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	$c(1)$	 −0.2 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}	
		−15 ~~=20~~
		0
		1
			dB

Continuous time filter, DC gain 2 Minimum value Maximum value Step size	g_{DC2}	 −5 ~~=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}	$f_b / 40$ ~~$f_b / 80$~~	GHz
Decision feedback equalizer (DFE) length	N_b	6 ~~TBD~~	—

Normalized DFE coefficient magnitude limit
    n = 1 ~~to N_b~~
    n = 2 to N_b
	$b_{max}(n)$	
		0.85 ~~TBD~~
		0.2
			—

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	0.02~~5~~	—
~~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 ~~=0.2~~	—

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

Parameter	Setting	Units	Information
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]	dB	[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

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

Legend:
- COM < 3 dB
- $3 \leq$ 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
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

Row label: z_p (RX)

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	−0.01	−0.02	−0.03	−0.04	−0.05
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

(left column label: z_p (TX))

| z_p (RX)	8		
$c(-3)$	0	−2%	0
N_b	5	5	6
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

(left column label: z_p (TX))

A closer look at z_p (TX, RX) = (22, 8), no $c(-3)$
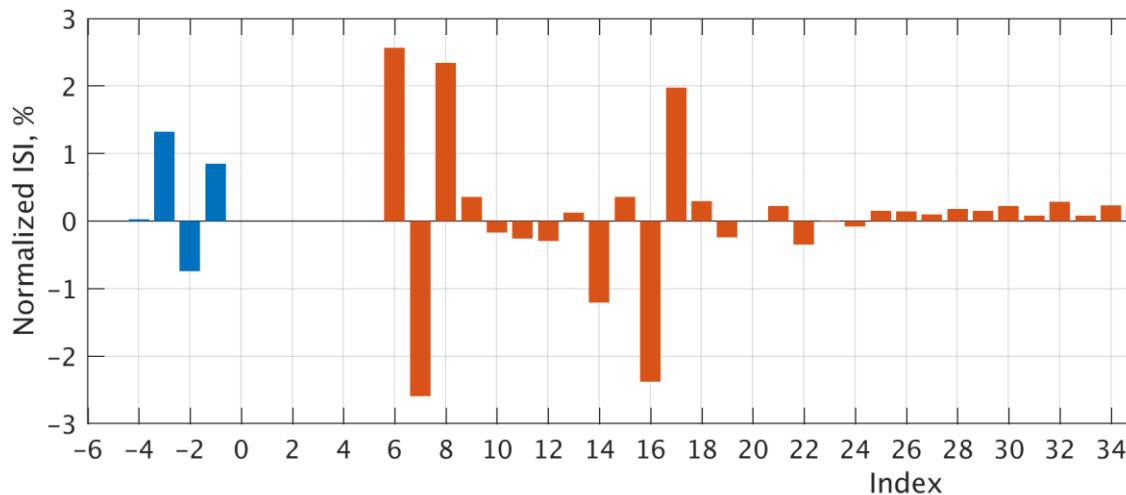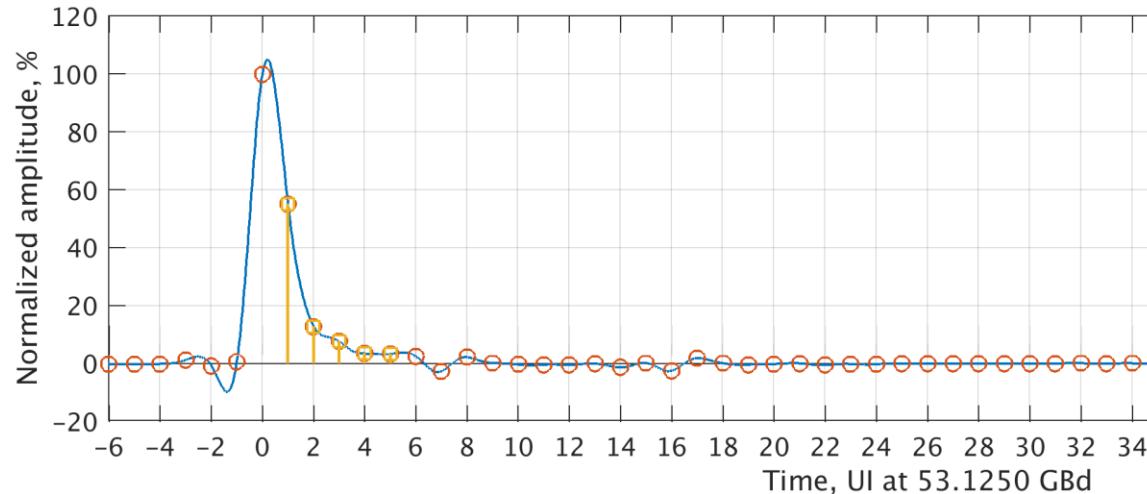
Residual pre-cursor inter-symbol interference (ISI) is not the problem

