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shaping tomorrow with you

Low-Frequency CTLE to support 3m cable w/o FEC

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Abstract

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- Low-Frequency CTLE (LF-CTLE)
  - A pair of pole and zero (i.e. not only zero) both in low frequency (<< fb)
  - A state-of-the-art analog equalizer
    - Also known as a long-tail equalizer
  - Already used in some implementations
  - A good alternative to FEC
    - Significantly reduces BER

- With LF-CTLE, we can easily support 3m cable without FEC, meeting 3dB COM criteria

Study of LF-CTLE Effect on COM

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- CTLE parameters of COM
  - Pole frequency, fp1
    - min fb/200, max fb/1, at selected frequencies
    - fz is set always same as fp1
  - DC gain
    - min -12dB, max 0dB, step 1dB when fp1 >= fb/40 (same as before)
    - min -8dB, max 0dB, step 0.5dB when fp1 < fb/40 (narrow range, fine step)
- Channel data
  - 11 cases for 3 meter cable
    - 5 levels of AWG: 2 x 24AWG,1 x 25AWG, 4 x 26AWG, 1 x 28AWG, 3 x 30AWG
    - 2 levels of connector type: 6 x QSFP-QSFP, 5 x QSFP-4xSFP breakout cable
  - 5 cases for 5 meter cable
    - 2 levels of AWG: 2 x 24AWG, 3 x 26AWG
    - 2 levels of connector type: 4 x QSFP-QSFP, 1 x QSFP-4xSFP breakout cable
- Test conditions
  - Test 1 (PKG trace=12mm) and Test 2 (PKG trace=30mm)
  - DER0 = 1E-12
  - bmax = 1
    - COM has a serious problem with bmax < 1. Will be reported separately.
- COM code
  - http://www.ieee802.org/3/bj/public/tools/ran_com_3bj_3bm_01_1114.zip (reference code)

Test 1 Result (DER0=1E-12) for 3m Cable

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COM value

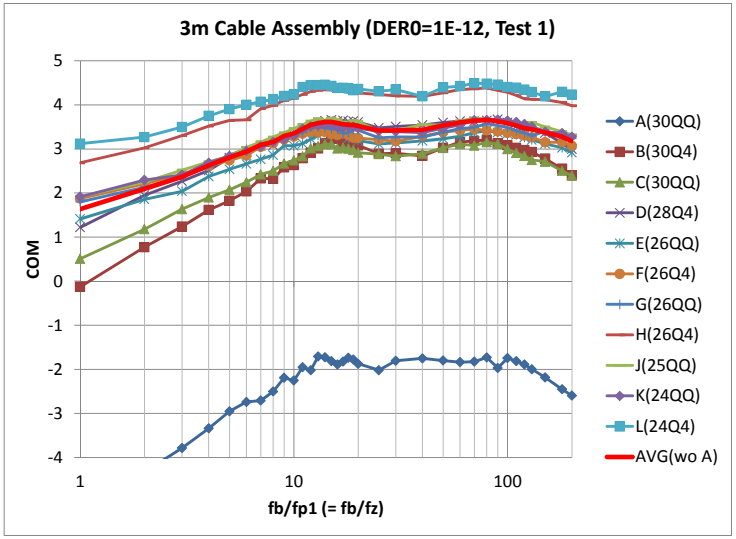
current →

comment #174 →

comment #146 →

fb/fp1	A(30QQ)	B(30Q4)	C(30QQ)	D(28Q4)	E(26QQ)	F(26Q4)	G(26QQ)	H(26Q4)	J(25QQ)	K(24QQ)	L(24Q4)	AVG(wo A)
1	-4.96	-0.13	0.51	1.22	1.41	1.87	1.80	2.69	1.92	1.92	3.12	1.63
2	-4.33	0.77	1.18	1.95	1.86	2.21	2.13	3.02	2.25	2.30	3.27	2.09
