXT
G6	11.5	C2C_CA_CONN_SYSVIA_12dB from gore_3ck_02_0519_Cabled.zip
G1	12.2	C2C_PCB_SYSVIA_12dB from gore_3ck_02_0519_PCB.zip
G7	13.8	C2C_CA_CONN_SYSVIA_14dB from gore_3ck_02_0519_Cabled.zip
G2	14.1	C2C_PCB_SYSVIA_14dB from gore_3ck_02_0519_PCB.zip
R2	15.8	Impaired_C2C_16dB_P1_to_P2 from rabinovich_3ck_informal_08162019.zip, 4x FEXT and 0x NEXT
G8	15.9	C2C_CA_CONN_SYSVIA_16dB from gore_3ck_02_0519_Cabled.zip
G3	16	C2C_PCB_SYSVIA_16dB from gore_3ck_02_0519_PCB.zip
L1	16.6	Channel1 from lim_3ck_05_0719_c2c.zip
L2	16.9	Channel2 from lim_3ck_05_0719_c2c.zip
L3	17.4	Channel3 from lim_3ck_05_0719_c2c.zip
L4	17.8	Channel4 from lim_3ck_05_0719_c2c.zip
G4	17.9	C2C_PCB_SYSVIA_18dB from gore_3ck_02_0519_PCB.zip
G9	18	C2C_CA_CONN_SYSVIA_18dB from gore_3ck_02_0519_Cabled.zip
R3	18.2	Impaired_C2C_18dB_P1_to_P2 from rabinovich_3ck_informal_08162019.zip, 4x FEXT and 0x NEXT
R4	19.5	Impaired_C2C_20dB_P1_to_P2 from rabinovich_3ck_informal_08162019.zip, 4x FEXT and 0x NEXT
G10	19.9	C2C_CA_CONN_SYSVIA_20dB from gore_3ck_02_0519_Cabled.zip
G5	20.1	C2C_PCB_SYSVIA_20dB from gore_3ck_02_0519_PCB.zip

Baseline parameter values (COM r276)

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)	[13 31; 1.8 1.8]	mm	[test cases]
z_p (NEXT)	[11 11; 1.8 1.8]	mm	[test cases]
z_p (FEXT)	[13 31; 1.8 1.8]	mm	[test cases]
z_p (RX)	[11 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	0.413	V	
A_fe	0.413	V	
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	5	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	1.328125	GHz	

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
CSV_REPORT	1	logical
RESULT_DIR		
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	KR_eval_	
COM_CONTRIBUTION	0	logical
Operational		
COM Pass threshold	3	dB
ERL Pass threshold	10.5	dB
DER_0	1.00E-05	
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	0.19	
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	8.2E-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
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]	
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	**0**	**logical**
Floating Tap Control		
N_bg	0	0 1 2 or 3 groups
N_bf	0	taps per group
N_f	5	UI span for floating taps
bmaxg	0.2	max DFE value for floating taps
B_float_RSS_MAX	**0.03**	rss tail tap limit
N_tail_start	**25**	(UI) start of tail taps limit
ICN parameters		
f_v	0.723	*Fb
f_f	0.723	*Fb
f_n	0.723	*Fb
f_2	39.844	GHz
A_ft	0.600	V
A_nt	**0.600**	V
heck_3ck_03b_0319	**Adopted Mar 2019**	**kasapi_3ck_02_1119**
walker_3ck_01d_0719	**Adopted July 2019**	**Adopted Nov 2019**
result of R_d=50		under consideration
benartsi_3ck_01a_0719	**no used for KR**	
mellitz_3ck_03_0919		

