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shaping tomorrow with you

Comment #146, #174: Low-Frequency CTLE to support 3m cable w/o FEC

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Fujitsu Laboratories of America, Inc.

September 16-18, 2015

Comment #146 and #174

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Cl **110** *SC* **110.10.7** *P* **154** *L* **5** # 146

Hidaka, Yasuo — Fujitsu Lab. of Americ

Comment Type **TR** *Comment Status* **X**

The current COM parameter does not include Low-Frequency CTLE (LF-CTLE) which is a state-of-the-art analog equalizer. LF-CTLE has a pair of pole and zero in much lower frequency than the CTLE of the current COM parameter. The LF-CTLE significantly reduces BER, and is already in some implementations in the market. The LF-CTLE is also known as a long-tail equalizer. The LF-CTLE is particularly effective for skin effect, and hence for cable appliations. With LF-CTLE, we can easily support 3m cable without FEC with solid high confidence, still maintaining 3dB COM margin in the same way as before without any compromise.

However, since the current COM parameter does not include LF-CTLE, there are no 3m cable assembly that passes 3dB COM test, although there are many good-enough 3m cable assembly, unless we make some compromise such as lowering 3dB COM criteria.

SuggestedRemedy

Add the following changes to COM parameter values in Table 110-10:

Continuous time filter, DC gain gDC
Minimum value -6 dB
Maximum value 0 dB
Step size 0.5 dB

Continuous time filter, zero frequency
fz fb / 60 GHz

Continuous time filter, pole frequencies
fp1 fb / 60 GHz
fp2 fb

I have a plan to submit a supporting presentation.

Proposed Response *Response Status* **O**

Cl **110** *SC* **110.10.7** *P* **154** *L* **5** # 174

Hidaka, Yasuo — Fujitsu Lab. of Americ

Comment Type **TR** *Comment Status* **X**

This is a follow-up comment to my prior comment regarding to Low-Frequency CTLE of COM parameter.

I revised my suggested remedy.

SuggestedRemedy

Add the following changes to COM parameter values in Table 110-10:

Continuous time filter, DC gain gDC
Minimum value -12 dB
Maximum value 0 dB
Step size 1 dB

Continuous time filter, zero frequency
fz fb / 15 GHz

Continuous time filter, pole frequencies
fp1 fb / 15 GHz
fp2 fb

Proposed Response *Response Status* **O**

Abstract

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- Low-Frequency CTLE (review)
  - A state-of-the-art analog equalizer
    - Effective for skin effect rather than dielectric loss
      - Hence, effective for cable applications
    - 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 COM 3dB criteria
- With LF-CTLE, we may support even 5m cable without FEC, meeting BER<1E-12 criteria

LF-CTLE – A Good Alternative to FEC

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- LF-CTLE reduces many (>100) invisibly small long-tail ISIs
  - Long-tail ISI is so small that it is invisible as individual ISIs
    - Long-tail ISI is visible only collectively
- As the Central Limit Theorem states, those many invisibly small long-tail ISIs collectively create a visible Gaussian-like distribution of ISI noise
- Tail part of the Gaussian-like ISI noise is the target of FEC
- As LF-CTLE reduces those many invisibly small long-tail ISIs, the standard deviation of the visible Gaussian-like ISI noise is reduced, and hence we can omit FEC

Material Loss with Linear Frequency Axis

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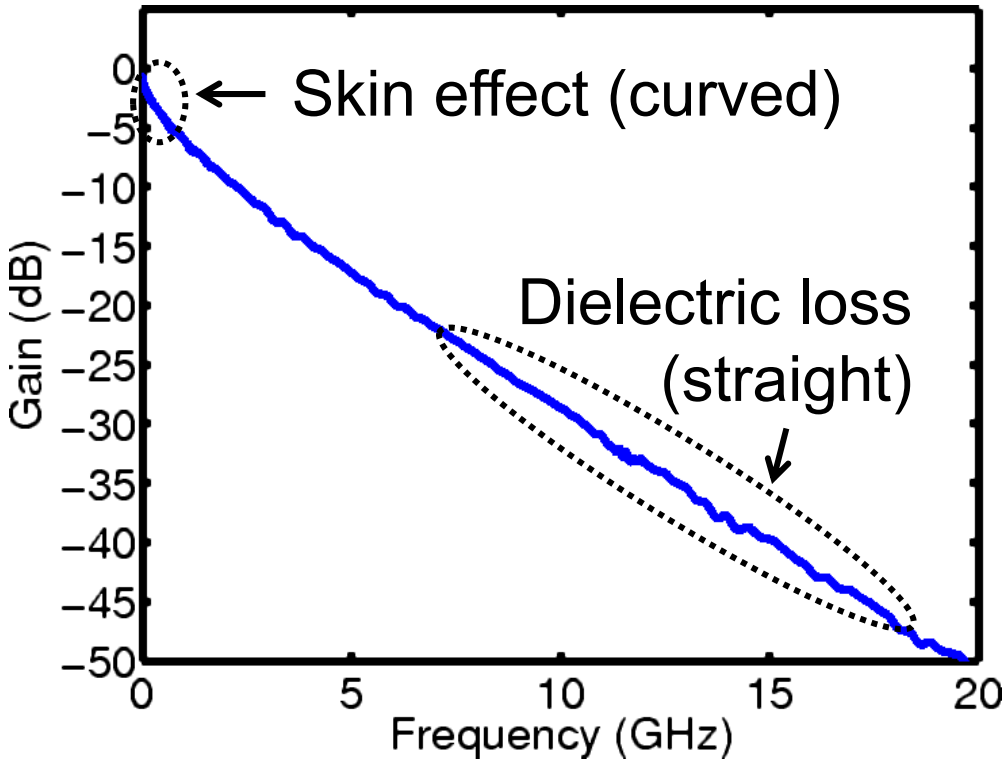
$$loss\ (dB) \propto k_1\sqrt{f} \quad + \quad k_2 f$$