3	-3.78	1.24	1.63	2.27	2.04	2.42	2.37	3.30	2.52	2.41	3.50	2.37
4	-3.34	1.62	1.90	2.51	2.37	2.61	2.59	3.52	2.71	2.69	3.75	2.63
5	-2.95	1.82	2.07	2.80	2.54	2.74	2.87	3.65	2.84	2.84	3.90	2.81
6	-2.74	2.03	2.24	2.94	2.66	2.85	3.00	3.66	3.03	2.95	4.00	2.94
7	-2.71	2.33	2.42	3.07	2.77	3.05	3.08	3.91	3.16	3.06	4.07	3.09
8	-2.50	2.32	2.50	3.08	2.86	3.13	3.17	3.99	3.27	3.15	4.12	3.16
9	-2.19	2.58	2.67	3.27	3.08	3.21	3.25	4.10	3.37	3.22	4.20	3.30
10	-2.25	2.63	2.74	3.31	3.07	3.28	3.33	4.15	3.46	3.31	4.23	3.35
11	-1.95	2.79	2.83	3.43	3.12	3.34	3.37	4.24	3.55	3.46	4.40	3.45
12	-2.02	2.91	3.01	3.52	3.22	3.38	3.48	4.30	3.63	3.51	4.45	3.54
13	-1.71	3.01	3.06	3.60	3.31	3.37	3.49	4.33	3.68	3.53	4.45	3.58
14	-1.73	3.12	3.11	3.64	3.41	3.38	3.48	4.34	3.65	3.55	4.45	3.61
15	-1.81	3.24	3.10	3.66	3.32	3.33	3.45	4.33	3.70	3.54	4.43	3.61
16	-1.89	3.23	3.01	3.63	3.37	3.31	3.44	4.34	3.66	3.49	4.38	3.59
17	-1.82	3.13	3.03	3.64	3.33	3.35	3.35	4.32	3.60	3.48	4.39	3.56
18	-1.74	3.14	3.01	3.63	3.25	3.31	3.37	4.28	3.60	3.51	4.37	3.55
19	-1.78	3.14	2.97	3.63	3.24	3.25	3.43	4.30	3.64	3.50	4.33	3.54
20	-1.87	3.08	2.92	3.61	3.19	3.25	3.42	4.27	3.62	3.47	4.36	3.52
25	-2.02	2.89	2.88	3.48	3.11	3.21	3.25	4.23	3.41	3.40	4.31	3.42
30	-1.81	2.90	2.84	3.51	3.13	3.18	3.27	4.20	3.42	3.39	4.35	3.42
40	-1.75	2.84	2.89	3.54	3.18	3.29	3.27	4.19	3.55	3.37	4.19	3.43
50	-1.80	3.02	3.02	3.60	3.23	3.38	3.38	4.27	3.54	3.47	4.40	3.53
60	-1.83	3.15	3.11	3.63	3.29	3.42	3.46	4.35	3.64	3.54	4.42	3.60
70	-1.82	3.19	3.08	3.63	3.37	3.45	3.49	4.36	3.70	3.65	4.49	3.64
80	-1.73	3.20	3.15	3.64	3.41	3.42	3.57	4.38	3.68	3.66	4.48	3.66
90	-1.97	3.13	3.11	3.67	3.37	3.39	3.53	4.33	3.63	3.66	4.46	3.63
100	-1.74	3.09	3.00	3.60	3.35	3.36	3.49	4.28	3.63	3.64	4.40	3.58
110	-1.81	3.03	2.91	3.51	3.32	3.34	3.41	4.22	3.58	3.61	4.39	3.53
120	-1.89	2.98	2.84	3.42	3.26	3.31	3.36	4.14	3.52	3.56	4.34	3.47
130	-2.00	2.93	2.75	3.48	3.20	3.27	3.30	4.13	3.60	3.51	4.29	3.45
150	-2.18	2.78	2.71	3.36	3.12	3.15	3.40	4.12	3.50	3.39	4.19	3.37
180	-2.45	2.55	2.50	3.13	3.03	3.15	3.31	4.05	3.39	3.36	4.29	3.28
200	-2.60	2.40	2.39	3.00	2.92	3.07	3.23	3.98	3.32	3.28	4.23	3.18