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

Impact of *c*(−3) is to shift the sampling time bit
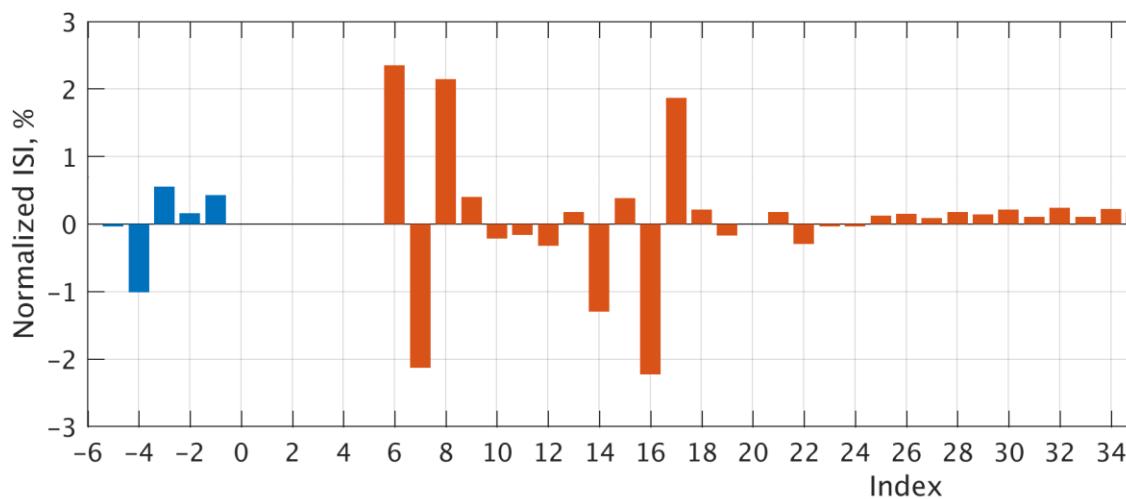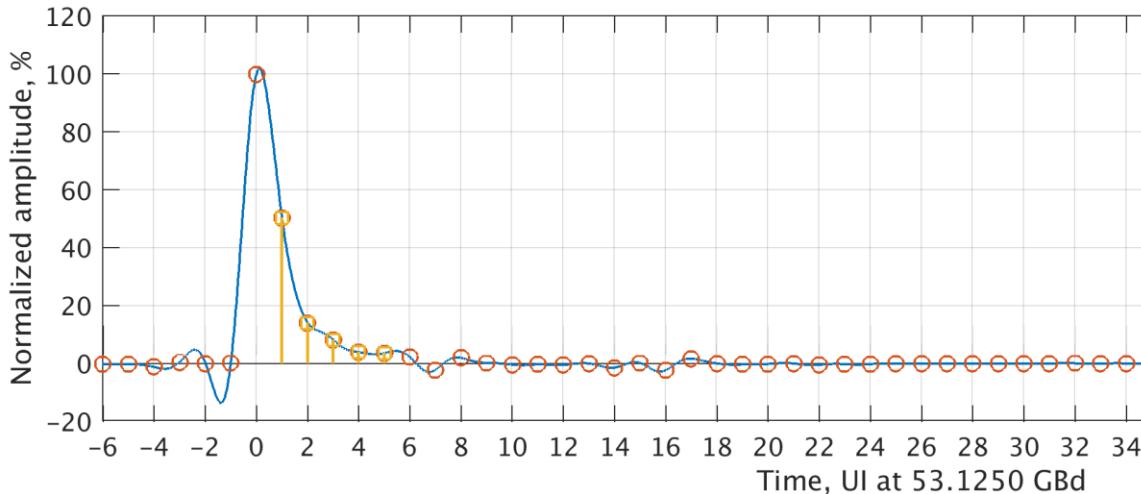
Addition of *c*(−3) changes the residual pre-cursor ISI to a small degree