Skin Effect Dielectric Loss



(Linear)

- Skin effect
  - Curved with concave up
  - Low frequency
- Dielectric loss
  - Straight line
  - High frequency
- *We often overlook or neglect low-frequency loss*
  - Loss is small
  - Degenerated at DC and hardly recognized

Material Loss with Log Frequency Axis

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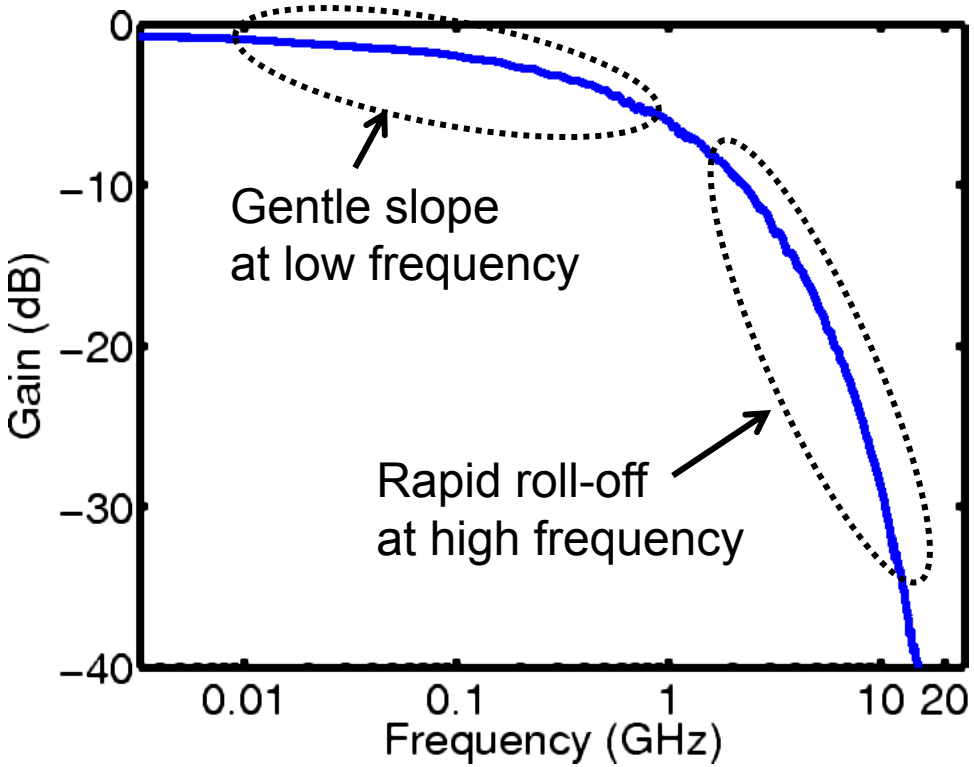
$$loss\ (dB) \propto k_1\sqrt{f} \quad + \quad k_2 f$$

Skin Effect Dielectric Loss



(Log)

- Always exponential roll-off
  - Regardless of skin effect or dielectric loss
- Low-frequency loss
  - Start as low as 0.1~10MHz
    - AWG26 cable diameter 405um
      - Skin depth ~200um@0.1MHz
    - PCB trace thickness 35um
      - Skin depth ~20um@10MHz
  - Gentle slope
    - < 3dB/dec
    - *Too gentle for high-frequency equalizers*

Low-Frequency CTLE (LF-CTLE)

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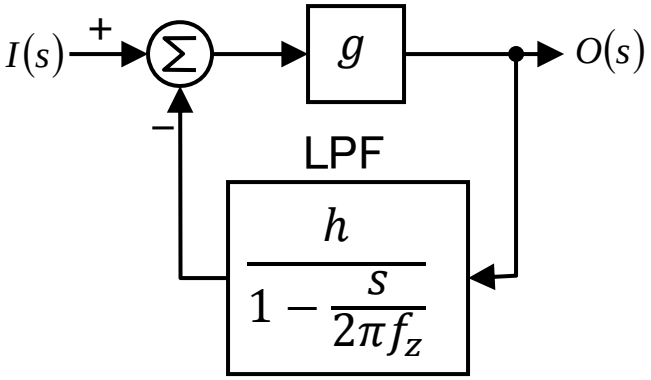
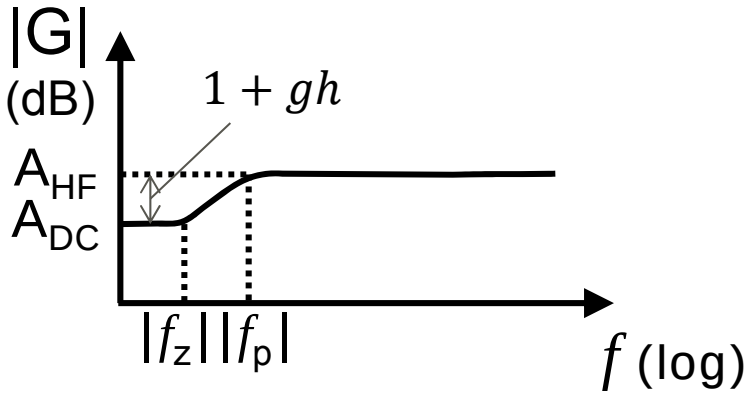
- CTLE with a pair of pole and zero both in low frequency
  - Amplify low-frequency by a small amount (compared to DC)