Appendix B

L4 sensitivity to package trace length

COM < 3 dB
3 ≤ COM < 3.2 dB
COM > 4 dB

L4, no $c(-3)$, 5 post-cursor taps

COM, dB		z_p (TX)																						
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
z_p (RX)	8	1.637	2.918	4.272	3.002	2.993	2.533	3.024	3.094	2.505	3.559	3.371	2.532	3.006	2.982	2.812	3.411	2.955	2.899	3.204	2.787	3.007	3.236	2.861	3.084
	9	2.954	3.056	2.730	4.347	4.719	2.970	3.569	3.741	3.081	4.678	4.393	2.993	3.789	3.909	3.374	4.081	3.760	3.571	3.931	3.488	3.745	4.027	3.528	3.917
	10	4.622	3.284	2.323	3.608	4.603	3.874	3.104	3.314	2.891	3.769	4.221	3.078	3.193	3.516	3.212	3.706	3.668	3.205	3.626	3.446	3.330	3.770	3.387	3.378
	11	3.001	4.457	3.786	2.343	3.265	4.751	3.684	3.093	2.761	3.993	3.900	2.940	3.550	3.431	3.106	3.737	3.437	3.333	3.640	3.143	3.470	3.708	3.153	3.508
	12	3.062	4.683	4.567	3.407	3.558	3.414	4.864	4.888	3.083	4.547	4.701	3.439	4.375	4.329	3.771	4.473	4.147	3.938	4.481	4.023	4.082	4.437	4.021	4.293
	13	2.687	3.189	3.648	4.965	3.930	2.336	3.715	4.477	3.377	3.722	3.963	2.923	3.403	3.921	3.389	3.731	3.708	3.330	3.712	3.543	3.479	3.889	3.427	3.531
	14	3.046	3.737	2.772	3.533	4.639	3.941	2.687	3.017	4.341	4.410	3.733	2.908	3.635	3.661	3.525	4.127	3.542	3.443	3.876	3.413	3.585	3.876	3.492	3.715
	15	3.119	3.944	3.114	3.030	4.438	4.452	3.296	3.033	3.173	4.891	4.877	2.880	3.554	3.661	3.492	4.293	3.888	3.527	3.836	3.493	3.728	4.041	3.466	3.742
	16	2.649	3.305	3.167	2.891	3.195	3.298	4.660	3.556	1.725	3.895	4.853	2.777	3.003	3.198	2.871	3.553	3.620	3.121	3.365	3.016	3.160	3.531	3.173	3.324
	17	3.417	4.626	3.732	4.029	4.598	3.474	4.436	5.019	4.061	3.660	3.866	4.803	4.792	3.786	3.947	4.852	4.308	4.320	4.717	4.082	4.293	4.657	4.180	4.510
	18	3.331	4.366	3.909	4.033	4.857	3.811	3.837	4.790	4.838	4.215	3.871	3.766	4.990	4.959	3.814	4.568	4.321	4.194	4.807	4.265	4.237	4.554	4.152	4.495
	19	2.597	3.115	2.903	2.960	3.520	3.045	3.086	2.989	2.607	4.937	4.057	1.616	3.216	4.152	2.781	3.292	3.185	2.938	3.324	3.148	3.223	3.363	2.938	3.210
	20	2.983	3.961	2.972	3.355	4.106	3.285	3.668	3.601	2.772	4.599	4.913	3.314	3.111	3.117	4.495	4.539	3.427	3.427	3.890	3.518	3.890	4.096	3.492	3.742
	21	3.006	4.199	3.516	3.375	4.220	3.678	3.866	3.992	3.049	3.860	4.760	4.365	3.544	3.227	3.904	4.867	4.568	3.544	3.986	3.636	3.876	4.365	3.890	3.931
	22	2.872	3.460	3.248	3.196	3.760	3.198	3.637	3.643	2.930	4.121	3.774	2.796	4.672	4.180	2.292	3.809	4.898	3.453	3.622	3.286	3.570	3.958	3.544	3.742
	23	3.355	4.168	3.368	3.751	4.470	3.542	4.043	4.152	3.494	4.867	4.568	3.203	4.466	4.837	3.849	3.782	3.596	4.928	5.005	3.636	4.041	4.495	3.972	4.452
	24	3.064	4.073	3.569	3.495	4.267	3.754	3.639	3.956	3.426	4.510	4.618	3.148	3.596	4.466	5.052	3.986	3.248	4.027	4.687	4.194	3.742	4.069	3.822	4.027
	25	2.859	3.740	3.171	3.279	3.862	3.269	3.609	3.591	2.858	4.302	4.223	2.930	3.596	3.466	3.401	4.990	4.194	2.686	3.636	4.627	3.728	3.755	3.440	3.742
	26	3.175	4.041	3.416	3.561	4.365	3.487	3.986	3.972	3.113	4.554	4.554	3.310	3.999	3.890	3.466	4.837	4.657	3.715	3.622	3.427	4.627	4.867	3.622	3.931
	27	2.896	3.685	3.370	3.259	4.117	3.464	3.498	3.723	3.036	4.110	4.208	3.086	3.702	3.849	3.286	3.728	4.055	4.807	3.742	2.793	3.945	4.613	3.917	3.649
	28	2.961	3.906	3.201	3.435	4.027	3.442	3.651	3.769	3.036	4.365	4.194	3.036	3.890	3.876	3.531	4.166	3.570	3.675	4.702	4.069	2.963	3.649	4.731	4.096
	29	3.236	4.194	3.554	3.688	4.379	3.688	3.999	4.110	3.324	4.717	4.627	3.236	4.055	4.194	3.945	4.657	3.999	3.769	4.792	4.642	3.795	3.769	3.795	4.777
	30	2.956	3.750	3.387	3.258	4.106	3.388	3.662	3.662	3.073	4.237	4.336	3.036	3.583	3.809	3.531	4.138	3.958	3.518	3.715	3.849	4.898	4.082	2.817	3.958
	31	3.089	4.013	3.266	3.469	4.194	3.414	3.742	3.769	3.160	4.466	4.394	3.198	3.876	3.809	3.557	4.351	3.999	3.742	4.041	3.492	4.041	4.837	4.041	3.337

Horizontal slice for L4 with z_p (RX) = 8 mm

Suggest ignoring zp (TX) = zp (RX)

- Unlikely to have mathematically identical transmitter and receiver

***c*(−3) improves COM for many of the cases**

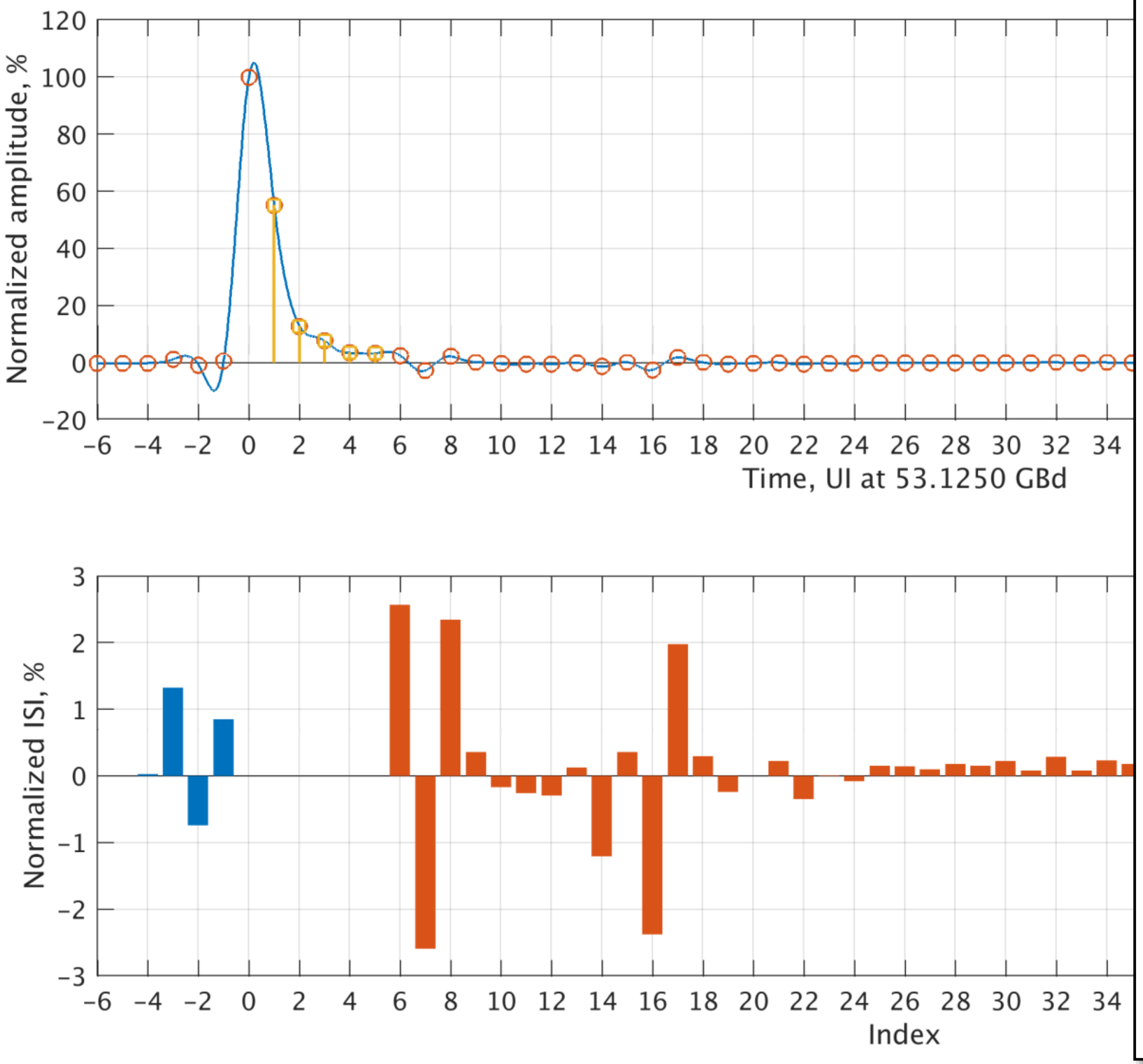
- Some cases that fail without *c*(−3) pass with *c*(−3) = −2%
- A couple of those cases only pass marginally
- High sensitivity to *c*(−3) value
- Many cases still fail – Have we really fixed the problem?