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM



Data label notation:

A (30 QQ)

- Label
- AWG (ex 30=30AWG)
- Assembly type
  - QQ: QSFP-QSFP
  - Q4: QSFP-4xSFP

- With fp1=fb/4, only 2 out of 11 exceed 3dB.
- With fp1=fb/15 or fb/60, 10 out of 11 exceed 3dB.
  - Improvement from fb/4 is 0.7~1.6dB (average 1.0dB).
  - Anyway, A is not acceptable.

Test 2 Result (DER0=1E-12) for 3m Cable

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COM value

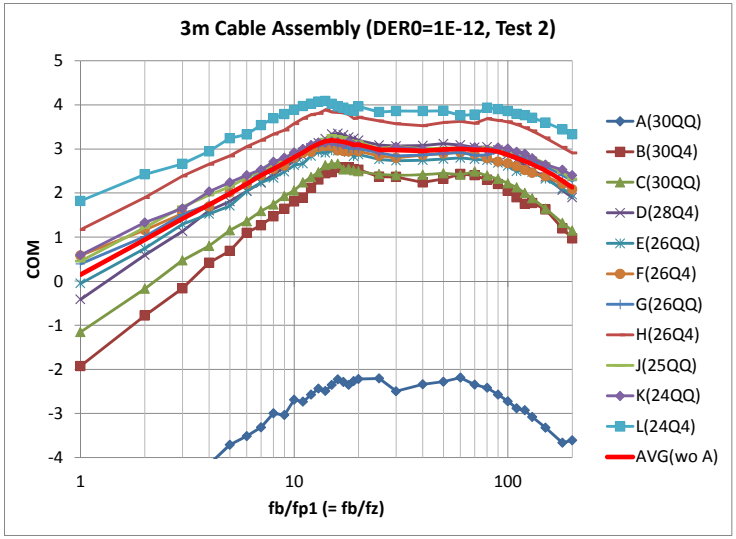
current →

comment #174 →

comment #146 →

fb/fp1	A(30QQ)	B(30Q4)	C(30QQ)	D(28Q4)	E(26QQ)	F(26Q4)	G(26QQ)	H(26Q4)	J(25QQ)	K(24QQ)	L(24Q4)	AVG(wo A)
1	-6.40	-1.92	-1.15	-0.42	-0.05	0.58	0.39	1.17	0.45	0.59	1.82	0.15
2	-5.37	-0.78	-0.17	0.59	0.74	1.16	1.01	1.89	1.22	1.33	2.42	0.94
3	-4.76	-0.16	0.47	1.13	1.29	1.54	1.51	2.39	1.69	1.65	2.66	1.42
4	-4.16	0.42	0.80	1.60	1.52	1.70	1.74	2.65	1.95	2.03	2.95	1.74
5	-3.71	0.69	1.15	1.81	1.71	2.01	2.01	2.84	2.14	2.24	3.24	1.98
6	-3.52	1.10	1.36	2.04	2.04	2.20	2.20	3.05	2.36	2.40	3.33	2.21
7	-3.32	1.27	1.59	2.23	2.24	2.40	2.51	3.20	2.51	2.53	3.54	2.40
8	-3.00	1.47	1.74	2.42	2.34	2.54	2.58	3.34	2.65	2.71	3.70	2.55
9	-3.04	1.64	1.93	2.58	2.48	2.62	2.79	3.43	2.75	2.80	3.79	2.68
10	-2.69	1.81	2.06	2.73	2.63	2.81	2.82	3.57	2.88	2.92	3.89	2.81
11	-2.73	1.89	2.24	2.84	2.67	2.91	2.96	3.69	3.00	3.00	3.97	2.92
12	-2.57	2.12	2.36	3.03	2.84	2.93	3.07	3.78	3.08	3.09	4.03	3.03
13	-2.44	2.30	2.47	3.14	2.93	3.04	3.07	3.81	3.15	3.14	4.07	3.11
14	-2.49	2.45	2.63	3.23	2.91	3.07	3.13	3.89	3.22	3.15	4.09	3.18
15	-2.35	2.47	2.66	3.34	2.96	3.06	3.11	3.84	3.30	3.17	4.02	3.19
16	-2.23	2.57	2.67	3.35	2.96	2.97	3.08	3.83	3.28	3.16	3.96	3.18
17	-2.29	2.58	2.53	3.32	2.97	2.95	3.10	3.82	3.26	3.11	3.93	3.16
18	-2.35	2.58	2.55	3.27	2.93	2.94	3.01	3.78	3.19	3.17	3.89	3.13
19	-2.27	2.54	2.51	3.24	2.83	2.99	3.01	3.69	3.18	3.09	3.87	3.09
20	-2.22	2.53	2.49	3.20	2.88	2.95	3.00	3.72	3.16	3.08	3.96	3.10
25	-2.21	2.37	2.43	3.09	2.76	2.84	2.91	3.63	3.01	2.95	3.84	2.98
30	-2.50	2.36	2.40	3.07	2.74	2.80	2.84	3.57	3.06	3.05	3.86	2.97
40	-2.34	2.24	2.41	3.08	2.75	2.86	2.86	3.53	3.01	2.99	3.86	2.96
50	-2.28	2.32	2.45	3.12	2.77	2.90	2.90	3.60	3.02	2.95	3.87	2.99
60	-2.19	2.43	2.41	3.09	2.80	2.93	2.92	3.63	3.03	3.04	3.76	3.00
70	-2.35	2.40	2.49	3.04	2.77	2.88	2.85	3.58	3.01	3.04	3.78	2.98
80	-2.42	2.30	2.39	3.05	2.75	2.79	2.87	3.69	3.03	2.98	3.94	2.98
90	-2.57	2.20	2.32	2.98	2.68	2.71	2.94	3.65	2.96	3.03	3.90	2.94
100	-2.73	2.06	2.22	2.88	2.61	2.67	2.90	3.61	2.86	3.01	3.86	2.87
110	-2.88	1.90	2.13	2.76	2.49	2.61	2.85	3.56	2.93	2.94	3.79	2.79
120	-2.93	1.75	2.00	2.63	2.53	2.52	2.80	3.48	2.87	2.89	3.77	2.72
130	-3.08	1.77	1.88	2.51	2.48	2.46	2.74	3.41	2.80	2.79	3.71	2.65
150	-3.32	1.63	1.65	2.36	2.32	2.38	2.60	3.25	2.67	2.64	3.60	2.51
180	-3.67	1.20	1.32	2.06	2.10	2.21	2.40	3.04	2.46	2.53	3.44	2.28
200	-3.61	0.97	1.15	1.90	1.97	2.08	2.28	2.91	2.32	2.40	3.33	2.13

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM



- With fp1=fb/4, none exceeds 3dB.
- With fp1=fb/15, 7 out of 11 exceed 3dB.
  - Improvement from fb/4 is 1.1~2.1dB (average 1.5dB)
- With fp1=fb/60, 5 out of 11 exceed 3dB.
  - Improvement from fb/4 is 0.8~2.0dB (average 1.3dB)