- Example





$$G(s) = A_{DC}\frac{1-\frac{s}{2\pi f_z}}{1-\frac{s}{2\pi f_p}}$$

$$f_p = (1+gh)f_z$$

$$A_{HF} = g$$

$$A_{DC} = \frac{g}{1+gh}$$

$$\frac{A_{HF}}{A_{DC}} = 1+gh$$

Effect of LF-CTLE (Frequency Domain)

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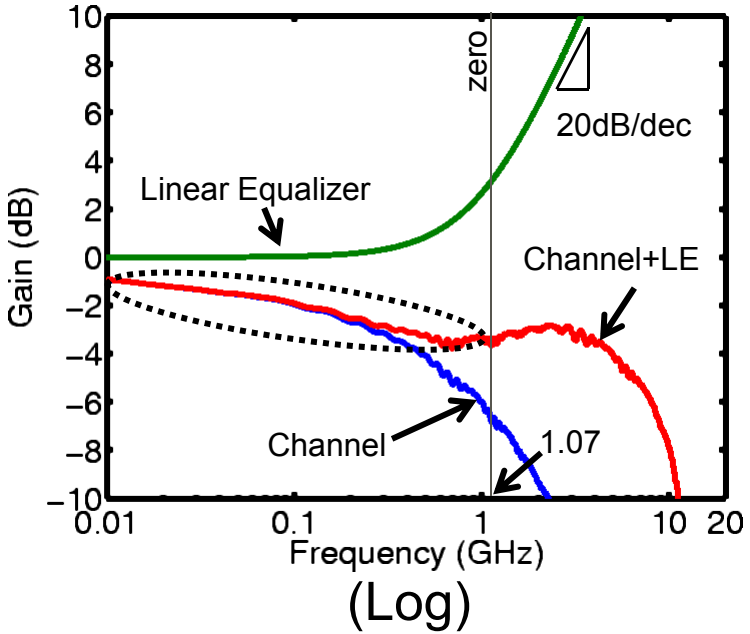
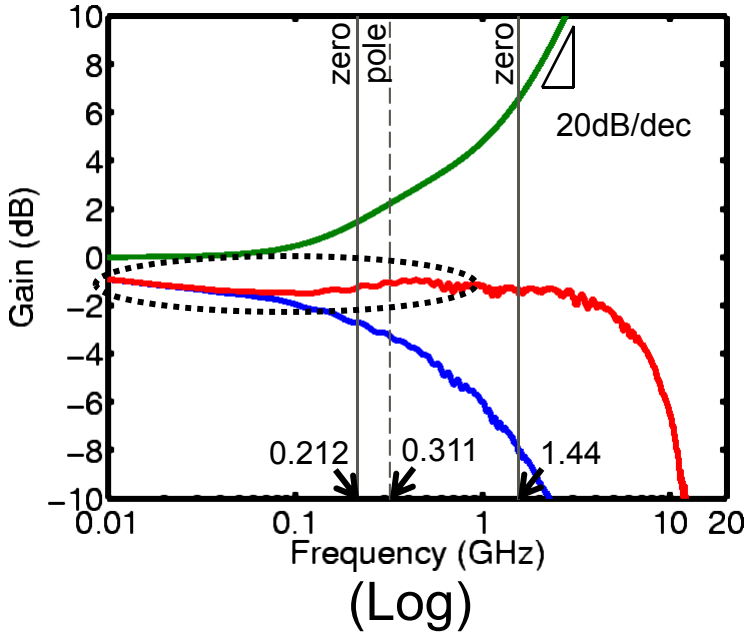
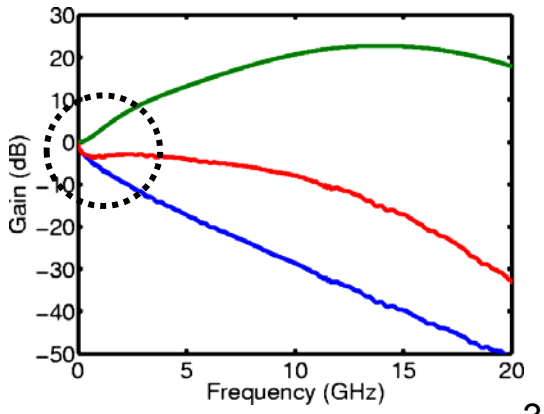
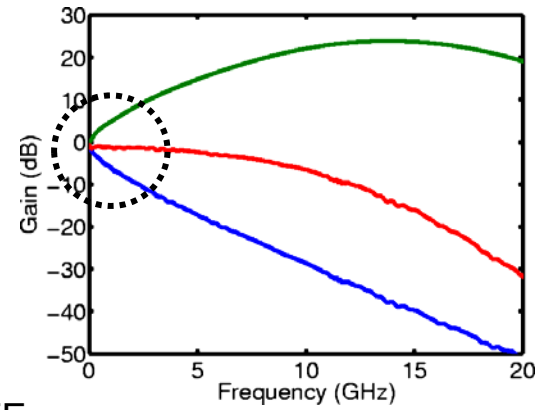
Without LF-CTLE



With LF-CTLE







32Gbps, 4-tap FFE, 1-tap DFE,
1st-order HF-CTLE

Effect of LF-CTLE (Time Domain)