All interesting cases pass with an additional post-cursor tap

	z_p (RX)	8					
	N_b	5					
	$c(-3)$	0	−1%	−2%	−3%	−4%	−5%
z_p (TX)	21	2.982	3.217	3.238	3.040	2.545	2.075
	22	2.812	3.097	3.256	3.176	2.722	2.236
	24	2.955	3.149	3.157	2.977	2.499	1.993
	25	2.899	3.214	3.389	3.324	2.926	2.384
	27	2.787	2.995	3.016	2.888	2.407	1.906
	30	2.861	3.066	3.135	2.976	2.545	2.048

	z_p (RX)	8		
	$c(-3)$	0	−2%	0
	N_b	5	5	6
z_p (TX)	8	1.637	2.106	2.297
	9	2.918	2.781	3.808
	10	4.272	4.339	4.751
	11	3.002	3.552	3.388
	12	2.993	2.912	3.629
	13	2.533	2.802	3.164
	14	3.024	3.692	3.649
	15	3.094	3.107	3.761
	16	2.505	2.833	3.129
	17	3.559	3.989	4.283
	18	3.371	3.517	4.152
	19	2.532	2.880	3.197
	20	3.006	3.321	3.580
	21	2.982	3.238	3.745
	22	2.812	3.256	3.475
	23	3.411	3.577	4.117
	24	2.955	3.157	3.609
	25	2.899	3.389	3.598
	26	3.204	3.377	3.960
	27	2.787	3.016	3.519
	28	3.007	3.479	3.753
	29	3.236	3.389	4.058
	30	2.861	3.135	3.638
	31	3.084	3.544	3.737

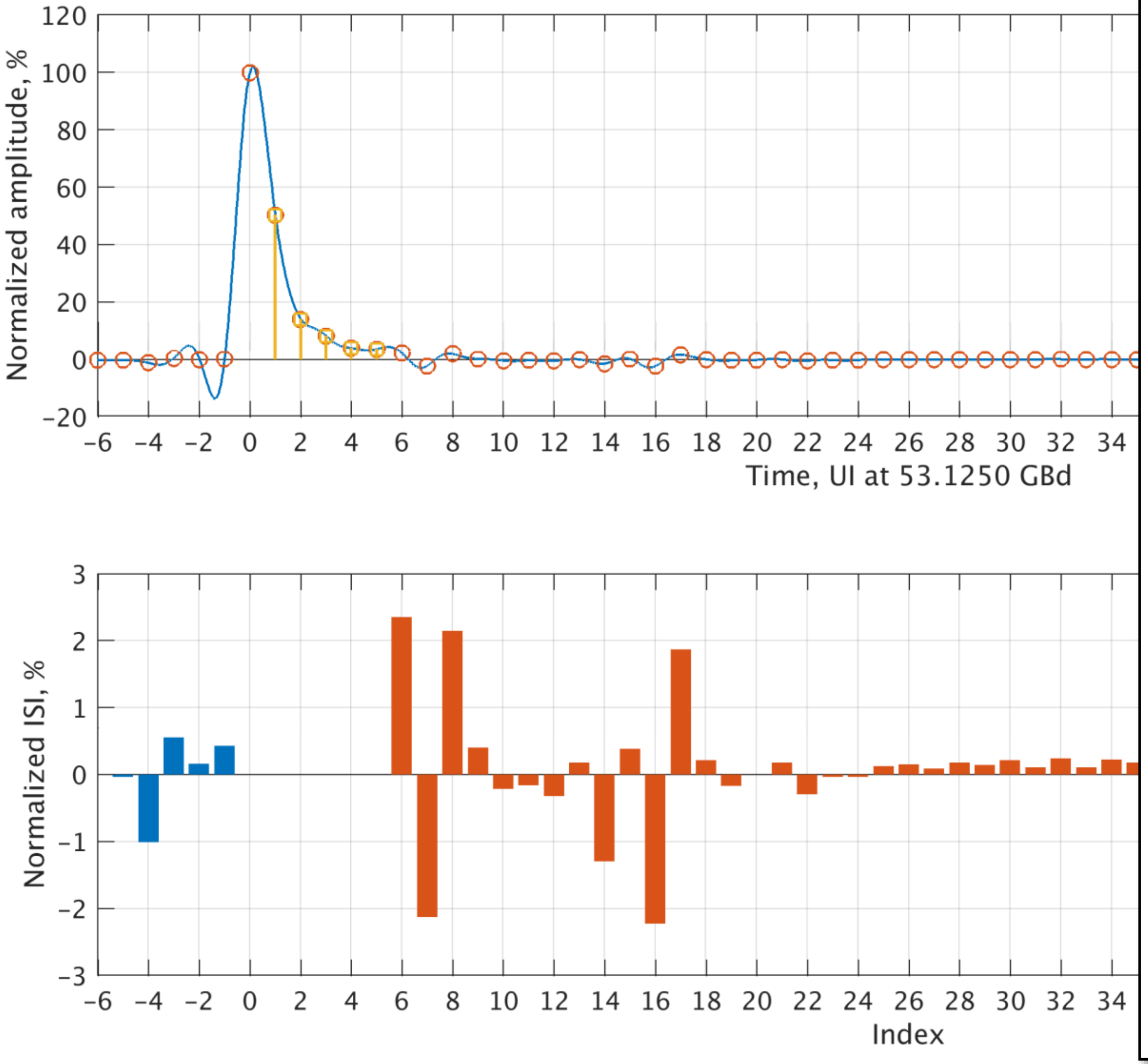
A closer look at z_p (TX, RX) = (22, 8), no $c(-3)$