Test 1 Result (DER0=1E-12) for 5m Cable

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COM value

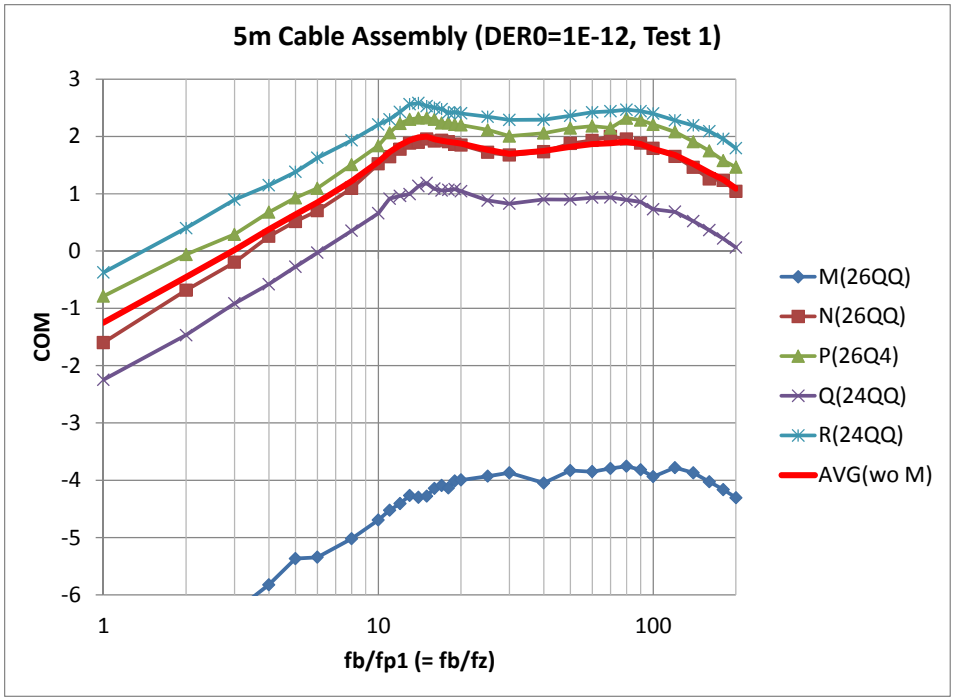
current →

comment #174 →

comment #146 →

fb/fp1	M(26QQ)	N(26QQ)	P(26Q4)	Q(24QQ)	R(24QQ)	AVG(wo M)
1	-7.22	-1.60	-0.79	-2.25	-0.37	-1.25
2	-6.72	-0.68	-0.06	-1.47	0.40	-0.45
3	-6.29	-0.20	0.29	-0.91	0.90	0.02
4	-5.82	0.26	0.68	-0.58	1.15	0.38
5	-5.37	0.52	0.93	-0.27	1.38	0.64
6	-5.34	0.70	1.09	-0.03	1.63	0.85
8	-5.02	1.10	1.51	0.35	1.93	1.22
10	-4.70	1.52	1.84	0.66	2.21	1.56
11	-4.52	1.65	2.06	0.91	2.30	1.73
12	-4.41	1.78	2.23	0.96	2.43	1.85
13	-4.27	1.88	2.30	0.99	2.56	1.93
14	-4.30	1.89	2.32	1.13	2.58	1.98
15	-4.28	1.95	2.32	1.18	2.53	2.00
16	-4.14	1.92	2.30	1.09	2.50	1.95
17	-4.09	1.93	2.23	1.06	2.48	1.92
18	-4.14	1.91	2.24	1.06	2.41	1.91
19	-4.01	1.86	2.21	1.08	2.42	1.89
20	-4.00	1.85	2.20	1.04	2.40	1.87
25	-3.93	1.72	2.11	0.88	2.34	1.76
30	-3.87	1.67	2.01	0.82	2.29	1.70
40	-4.05	1.73	2.06	0.90	2.29	1.75
50	-3.83	1.88	2.15	0.90	2.36	1.82
60	-3.85	1.93	2.18	0.93	2.42	1.87
70	-3.79	2.00	2.15	0.93	2.44	1.88
80	-3.76	1.95	2.32	0.89	2.47	1.91
90	-3.82	1.88	2.28	0.86	2.44	1.87
100	-3.94	1.79	2.21	0.73	2.40	1.78
120	-3.78	1.65	2.08	0.68	2.28	1.67
140	-3.87	1.46	1.91	0.52	2.19	1.52
160	-4.03	1.26	1.75	0.36	2.09	1.37
180	-4.16	1.23	1.58	0.22	1.96	1.25
200	-4.30	1.04	1.46	0.06	1.79	1.09

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM



- None exceeds 3dB.
- With fp1=fb/4, 1 out of 5 exceeds 1dB.
- With fp1=fb/15, 4 out of 5 exceed 1dB.
- With fp1=fb/60, 3 out of 5 exceed 1dB.