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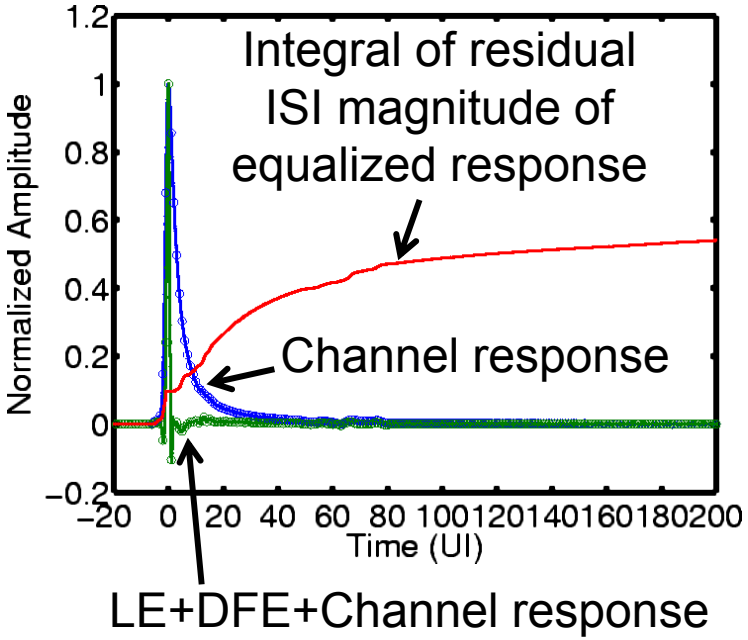
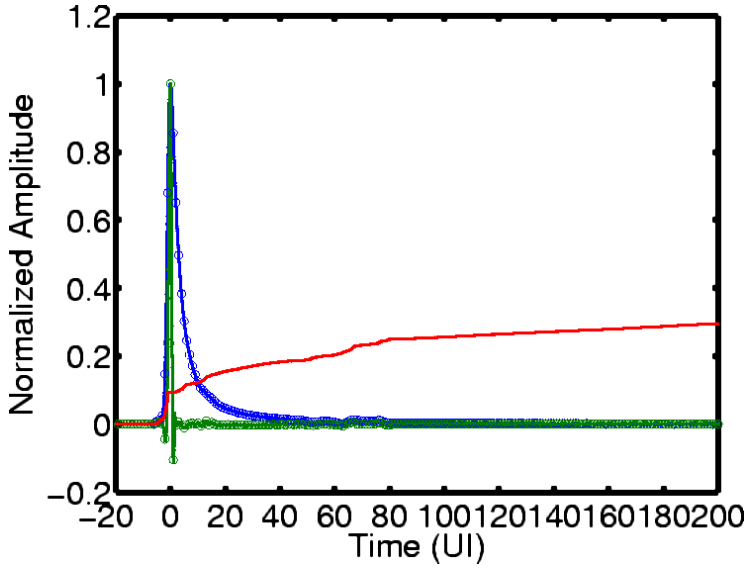
Without LF-CTLE



With LF-CTLE



32Gbps, 4-tap FFE, 1-tap DFE,
1st-order HF-CTLE

Effect of LF-CTLE (Eye Diagram)

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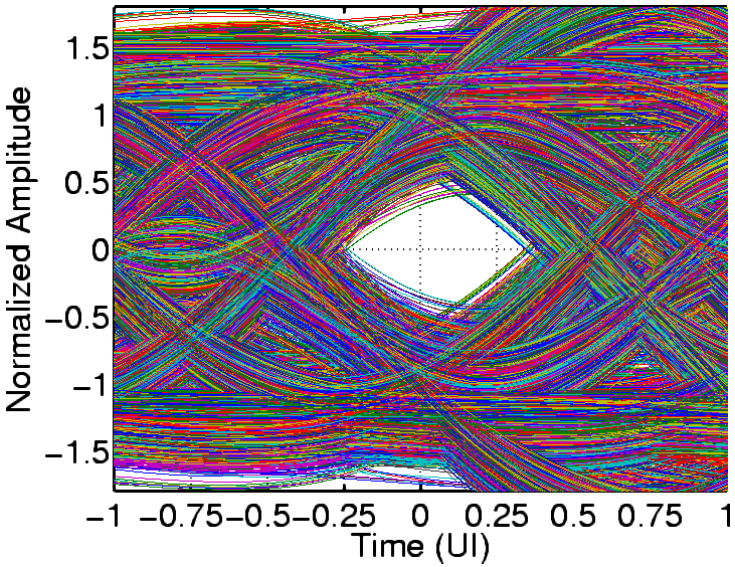
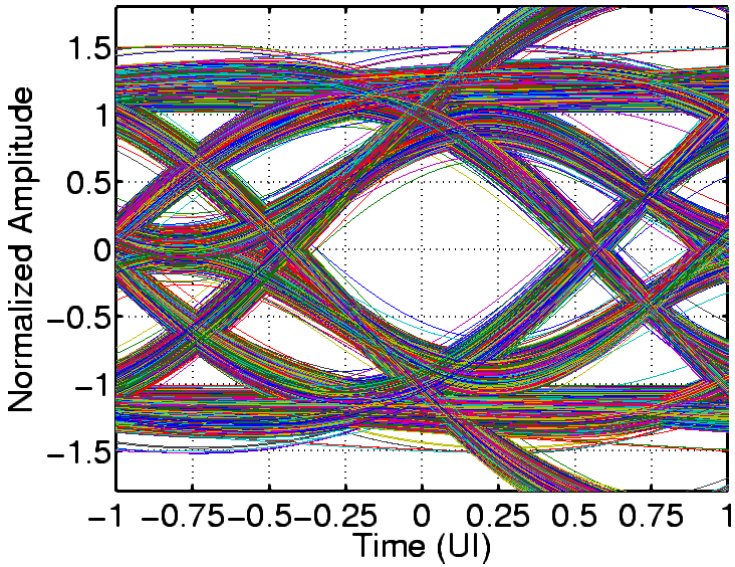
Without LF-CTLE