Residual pre-cursor inter-symbol interference (ISI) is not the problem

COM is dominated by a number of larger post-cursor ISI terms

Impact of *c*(−3) is to shift the sampling time bit



Addition of *c*(−3) changes the residual pre-cursor ISI to a small degree

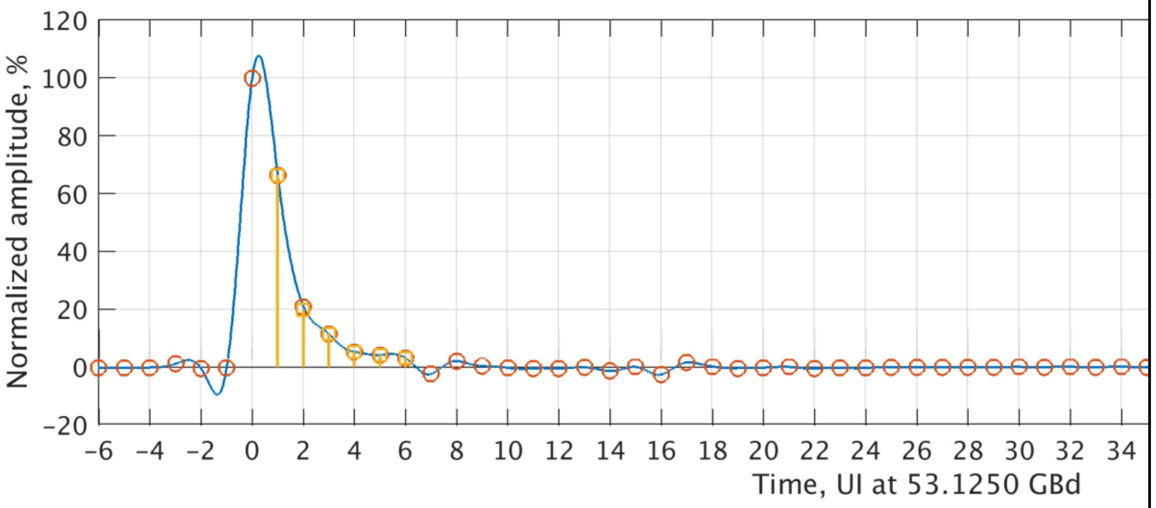
It also shifts the sample time which changes how the post-cursor reflections are sampled

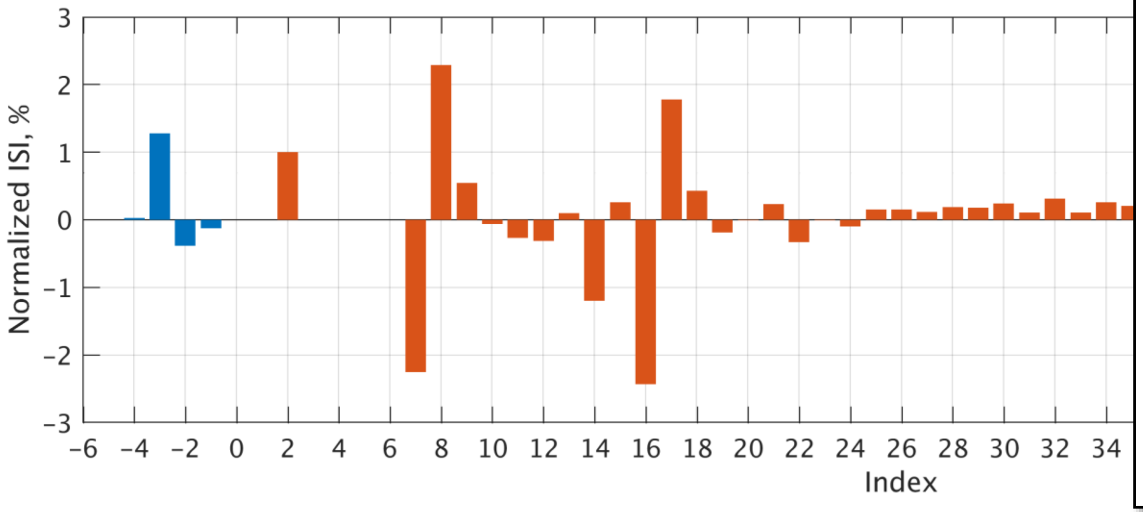
In general, sample time shifts are expected to present trade-offs (some reflections could appear to be larger while others are reduced)

It is unclear how easy it is to optimize such trade-offs

It is unclear how the solution holds up over time (e.g., changes to temperature)

Another post-cursor tap is more effective





An additional post-cursor tap directly addresses the most glaring problem

Availability of extra tap may also tweak the "optimal" solution

Clearly, 6 post-cursor taps is inadequate to address all of the post-cursor ISI

Despite this, it is more effective than *c*(−3)