Test 2 Result (DER0=1E-12) for 5m Cable

COM value

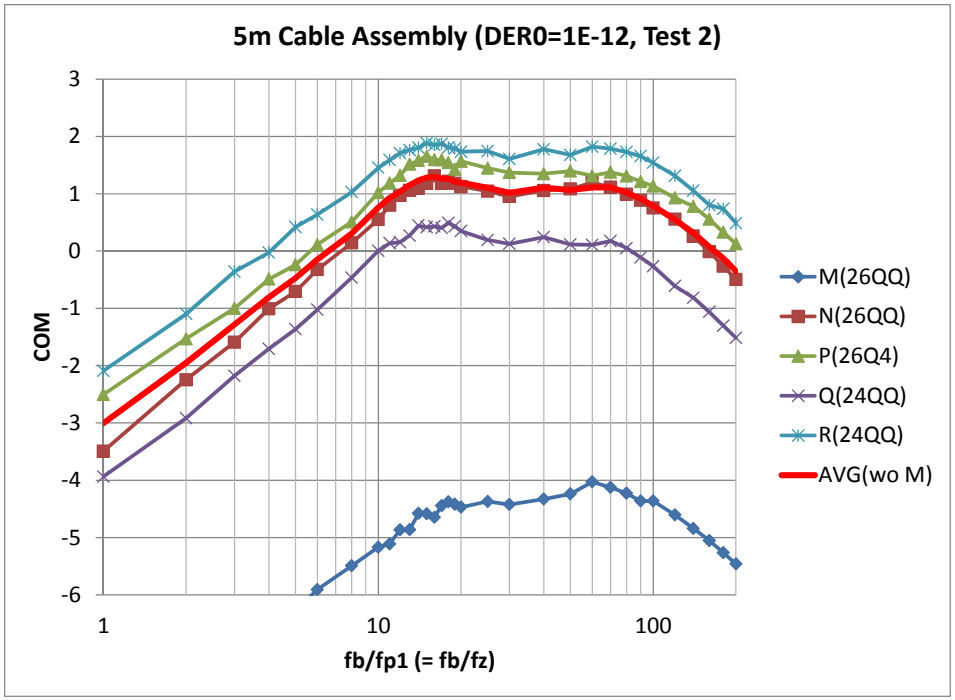
current →

comment #174 →

comment #146 →

fb/fp1	M(26QQ)	N(26QQ)	P(26Q4)	Q(24QQ)	R(24QQ)	AVG(wo M)
1	-8.36	-3.49	-2.50	-3.93	-2.09	-3.01
2	-7.89	-2.25	-1.53	-2.92	-1.10	-1.95
3	-7.10	-1.59	-1.00	-2.18	-0.36	-1.28
4	-6.73	-1.01	-0.49	-1.71	-0.03	-0.81
5	-6.29	-0.71	-0.24	-1.36	0.42	-0.47
6	-5.91	-0.32	0.11	-1.02	0.64	-0.15
8	-5.49	0.14	0.51	-0.47	1.03	0.30
10	-5.17	0.55	1.02	0.01	1.45	0.76
11	-5.11	0.80	1.18	0.14	1.59	0.93
12	-4.87	0.97	1.32	0.15	1.71	1.04
13	-4.86	1.06	1.51	0.27	1.76	1.15
14	-4.58	1.10	1.58	0.45	1.80	1.23
15	-4.58	1.18	1.65	0.42	1.88	1.28
16	-4.64	1.31	1.59	0.43	1.85	1.30
17	-4.44	1.19	1.59	0.40	1.87	1.26
18	-4.38	1.22	1.54	0.49	1.81	1.27
19	-4.42	1.18	1.43	0.43	1.79	1.21
20	-4.47	1.12	1.57	0.35	1.73	1.19
25	-4.37	1.04	1.45	0.19	1.74	1.11
30	-4.42	0.95	1.37	0.13	1.61	1.01
40	-4.33	1.06	1.35	0.24	1.78	1.11
50	-4.24	1.08	1.39	0.11	1.68	1.07
60	-4.03	1.19	1.31	0.11	1.82	1.11
70	-4.13	1.11	1.38	0.18	1.79	1.11
80	-4.23	0.99	1.31	0.05	1.73	1.02
90	-4.36	0.89	1.21	-0.11	1.66	0.91
100	-4.36	0.75	1.13	-0.27	1.54	0.79
120	-4.60	0.55	0.93	-0.61	1.31	0.55
140	-4.84	0.26	0.78	-0.82	1.05	0.32
160	-5.05	-0.01	0.56	-1.06	0.80	0.07
180	-5.26	-0.26	0.33	-1.30	0.74	-0.13
200	-5.46	-0.50	0.13	-1.52	0.49	-0.35

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM



- With fp1=fb/4, none exceeds 1dB.
- With fp1=fb/15 or fb/60, 3 out of 5 exceed 1dB.

Study of LF-CTLE Effect on BER and Eye

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- For selected channels, equalizer parameters were taken from above results that were optimized by reference COM code
  - Channels
    - 3m cable: B(30Q4) – fair, G(26QQ) – typical, H(26Q4) – good
    - 5m cable: Q(24QQ) – fair, N(26QQ) – typical, R(24QQ) – good
- BER and Eye were analyzed by in-house tools
  - Parameters of BER and Eye analysis:
    - TX RJ = 0.01UI (rms), TX DJ = 0.15UI (δ-δ), TX EOJ = 0.035UI (p-p)
    - RX RJ = 0.005UI (rms), RX DJ = 0.075UI (δ-δ), RX EOJ = 0.0175UI (p-p)
    - TX output noise SNR_{TX} = 27 (dB)
    - RX input noise η_0 = 5.20E-8 (V^2/GHz)
    - Receiver 3dB bandwidth = 0.75 (fb)
  - These are more stressful than COM parameters, c.f.
    - Random jitter σ_{RJ} = 0.01 UI (rms)
    - Dual-dirac jitter A_{DD} = 0.05 UI (peak) This is equivalent to DJ 0.10 UI (δ-δ).

Results for 3m Cable

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM

BER > 1E-10
1E-10>BER>1E-14
1E-14>BER>1E-16
1E-16 > BER

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fp1(=fz)	Evaluated item	Test 1			Test 2		
		B(30Q4)	G(26QQ)	H(26Q4)	B(30Q4)	G(26QQ)	H(26Q4)
fb/4	COM (1E-12)	1.62	2.59	3.52	0.42	1.74	2.65
	COM (1E-15)	0.70	1.70	2.63	-0.51	0.85	1.75
	BER	5.94E-15	1.76E-18	7.91E-23	1.24E-11	4.25E-15	1.92E-18
	EW (1E-12)	0.07UI	0.15UI	0.20UI	0.00UI	0.07UI	0.14UI
	EH (1E-12)	1.88mV	6.20mV	8.71mV	0.00mV	2.42mV	4.60mV
fb/15	COM (1E-12)	3.24	3.45	4.33	2.47	3.11	3.84
	COM (1E-15)	2.33	2.57	3.46	1.54	2.11	2.95
	BER	1.93E-22	5.92E-23	1.41E-27	4.42E-19	4.42E-21	4.15E-25
	EW (1E-12)	0.26UI	0.24UI	0.30UI	0.21UI	0.23UI	0.28UI
	EH (1E-12)	10.48mV	12.97mV	19.33mV	6.10mV	10.14mV	13.76mV
fb/60	COM (1E-12)	3.15	3.46	4.35	2.43	2.92	3.63
	COM (1E-15)	2.23	2.57	3.45	1.50	2.00	2.72
	BER	8.14E-23	3.93E-24	1.03E-28	1.16E-19	2.15E-20	2.71E-24
	EW (1E-12)	0.29UI	0.48UI	0.33UI	0.23UI	0.23UI	0.29UI
	EH (1E-12)	10.09mV	28.26mV	19.96mV	6.48mV	8.63mV	13.37mV