DDJ=0.42UI

With LF-CTLE



DDJ=0.21UI

Simulated with PRBS31 test pattern
No additional jitter injected

Effect of LF-CTLE (Measured BER)

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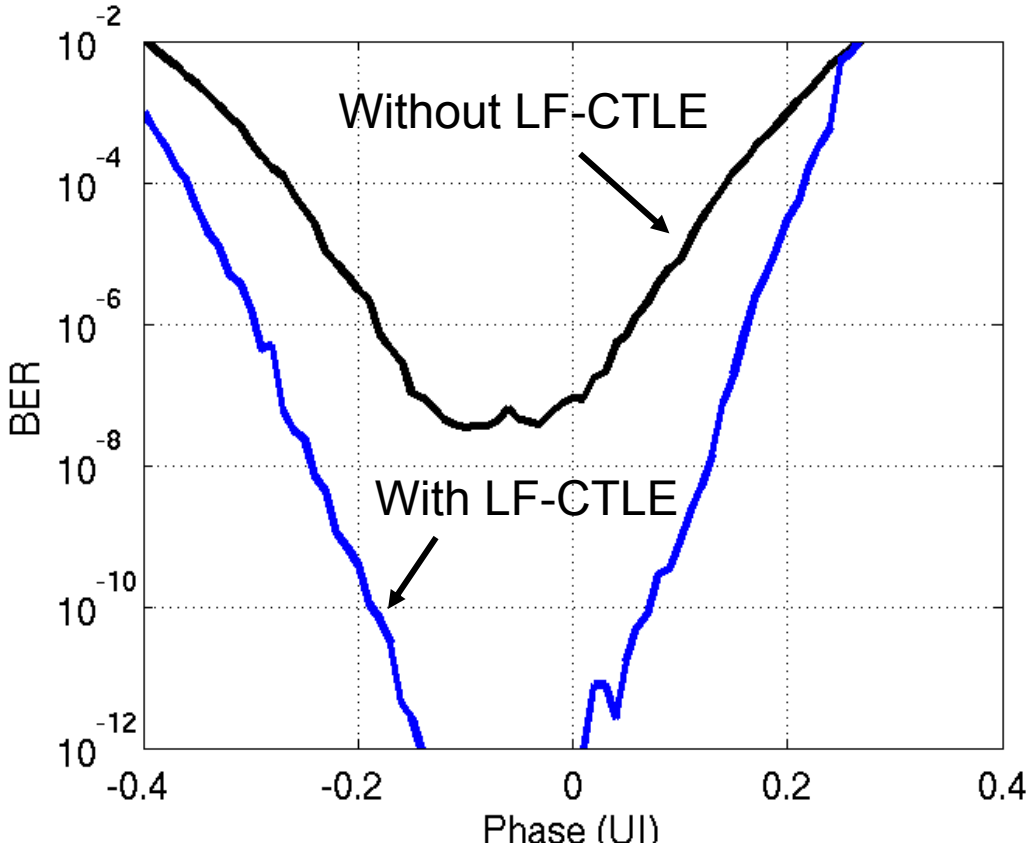
32Gb/s PRBS31 Bathtub Curve



Measured with
- 3-tap FFE
- 1st-order HF-CTLE
- 2-tap speculative DFE

Channel Loss at fb/2 ~ 40dB incl. PKG

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 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 cable size: 2 x 24AWG,1 x 25AWG, 4 x 26AWG, 1 x 28AWG, 3 x 30AWG
    - 2 levels of connector types: 6 x QSFP-QSFP, 5 x QSFP-4xSFP breakout cable
  - 5 cases for 5 meter cable
    - 2 levels of cable size: 2 x 24AWG, 3 x 26AWG
    - 2 levels of connector types: 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. Reported separately in hidaka_3by_02_0915.pdf.
- 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

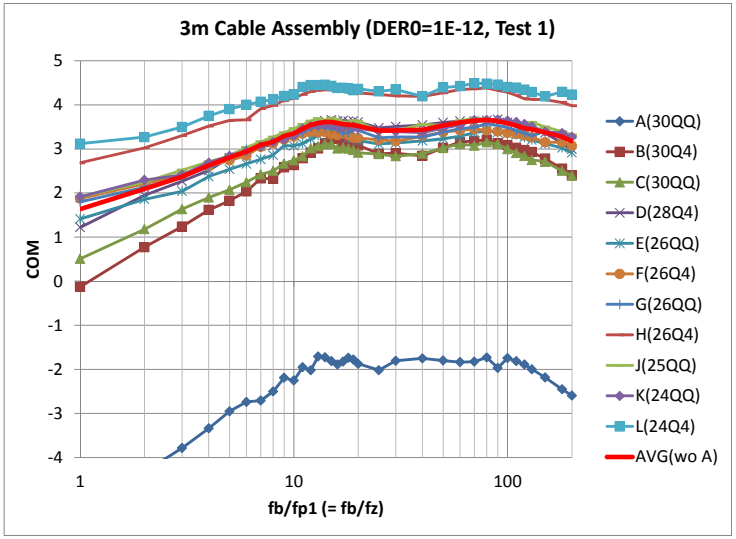
current →

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, 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