L4, no $c(-3)$, 6 post-cursor taps

	COM, dB	z_p (TX)																							
		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
z_p (RX)	8	2.297	3.808	4.751	3.388	3.629	3.164	3.649	3.761	3.129	4.283	4.152	3.197	3.580	3.745	3.475	4.117	3.609	3.598	3.960	3.519	3.753	4.058	3.638	3.737
	9	3.857	3.856	3.012	4.785	5.220	3.445	4.040	4.215	3.619	5.207	4.934	3.459	4.281	4.444	3.887	4.541	4.313	4.150	4.475	4.022	4.292	4.540	4.030	4.428
	10	5.102	3.621	2.412	3.627	4.656	3.974	3.210	3.520	3.115	3.988	4.401	3.282	3.342	3.676	3.400	3.861	3.816	3.324	3.750	3.550	3.478	3.859	3.521	3.547
	11	3.396	4.975	3.846	2.448	3.470	4.926	3.797	3.366	2.972	4.106	4.160	3.174	3.730	3.580	3.379	3.974	3.650	3.468	3.854	3.386	3.575	3.917	3.462	3.687
	12	3.695	5.209	4.686	3.666	3.800	3.723	5.026	4.995	3.364	4.738	4.840	3.748	4.585	4.545	4.086	4.730	4.398	4.244	4.709	4.273	4.294	4.651	4.287	4.493
	13	3.321	3.721	3.771	5.144	4.112	2.619	3.940	4.670	3.544	4.021	4.196	3.232	3.683	4.155	3.699	4.024	3.933	3.616	3.885	3.769	3.788	4.085	3.723	3.781
	14	3.628	4.269	2.906	3.652	4.870	4.099	2.927	3.350	4.501	4.580	3.920	3.206	3.885	3.893	3.788	4.375	3.806	3.642	4.057	3.716	3.788	4.068	3.721	3.910
	15	3.759	4.450	3.314	3.293	4.669	4.646	3.549	3.224	3.371	5.051	4.964	3.184	3.776	3.874	3.798	4.526	4.059	3.791	4.034	3.760	3.949	4.173	3.756	3.944
	16	3.266	3.916	3.361	3.107	3.536	3.452	4.816	3.788	1.962	4.084	4.942	2.975	3.227	3.490	3.171	3.840	3.894	3.417	3.615	3.352	3.445	3.782	3.431	3.521
	17	4.113	5.207	3.910	4.169	4.793	3.743	4.614	5.187	4.267	3.847	4.107	4.947	4.863	4.047	4.120	4.956	4.545	4.566	4.913	4.251	4.441	4.792	4.336	4.594
	18	4.060	4.912	4.094	4.244	5.021	4.091	4.033	4.952	5.003	4.425	4.012	3.938	5.031	5.122	4.033	4.718	4.532	4.395	4.944	4.451	4.471	4.702	4.306	4.627
	19	3.263	3.642	3.120	3.193	3.795	3.385	3.389	3.257	2.800	5.031	4.209	1.964	3.427	4.270	3.073	3.591	3.437	3.245	3.657	3.377	3.460	3.630	3.223	3.414
	20	3.579	4.496	3.136	3.490	4.333	3.621	3.909	3.834	3.101	4.715	4.990	3.448	3.239	3.411	4.619	4.672	3.648	3.644	4.101	3.706	4.042	4.251	3.662	3.839
	21	3.756	4.722	3.644	3.513	4.418	3.904	4.095	4.165	3.381	4.148	4.968	4.453	3.714	3.429	4.041	4.974	4.657	3.783	4.152	3.826	4.110	4.495	4.011	4.069
	22	3.514	4.018	3.469	3.483	4.120	3.537	3.899	3.943	3.268	4.278	4.010	3.084	4.805	4.336	2.620	4.035	5.005	3.695	3.858	3.513	3.755	4.063	3.769	3.986
	23	4.028	4.691	3.611	3.977	4.717	3.831	4.257	4.392	3.768	5.002	4.718	3.479	4.613	4.959	4.090	3.998	3.736	4.990	5.036	3.836	4.103	4.583	4.194	4.583
	24	3.689	4.616	3.706	3.673	4.483	3.953	3.881	4.133	3.696	4.718	4.826	3.388	3.820	4.562	5.161	4.075	3.401	4.166	4.867	4.394	3.931	4.208	3.972	4.138
	25	3.592	4.338	3.354	3.506	4.163	3.586	3.770	3.848	3.163	4.535	4.451	3.295	3.806	3.725	3.644	5.083	4.308	2.777	3.710	4.687	3.931	3.904	3.596	3.931
	26	3.907	4.602	3.589	3.775	4.578	3.696	4.139	4.133	3.413	4.717	4.717	3.669	4.205	4.069	3.743	4.913	4.852	3.813	3.742	3.622	4.777	4.928	3.795	4.096
	27	3.571	4.240	3.490	3.461	4.323	3.719	3.813	3.915	3.328	4.277	4.380	3.312	3.844	4.023	3.570	3.931	4.293	4.867	3.945	3.012	4.013	4.657	4.027	3.795
	28	3.721	4.458	3.366	3.552	4.234	3.706	3.866	3.975	3.349	4.498	4.441	3.299	4.026	4.082	3.728	4.293	3.782	3.863	4.837	4.152	3.210	3.795	4.807	4.152
	29	4.047	4.709	3.689	3.871	4.558	3.906	4.152	4.212	3.607	4.852	4.746	3.518	4.237	4.308	4.076	4.717	4.180	3.890	4.852	4.717	3.972	3.904	3.836	4.792
	30	3.710	4.323	3.535	3.527	4.327	3.696	3.875	3.906	3.306	4.394	4.477	3.277	3.755	3.933	3.742	4.351	4.096	3.688	3.917	3.986	4.990	4.082	2.950	4.069
	31	3.747	4.564	3.448	3.636	4.422	3.671	3.923	4.015	3.400	4.565	4.539	3.375	3.946	3.972	3.782	4.481	4.096	3.945	4.194	3.609	4.124	4.852	4.152	3.312