Fair 3m Cable B(30Q4) Test 2

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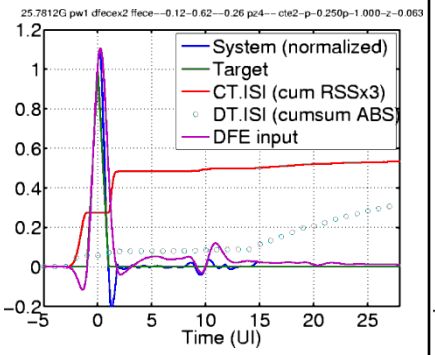
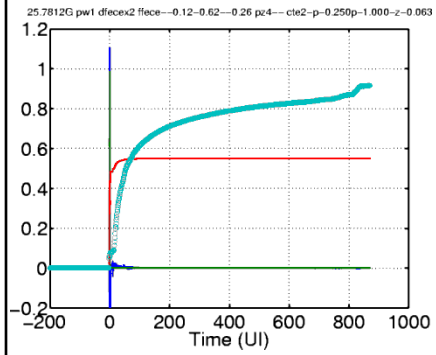
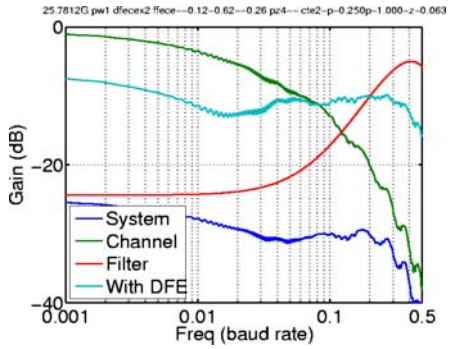
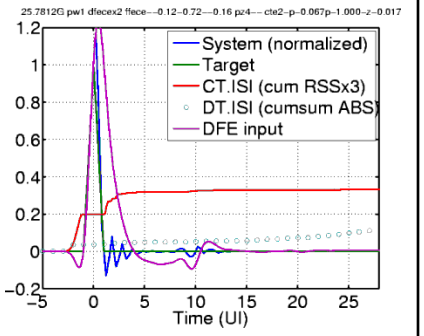
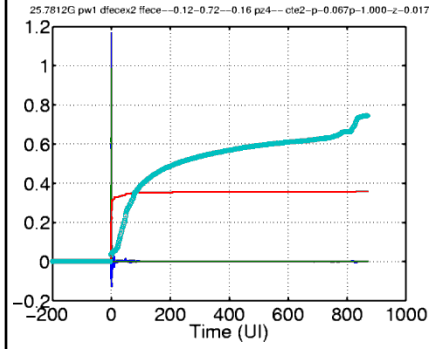
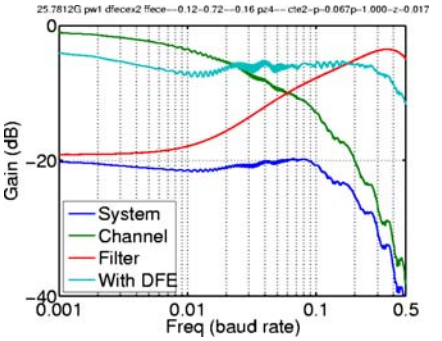
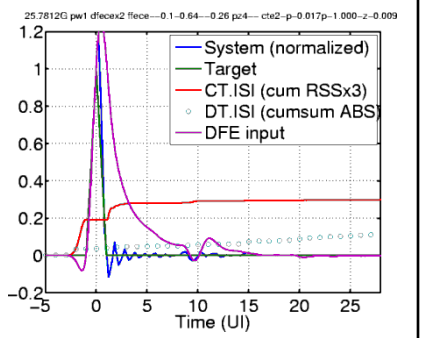
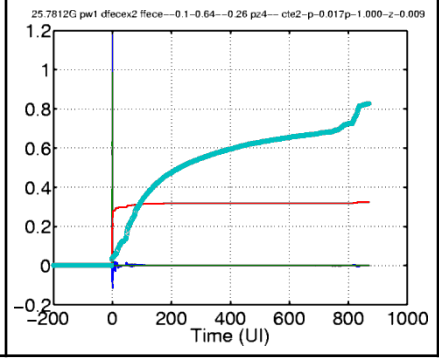
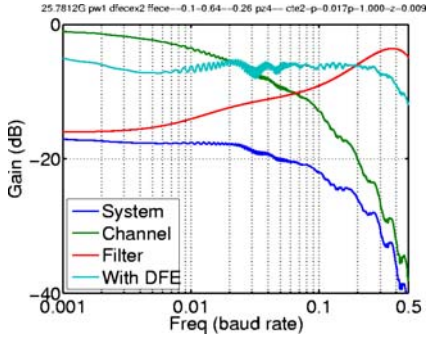
fp1	Statistical Eye	Short Term Resp.	Long Term Resp.	Frequency Resp.
fb/4	COM(1E-12) = 0.42			
fb/15	COM(1E-12) = 2.47			
fb/60	COM(1E-12) = 2.43			

Results for 5m Cable

COM < -1
-1 < COM < +1
+1 < COM < 3
+3 < COM

BER > 1E-10
1E-10>BER>1E-14
1E-14>BER>1E-16
1E-16 > BER

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fp1(=fz)	Evaluated item	Test 1			Test 2		
		Q(24QQ)	N(26QQ)	R(24QQ)	Q(24QQ)	N(26QQ)	R(24QQ)
fb/4	COM (1E-5)	3.41	4.25	5.09	2.34	3.05	4.01
	COM (1E-12)	-0.58	0.26	1.15	-1.71	-1.01	-0.03
	BER	1.75E-9	8.51E-11	4.92E-14	1.24E-7	8.80E-9	3.37E-11
	EW (1E-12)	0.00UI	0.00UI	0.05UI	0.00UI	0.00UI	0.00UI
	EH (1E-12)	0.00mV	0.00mV	1.25mV	0.00mV	0.00mV	0.00mV
fb/15	COM (1E-5)	5.16	5.84	6.40	4.46	5.20	5.79
	COM (1E-12)	1.18	1.95	2.53	0.42	1.18	1.88
	BER	5.73E-15	1.76E-17	1.14E-20	2.06E-12	2.78E-14	4.58E-18
	EW (1E-12)	0.10UI	0.17UI	0.23UI	0.00UI	0.07UI	0.19UI
	EH (1E-12)	2.57mV	5.03mV	7.92mV	0.00mV	1.61mV	5.12mV
fb/60	COM (1E-5)	4.95	5.89	6.36	4.07	5.16	5.77
	COM (1E-12)	0.93	1.93	2.42	0.11	1.19	1.82
	BER	2.35E-14	1.64E-17	3.61E-20	1.27E-13	5.43E-15	2.76E-17
	EW (1E-12)	0.08UI	0.18UI	0.23UI	0.06UI	0.11UI	0.17UI
	EH (1E-12)	1.97mV	4.59mV	7.09mV	0.98mV	2.30mV	4.38mV