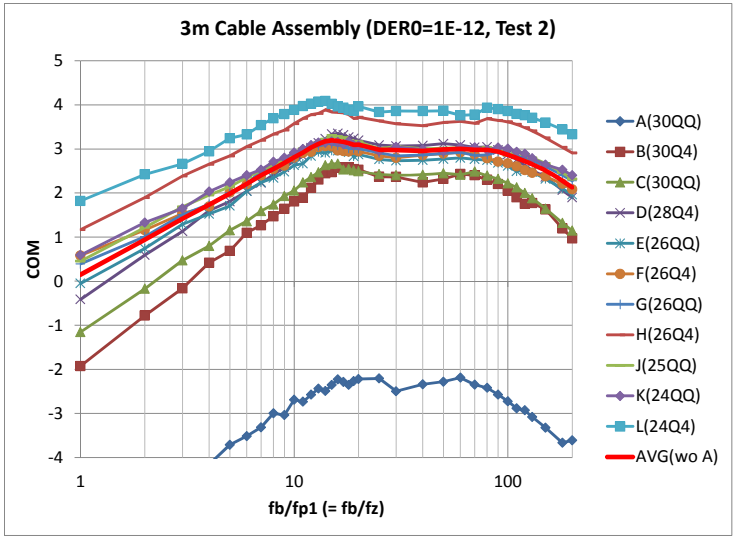
current →

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

FUJITSU

COM value

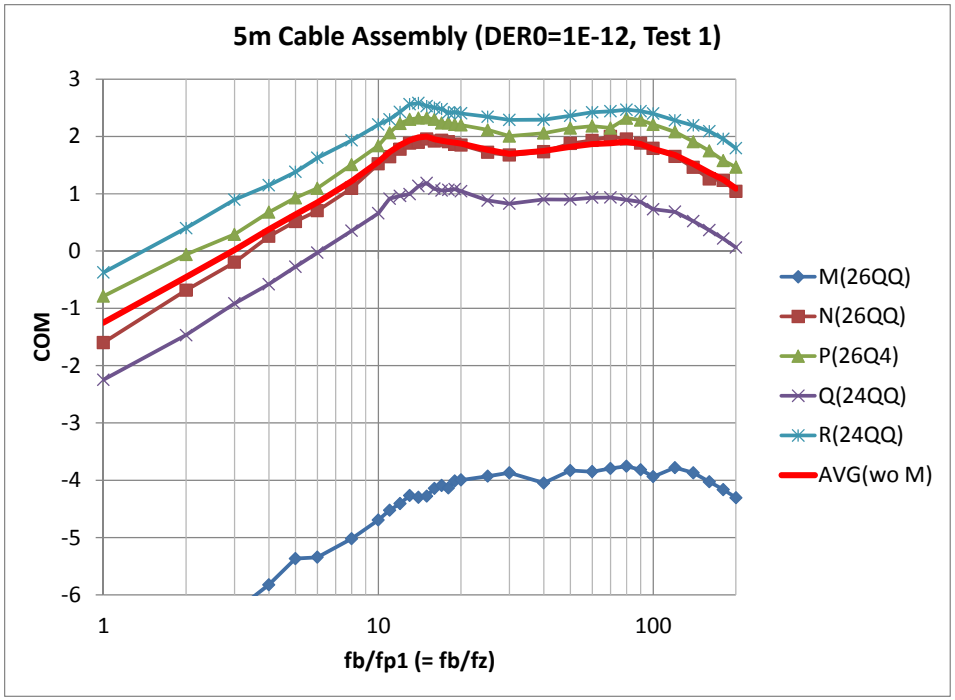
current →

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

FUJITSU

COM value

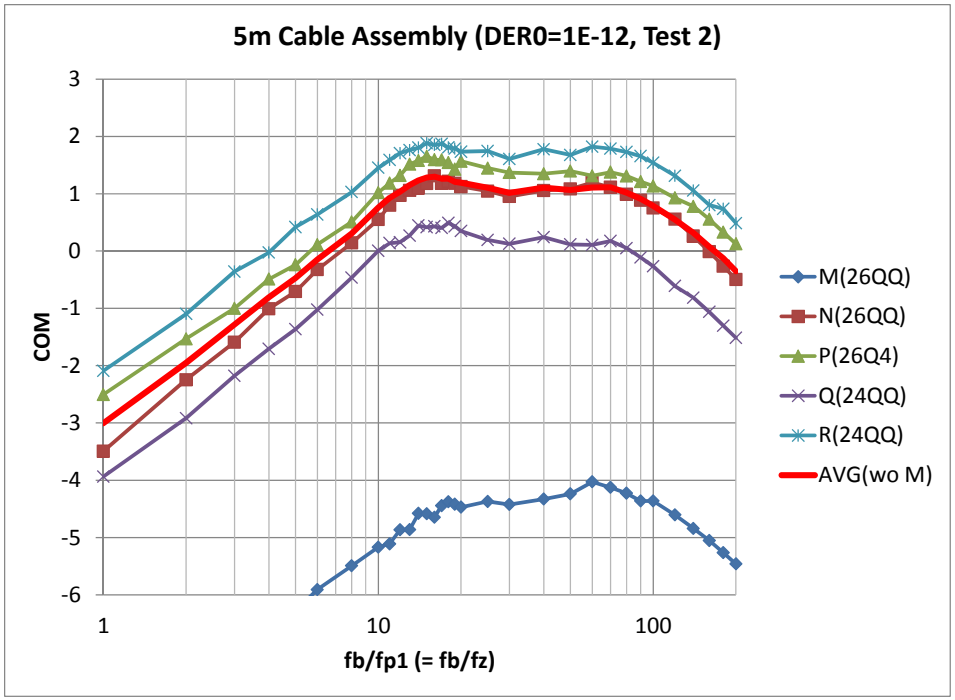
current →

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 statistical 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)
      - In additional study for 5m cable, SNR_{TX} = 31 (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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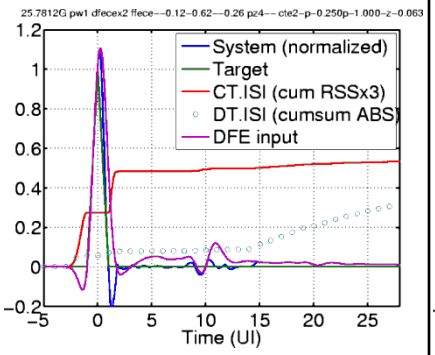