Appendix C

R4 sensitivity to package trace length

R4, no $c(-3)$, 5 post-cursor taps

COM < 3 dB
3 ≤ COM < 3.2 dB
COM > 4 dB

COM, dB	z_p (TX) 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
z_p (RX) 8	1.024	3.230	4.568	2.425	2.737	2.780	2.963	3.381	2.686	2.795	3.305	2.975	3.073	2.920	2.717	3.583	3.299	2.545	3.299	3.440	2.651	3.236	3.274	2.938
9	3.611	2.963	3.235	4.746	4.279	3.200	3.673	4.223	3.518	3.754	3.972	3.557	4.013	3.863	3.236	4.524	4.265	3.173	4.124	4.322	3.453	3.945	4.055	3.742
10	4.928	3.612	2.703	3.500	4.507	3.927	3.148	3.917	3.622	3.634	3.890	3.563	3.849	3.728	3.299	4.408	4.096	3.086	4.041	4.265	3.401	3.849	3.958	3.728
11	2.408	4.714	3.711	2.145	3.498	4.543	3.172	3.267	3.146	3.337	3.440	3.063	3.427	3.274	2.914	3.849	3.636	2.722	3.492	3.636	2.987	3.401	3.414	3.248
12	2.729	4.124	4.384	3.691	3.004	3.304	4.568	4.568	3.078	3.654	4.279	3.649	3.809	3.742	3.427	4.598	4.166	3.123	4.208	4.452	3.261	3.876	4.096	3.742
13	2.907	3.329	3.722	4.810	3.688	2.878	3.782	4.792	3.890	3.453	3.876	3.715	3.890	3.649	3.274	4.394	4.180	3.148	3.972	4.166	3.453	3.931	3.890	3.622
14	3.032	3.703	3.031	2.995	4.584	3.917	2.592	3.570	4.568	3.492	3.337	3.401	3.769	3.479	2.987	4.166	3.917	2.865	3.755	4.013	3.185	3.557	3.675	3.544
15	3.421	4.394	3.917	3.243	4.466	4.777	3.889	3.609	3.649	4.731	4.852	3.427	4.110	4.194	3.622	4.598	4.437	3.312	4.336	4.554	3.649	4.194	4.237	3.890
16	2.744	3.702	3.742	3.257	3.180	3.715	4.822	3.917	2.757	3.702	4.583	3.795	3.492	3.518	3.274	4.251	3.917	2.975	3.904	4.110	3.312	3.742	3.876	3.609
17	2.798	3.780	3.508	3.337	3.732	3.281	3.492	4.717	3.863	2.865	3.583	4.807	3.795	3.261	3.135	4.394	3.999	2.914	3.917	4.082	3.261	3.728	3.809	3.544
18	3.395	4.082	3.863	3.587	4.351	3.931	3.337	4.717	4.702	3.849	3.518	3.755	4.822	4.495	3.148	4.583	4.702	3.363	4.194	4.495	3.702	4.208	4.208	3.986
19	3.024	3.702	3.440	3.132	3.728	3.742	3.492	3.453	3.596	4.913	3.972	2.686	3.917	4.394	3.236	4.096	3.958	3.049	3.958	4.069	3.223	3.755	3.876	3.609
20	3.073	4.124	3.796	3.401	3.809	3.795	3.795	4.152	3.363	3.795	4.717	4.096	3.173	3.479	4.466	4.687	3.822	3.185	4.265	4.394	3.414	3.999	4.124	3.715
21	2.926	3.958	3.728	3.299	3.782	3.570	3.505	4.279	3.531	3.248	4.322	4.495	3.662	3.160	3.261	5.067	4.510	2.902	3.999	4.351	3.440	3.836	3.917	3.755
22	2.794	3.388	3.261	2.987	3.544	3.198	3.049	3.622	3.324	3.248	3.160	3.135	4.554	3.596	2.338	4.082	4.583	2.698	3.505	3.809	3.111	3.440	3.544	3.350
23	3.662	4.642	4.336	3.945	4.613	4.379	4.180	4.657	4.265	4.466	4.687	3.999	4.642	5.099	4.308	4.055	4.251	4.583	5.146	4.568	3.986	4.731	4.761	4.293
24	3.337	4.423	4.013	3.728	4.251	4.124	3.931	4.437	3.876	4.069	4.717	4.013	3.795	4.437	4.672	4.495	3.688	3.662	5.161	5.083	3.662	4.293	4.554	4.096
25	2.545	3.286	3.061	2.745	3.173	3.086	2.878	3.440	2.938	2.950	3.299	3.061	3.261	2.865	2.627	4.583	3.769	2.004	3.401	4.308	2.805	3.098	3.248	3.123
26	3.363	4.237	4.069	3.557	4.293	3.931	3.822	4.394	3.890	3.945	4.223	3.945	4.379	4.055	3.453	5.052	5.224	3.636	3.636	4.082	4.524	4.598	3.972	3.999
27	3.557	4.481	4.180	3.742	4.510	4.055	4.096	4.613	4.082	4.138	4.481	4.096	4.466	4.452	3.836	4.554	5.021	4.423	4.308	3.931	3.999	4.990	4.837	4.110
28	2.698	3.544	3.324	3.012	3.350	3.401	3.198	3.662	3.236	3.324	3.675	3.210	3.440	3.401	3.061	4.013	3.583	2.734	4.510	4.180	2.569	3.518	4.524	3.388
29	3.185	4.096	3.863	3.453	4.027	3.863	3.609	4.237	3.755	3.849	4.251	3.795	4.069	3.863	3.466	4.807	4.379	3.135	4.495	5.083	3.728	3.492	3.742	4.613
30	3.312	4.208	3.986	3.492	4.194	3.849	3.782	4.351	3.822	3.917	4.237	3.945	4.237	3.945	3.570	4.792	4.687	3.299	3.999	4.746	4.687	3.931	3.505	4.124
31	3.012	3.755	3.596	3.248	3.769	3.570	3.557	3.917	3.518	3.518	3.958	3.570	3.755	3.702	3.248	4.293	4.055	3.123	3.986	3.972	3.324	4.481	4.237	2.975