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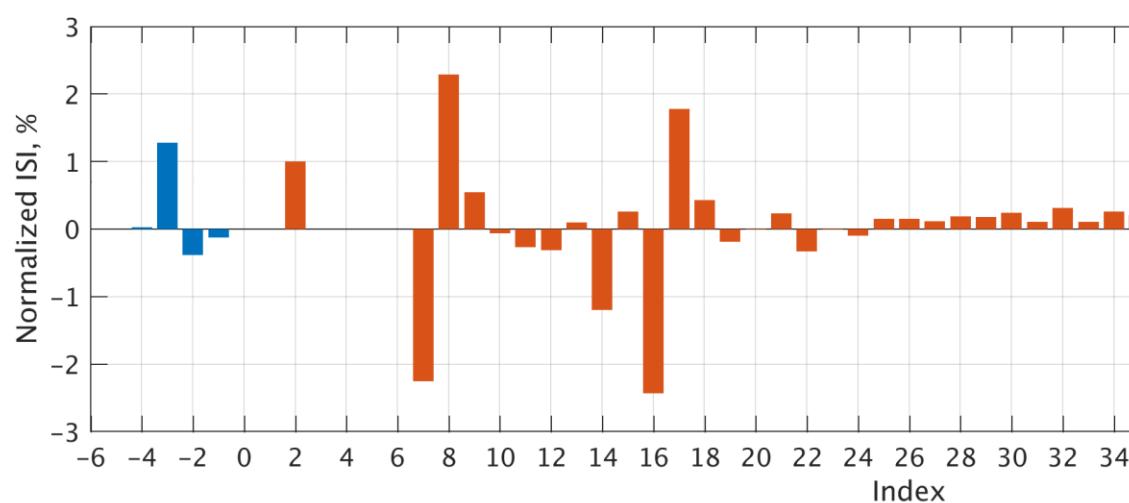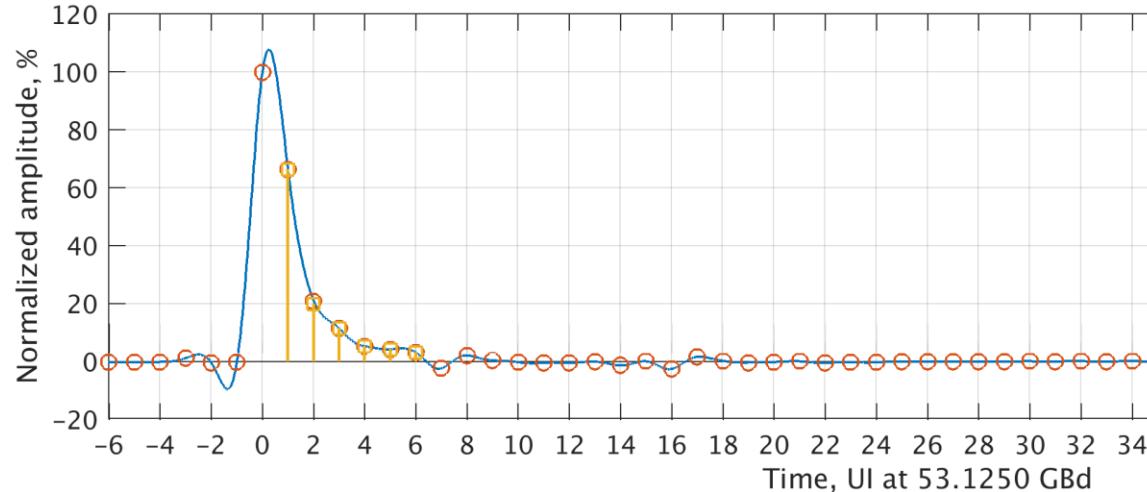
An additional post-cursor tap directly addresses the most glaring problem

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

	z_p (TX)																							
COM, dB	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	2.297	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

Row label: z_p (RX)

Appendix C

R4 sensitivity to package trace length

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

Legend: COM < 3 dB | 3 ≤ COM < 3.2 dB | COM > 4 dB

COM, dB (z_p RX \ 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
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

Column header: z_p (TX); Row header: z_p (RX)

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

z_p (TX)		8	
c(−3)	0	-2%	0
N_b	5	5	6
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

(left axis: z_p (RX))

Similar trends to those observed for L4

z_p (TX)			8			
N_b			5			
c(−3)	0	−0.01	−0.02	−0.03	−0.04	−0.05
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

(left axis: z_p (RX))

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. $c(-3)$, $\Delta c = 2\%$, $N_b = 5$		No $c(-3)$, $\Delta c = 2.5\%$, $N_b = 5$		No $c(-3)$, $\Delta c = 2.5\%$, $N_b = 6$		No $c(-3)$, $\Delta c = 3\%$, $N_b = 5$		No $c(-3)$, $\Delta c = 3\%$, $N_b = 6$	
	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
		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