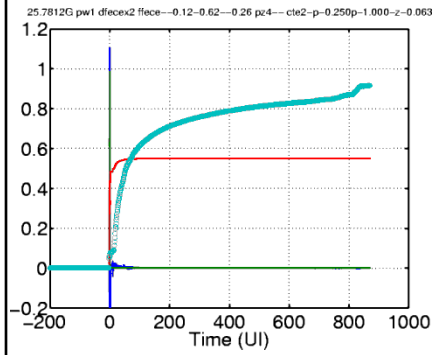
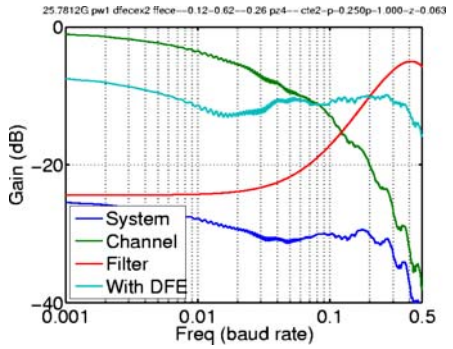
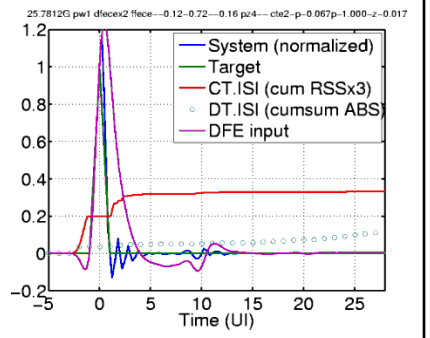
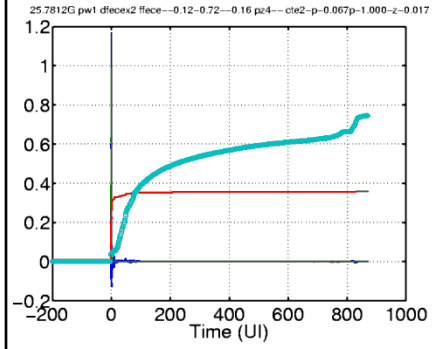
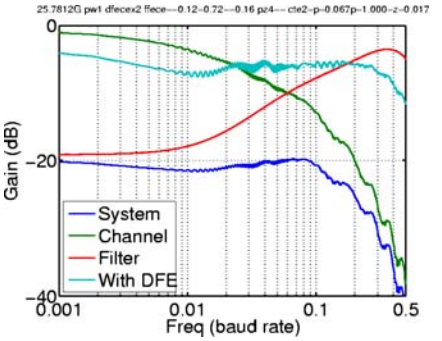
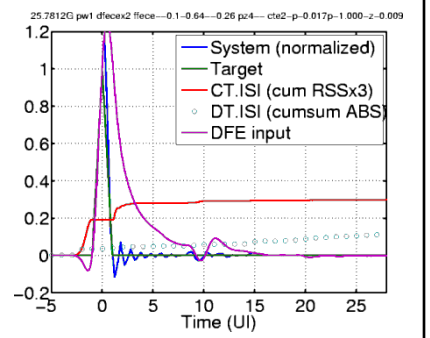
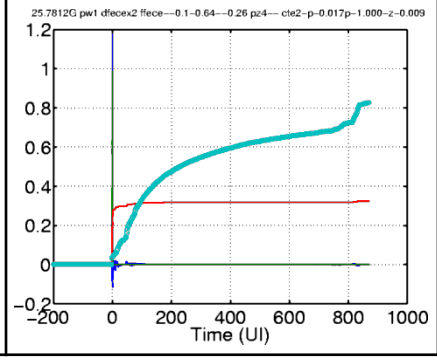
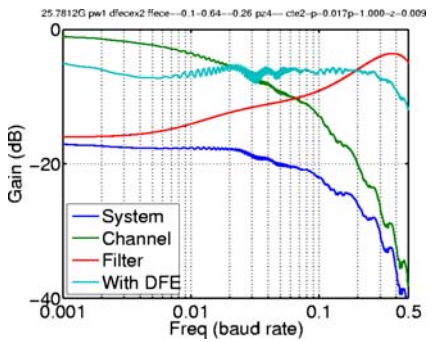
fp1	Statistical Eye	Short Term Resp.	Long Term Resp.	Frequency Resp.
fb/4	COM(1E-12) = 0.42			
fb/15	COM(1E-12) = 2.47			
fb/60	COM(1E-12) = 2.43			