Vertical slice for R4 with z_p (TX) = 8 mm

Similar trends to those observed for L4

z_p (TX)		8				
N_b		5				
$c(-3)$	0	−1%	−2%	−3%	−4%	−5%
z_p (RX) 13	2.907	3.137	3.023	2.863	2.338	1.703
17	2.798	3.228	3.312	3.210	2.710	2.015
21	2.926	3.185	3.098	2.841	2.361	1.703
22	2.794	2.950	3.049	2.999	2.604	1.906
28	2.698	2.975	3.086	3.061	2.627	1.906

z_p (TX)	8		
$c(-3)$	0	-2%	0
N_b	5	5	6
z_p (RX) 8	1.024	1.587	2.022
9	3.611	3.554	4.645
10	4.928	5.193	5.489
11	2.408	2.796	2.917
12	2.729	2.885	3.432
13	2.907	3.023	3.437
14	3.032	3.414	3.509
15	3.421	3.555	4.105
16	2.744	2.774	3.200
17	2.798	3.312	3.379
18	3.395	3.492	4.064
19	3.024	3.135	3.553
20	3.073	3.414	3.570
21	2.926	3.098	3.505
22	2.794	3.049	3.306
23	3.662	3.809	4.308
24	3.337	3.427	3.945
25	2.545	2.745	3.073
26	3.363	3.518	3.972
27	3.557	3.636	4.152
28	2.698	3.086	3.223
29	3.185	3.324	3.702
30	3.312	3.375	3.890
31	3.012	3.414	3.609

R4, no $c(-3)$, 6 post-cursor taps

COM, dB	z_p (TX)																							
z_p (RX)	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
8	2.022	4.416	5.301	3.062	3.534	3.345	3.447	4.138	3.192	3.367	4.005	3.558	3.622	3.579	3.195	4.265	3.958	3.123	3.931	4.082	3.299	3.836	3.904	3.544
9	4.645	4.041	3.333	4.961	4.606	3.413	4.054	4.365	3.727	4.059	4.159	3.775	4.308	4.067	3.544	4.657	4.481	3.544	4.308	4.495	3.945	4.124	4.237	4.265
10	5.489	3.726	2.703	3.511	4.510	3.927	3.148	3.917	3.622	3.659	3.903	3.601	3.889	3.769	3.312	4.379	4.124	3.098	4.041	4.308	3.440	3.836	3.972	3.782
11	2.917	4.900	3.723	2.204	3.546	4.581	3.244	3.327	3.207	3.401	3.479	3.149	3.505	3.312	3.012	3.917	3.715	2.829	3.583	3.728	3.061	3.427	3.531	3.299
12	3.432	4.427	4.422	3.741	3.117	3.435	4.669	4.613	3.163	3.758	4.388	3.742	3.876	3.876	3.505	4.627	4.208	3.223	4.293	4.495	3.414	3.999	4.166	3.809
13	3.437	3.556	3.722	4.825	3.763	2.902	3.846	4.807	3.945	3.569	3.972	3.742	4.027	3.728	3.350	4.423	4.293	3.261	4.027	4.237	3.583	3.999	3.999	3.795
14	3.509	4.015	3.042	3.053	4.683	4.013	2.578	3.584	4.720	3.596	3.375	3.531	3.917	3.531	3.185	4.279	4.027	2.963	3.849	4.110	3.312	3.609	3.836	3.675
15	4.105	4.583	3.917	3.304	4.506	4.792	3.995	3.678	3.636	4.761	4.898	3.505	4.138	4.208	3.715	4.657	4.495	3.414	4.423	4.598	3.688	4.322	4.336	3.931
16	3.200	3.900	3.742	3.319	3.267	3.782	4.944	4.013	2.769	3.836	4.672	3.795	3.570	3.609	3.375	4.379	3.986	3.086	4.013	4.208	3.479	3.863	3.904	3.715
17	3.379	4.032	3.533	3.388	3.836	3.382	3.596	4.731	3.999	2.975	3.662	4.807	3.958	3.363	3.299	4.466	4.096	3.024	3.958	4.251	3.414	3.795	3.904	3.675
18	4.064	4.282	3.863	3.664	4.456	4.013	3.414	4.822	4.746	3.931	3.531	3.782	4.883	4.510	3.248	4.672	4.702	3.414	4.293	4.583	3.742	4.237	4.336	4.041
19	3.553	3.864	3.453	3.218	3.809	3.769	3.622	3.518	3.596	4.913	4.082	2.734	3.958	4.408	3.248	4.180	4.013	3.210	4.055	4.138	3.414	3.863	3.972	3.675
20	3.570	4.449	3.836	3.479	3.876	3.945	3.931	4.180	3.427	3.958	4.792	4.124	3.350	3.609	4.466	4.731	3.986	3.248	4.308	4.394	3.531	4.055	4.166	3.809
21	3.505	4.174	3.769	3.375	3.931	3.649	3.596	4.293	3.622	3.350	4.394	4.495	3.809	3.236	3.388	5.067	4.642	2.950	4.027	4.452	3.492	3.876	3.945	3.836
22	3.306	3.649	3.274	3.098	3.609	3.286	3.236	3.728	3.375	3.363	3.223	3.148	4.598	3.609	2.476	4.166	4.598	2.878	3.622	3.876	3.148	3.492	3.649	3.401
23	4.308	4.807	4.379	3.999	4.642	4.437	4.293	4.717	4.351	4.554	4.746	4.110	4.672	5.099	4.394	4.069	4.308	4.642	5.177	4.598	3.986	4.822	4.807	4.308
24	3.945	4.613	4.041	3.769	4.279	4.237	3.986	4.466	3.931	4.180	4.731	4.055	3.972	4.510	4.687	4.510	3.782	3.636	5.177	5.099	3.742	4.336	4.583	4.194
25	3.073	3.570	3.086	2.865	3.261	3.185	3.024	3.557	3.061	3.061	3.337	3.210	3.350	2.950	2.805	4.627	3.769	2.114	3.440	4.379	2.890	3.160	3.427	3.210
26	3.972	4.423	4.069	3.636	4.379	3.999	3.917	4.481	4.013	3.986	4.293	4.055	4.423	4.055	3.570	5.067	5.240	3.636	3.702	4.138	4.554	4.627	4.041	4.027
27	4.152	4.627	4.223	3.822	4.568	4.166	4.194	4.627	4.208	4.265	4.554	4.166	4.466	4.510	3.904	4.568	5.021	4.495	4.351	3.972	4.124	5.021	4.883	4.069
28	3.223	3.917	3.363	3.098	3.453	3.531	3.324	3.715	3.401	3.440	3.728	3.248	3.557	3.466	3.123	4.013	3.675	2.853	4.524	4.223	2.651	3.557	4.524	3.570
29	3.702	4.279	3.863	3.479	4.138	3.958	3.702	4.351	3.849	3.890	4.265	3.904	4.124	3.904	3.518	4.883	4.394	3.173	4.568	5.099	3.742	3.505	3.863	4.627
30	3.890	4.379	4.027	3.609	4.293	3.958	3.958	4.452	3.945	4.013	4.351	4.041	4.265	3.972	3.688	4.822	4.702	3.479	4.055	4.777	4.687	4.055	3.596	4.124
31	3.609	4.194	3.662	3.324	3.822	3.742	3.688	3.958	3.636	3.688	4.027	3.636	3.822	3.782	3.312	4.308	4.166	3.236	4.013	3.958	3.505	4.524	4.237	3.160