Typical 5m Cable N(26QQ) Test 1

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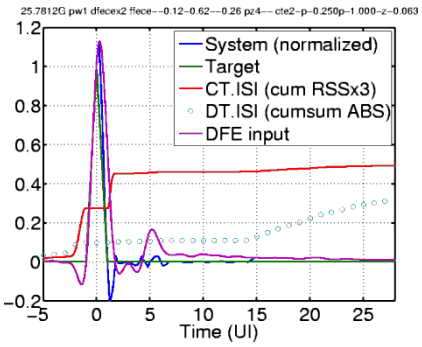
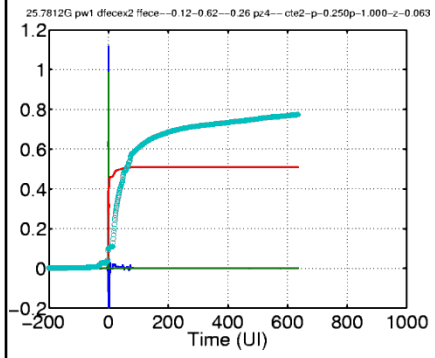
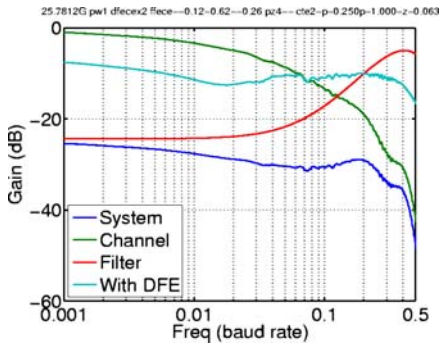
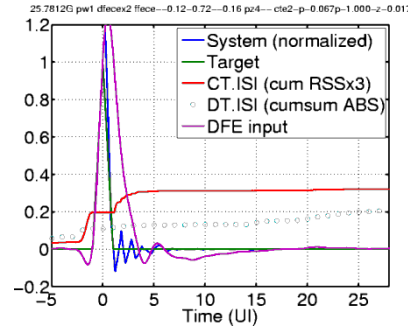
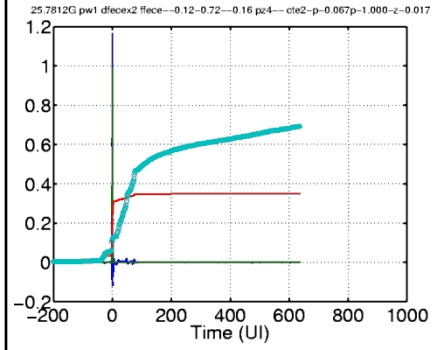
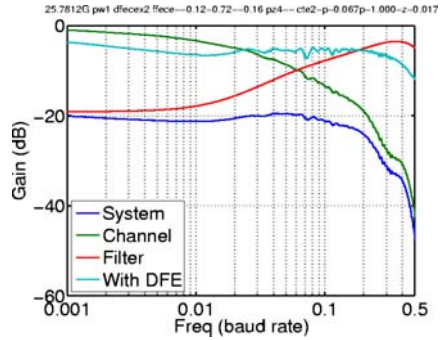
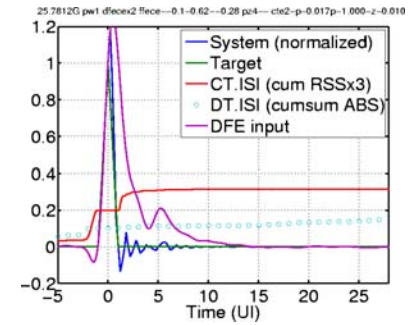
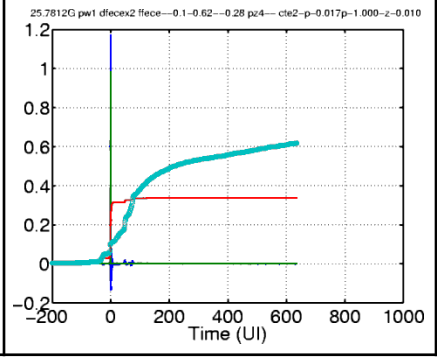
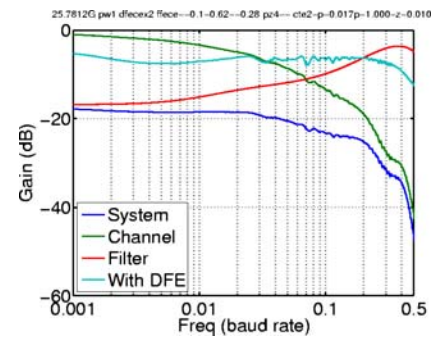
fp1	Statistical Eye	Short Term Resp.	Long Term Resp.	Frequency Resp.
fb/4	COM(1E-12) = 0.26			
fb/15	COM(1E-12) = 1.95			
fb/60	COM(1E-12) = 1.93			

LF-CTLE – A Good Alternative to FEC

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- LF-CTLE reduces many small long-term (over 50-100UI) ISIs
- As the Central Limit Theorem states, those many small ISIs collectively create a (mostly) Gaussian distribution of ISI noise
- Tail parts of the Gaussian ISI noise is a target of FEC
- Since LF-CTLE reduces those many small long-term ISIs, distribution of the Gaussian ISI noise is reduced, and hence we can omit FEC