Appendix D

COM results summary

COM results for various configurations

Channel	IL, dB	Incl. $c(-3)$, Δc = 2%, N_b = 5		No $c(-3)$, Δc = 2.5%, N_b = 5		No $c(-3)$, Δc = 2.5%, N_b = 6		No $c(-3)$, Δc = 3%, N_b = 5		No $c(-3)$, Δc = 3%, N_b = 6	
	z_p (TX)	13	31	13	31	13	31	13	31	13	31
	z_p (RX)	11	29	11	29	11	29	11	29	11	29
Channel	**IL, dB**	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
R1	10.20	5.048	5.041	4.690	4.778	4.695	4.881	4.761	4.886	4.766	4.979
G6	11.54	5.506	5.743	5.346	5.389	5.379	5.396	5.419	5.497	5.471	5.518
G1	12.17	5.969	6.019	5.734	5.718	5.713	5.752	5.832	5.823	5.832	5.889
G7	13.82	5.649	5.564	5.453	5.304	5.490	5.303	5.561	5.400	5.588	5.400
G2	14.09	5.742	6.037	5.555	5.743	5.523	5.770	5.636	5.894	5.655	5.894
R2	15.80	5.107	4.944	4.615	4.657	4.771	4.731	4.558	4.702	4.700	4.717
G8	15.93	5.388	5.288	5.213	5.036	5.262	5.036	5.331	5.083	5.364	5.114
G3	16.03	5.820	5.832	5.501	5.663	5.543	5.663	5.639	5.697	5.639	5.730
L1	16.56	4.732	4.990	4.500	4.777	4.529	4.822	4.563	4.944	4.634	4.944
L2	16.88	5.154	5.320	4.860	5.177	4.970	5.224	4.994	5.288	5.105	5.384
L3	17.35	4.242	4.394	4.121	4.365	4.188	4.365	4.215	4.423	4.229	4.437
L4	17.77	4.751	4.777	4.692	4.731	4.821	4.792	4.763	4.761	4.902	4.837
G4	17.94	5.768	5.680	5.548	5.401	5.562	5.417	5.646	5.597	5.646	5.597
G9	17.98	5.269	5.083	5.223	5.036	5.253	5.036	5.342	5.099	5.342	5.114
R3	18.18	4.807	4.717	4.286	4.495	4.501	4.510	4.231	4.466	4.374	4.466
R4	19.52	4.867	4.657	4.431	4.423	4.524	4.437	4.389	4.466	4.423	4.510
G10	19.86	5.256	4.807	5.099	4.672	5.130	4.672	5.224	4.777	5.240	4.761
G5	20.08	5.613	5.177	5.368	5.161	5.368	5.161	5.466	5.224	5.466	5.288
		Min. COM = 4.242 dB		**Min. COM = 4.121 dB**		**Min. COM = 4.188 dB**		**Min. COM = 4.215 dB**		**Min. COM = 4.229 dB**	

Equalizer utilization over all channels

Transmitter equalizer	Min.					Max.				
	$c(-3)$	$c(-2)$	$c(-1)$	$c(0)$	$c(1)$	$c(-3)$	$c(-2)$	$c(-1)$	$c(0)$	$c(1)$
Incl. $c(-3)$, Δc = 2%, N_b = 5	−0.02	0.04	−0.24	0.66	−0.05	0	0.08	−0.2	0.76	0
No $c(-3)$, Δc = 2.5%, N_b = 5	0	0.025	−0.225	0.675	−0.15	0	0.05	−0.15	0.8	0
No $c(-3)$, Δc = 2.5%, N_b = 6	0	0.025	−0.225	0.675	−0.15	0	0.05	−0.15	0.8	0
No $c(-3)$, Δc = 3%, N_b = 5	0	0.03	−0.18	0.73	−0.06	0	0.03	−0.18	0.79	0
No $c(-3)$, Δc = 3%, N_b = 6	0	0.03	−0.18	0.73	−0.06	0	0.03	−0.18	0.79	0

Receiver CTLE	Min.		Max.	
	g_{DC}, dB	g_{DC2}, dB	g_{DC}, dB	g_{DC2}, dB
Incl. $c(-3)$, Δc = 2%, N_b = 5	−14	−4	0	−2
No $c(-3)$, Δc = 2.5%, N_b = 5	−14	−4	0	−2
No $c(-3)$, Δc = 2.5%, N_b = 6	−13	−4	0	−2
No $c(-3)$, Δc = 3%, N_b = 5	−14	−4	0	−2
No $c(-3)$, Δc = 3%, N_b = 6	−14	−4	0	−2