Discussion on P802.3bj receiver

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- COM parameters for P802.3bj does not include LF-CTLE
  - If we change fp1 of COM, requirements for receiver are loosely affected
  - It may make P802.3bj receiver w/o LF-CTLE difficult to pass the compliance test
- No FEC is a new feature for P802.3by
  - FEC was mandatory for P802.3bj
  - If we need to use P802.3bj receiver w/o LF-CTLE, we should use FEC
- LF-CTLE has been used in some implementations
  - Existing P802.3bj receiver may have LF-CTLE
    - LF-CTLE has been used as a performance booster
    - Extra margin earned by LF-CTLE has been allocated within a device margin
      - We should re-allocate this margin to the most beneficial part, i.e. channel skin effect
  - Changing fp1 is probably OK for P802.3bj receiver with LF-CTLE

How to integrate LF-CTLE to COM

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- We have two options
  - Option 1: Change current CTLE parameters of COM to low frequency
    - Equalizer capability in high frequency is degraded and may become insufficient
  - Option 2: Add LF-CTLE on top of current CTLE of COM
    - Equalizer capability in high frequency is maintained
- Option 1 works fine for 3m cable according to my study
- Option 2 may be needed for other applications
  - E.g. 5m cable, backplane, 50Gbps, etc
- I recommend option 1, because our current focus is 3m cable
  - We may choose option 2 for other channels, but we need more study
    - For 5m cable, option 1 improves the performance, but not enough for 3dB COM with no FEC. With option 2, we might get 3dB COM with no FEC for 5m cable.
  - Option 2 needs more efforts such as developing COM model and formulas
- Receiver implementation may take always option 2
  - COM is not a specification of the receiver implementation

fp1=fb/15 vs fp1=fb/60

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- For COM value, fb/15 is always slightly better than fb/60
- For BER value, fb/15 is not necessarily better than fb/60
  - Sometime, fb/60 is better than fb/15
  - It may be due to quantization effect of CTLE
- While receiver may implement fp1=fb/60 to minimize BER, I recommend fp1=fb/15, because COM with fp1=fb/15 is always slightly better than fp1=fb/60

Only CA-N or also CA-S and/or CA-N

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- We have three options:
  - Option 1: Apply the change only to CA-N
  - Option 2: Apply the change to CA-N and CA-S
  - Option 3: Apply the change to all of CA-N, CA-S, and CA-L
- My recommendation is option 3, because
  - LF-CTLE is effective even if there is FEC
  - We may support cable longer than 3m with BASE-R FEC
    - E.g. we may support 5m cable with BASE-R FEC to reduce latency
  - We may support cable longer than 5m with RS FEC
- With option 1 or 2, P802.3bj receiver without LF-CTLE may be easier to pass compliance test, but I think low latency or extensibility may be more valuable than compatibility

References of LF-CTLE

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[1] J. Savoj, et al., “A Wide Common-Mode Fully-Adaptive Multi-Standard 12.5Gb/s Backplane Transceiver in 28nm CMOS,” VLSI Circuits Dig. Tech. Papers, pp.104-105, June 2012.

[2] S. Parikh, et al., “A 32Gb/s Wireline Receiver with a Low-Frequency Equalizer, CTLE and 2-Tap DFE in 28nm CMOS,” ISSCC Dig. Tech. Papers, pp.28-29, Feb. 2013.

[3] B. Zhang, et al., “A 28Gb/s Multi-Standard Serial-Link Transceiver for Backplane Applications in 28nm CMOS,” ISSCC Dig. Tech. Papers, pp. 52-53, Feb. 2015.

References of Channel Data

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- ~ = http://www.ieee802.3.org/3/
- 3 meter cable assembly
  - A: ~/100GCU/public/ChannelData/CD_11_0415/3m_QSFP_30AWG.zip (Tx2-Rx2.s4p)
  - B: ~/by/public/channel/TE_QSFP_4SFP_3m_30AWG.zip (TE_3m30AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
  - C: ~/100GCU/public/ChannelData/Molex_11_0516/bugg_02_0511.zip (3m 30AWG Unicore/Cable 1/P1 RX1/TX1.s4p)
  - D: ~/by/public/channel/TE_QSFP_4SFP_3m_28AWG.zip (TE_3m28AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
  - E: ~/by/public/channel/TE_QSFP_QSFP_3m_26AWG_MaxLossExample_15p993dB.zip
  - F: ~/by/public/channel/Amphenol_NDACGJ-0003-QSFP-4SFP_3m_26AWG_APN43140033HXJ.zip (P2TX1_P1RX1.s4p)
  - G: ~/100GCU/public/ChannelData/Molex_11_0516/bugg_02_0511.zip (3m 26AWG leoni/P1 RX1/TX1.s4p)
  - H: ~/by/public/channel/TE_QSFP_4SFP_3m_26AWG.zip (TE_3m26AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
  - J: ~/by/public/channel/TE_QSFP_QSFP_3m_25AWG_MaxLossExample_15p35dB.zip
  - K: ~/by/public/channel/TE_QSFP_QSFP_3m_24AWG_MaxLossExample_14p49dB.zip
  - L: ~/by/public/channel/TE_QSFP_4SFP_3m_24AWG.zip (TE_3m24AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
- 5 meter cable assembly
  - M: ~/100GCU/public/ChannelData/CD_11_0415/5m_QSFP_26AWG.zip (Tx1-Rx1.s4p)
  - N: ~/100GCU/public/ChannelData/Molex_11_0516/bugg_02_0511.zip (5m 26AWG Leoni/P1 RX1/TX1.s4p)
  - P: ~/by/public/channel/Amphenol_NDACGJ-0005-QSFP_4SFP_5m_26AWG_APN14440053HYT.zip(P2TX1_P1RX1.s4p)
  - Q: ~/100GCU/public/ChannelData/Molex_11_0210/5m/5m_all.zip (P1 RX0/TX0.s4p)
  - R: ~/100GCU/public/ChannelData/molex_12_0310/cableb_bugg_03_0312.zip (P1RX1/P2TX1.s4p)

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Thank you