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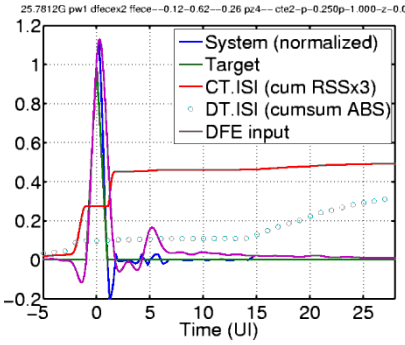
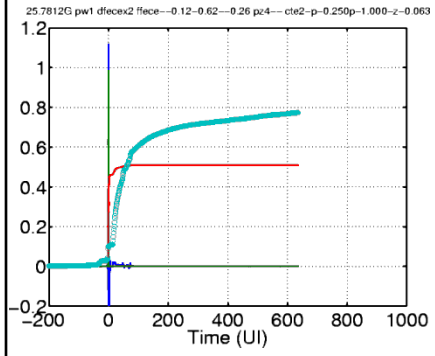
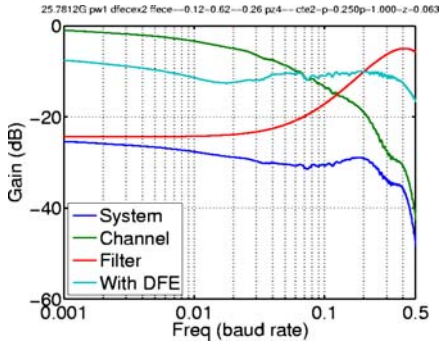
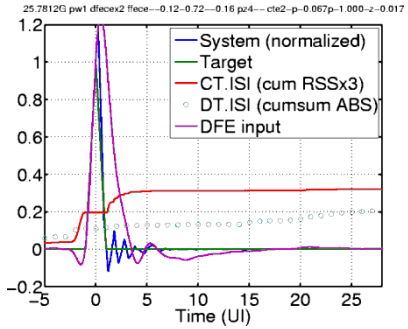
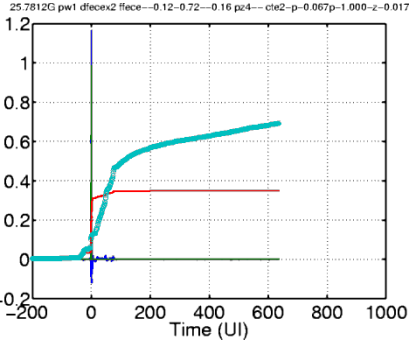
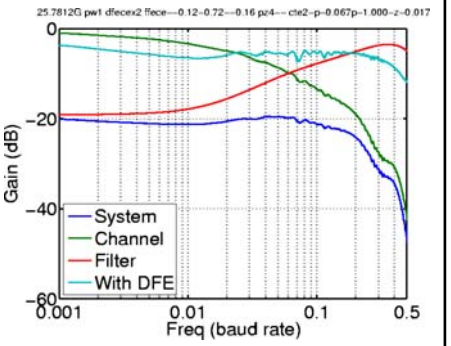
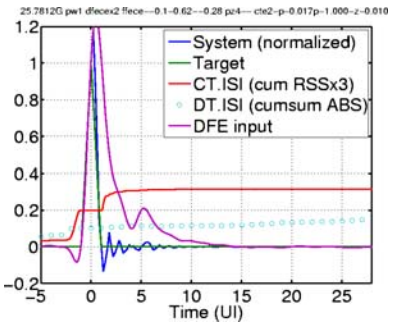
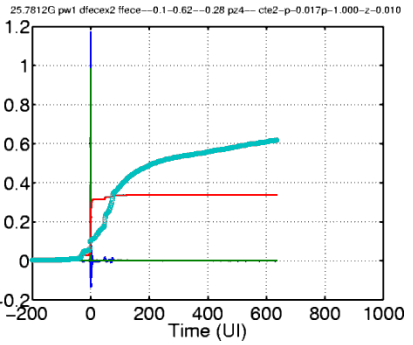
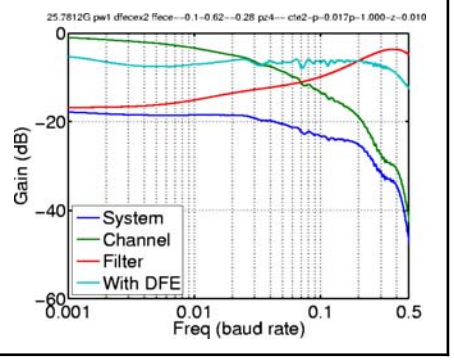
fp1	Statistical Eye	Short Term Resp.	Long Term Resp.	Frequency Resp.
fb/4	COM(1E-12) = 0.26			
fb/15	COM(1E-12) = 1.95			
fb/60	COM(1E-12) = 1.93			

Effect on P802.3bj Rx

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- If COM fp1 is changed to low frequency, channels are allowed to have more skin effect
  - Dielectric loss may have to be reduced
- Although P802.3bj does not require LF-CTLE, P802.3bj Rx may have already implemented LF-CTLE (or equivalent e.g. long-tail EQ)
  - Foreseeing vendors may have silently implemented it
    - It was implementer's choice
- We can earn actual margin, if Rx has LF-CTLE (or equivalent)
  - The increased skin effect is easily cancelled by LF-CTLE
  - This is different from most of other COM parameters
    - We loose margin for change of most of other COM parameters (e.g. SNR_{TX}, C_d, C_p)
- We loose margin, only if Rx does not have LF-CTLE (or equivalent)
  - The increased skin effect is not well cancelled w/o LF-CTLE

Summary

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- If we want to re-use P802.3bj components for no-FEC 3m cable support
  - Anyway, we have to cut margin somewhere
    - Reduction of host board trace is not enough to support 3m cable w/o FEC

- If we do not want to lose margin in some way
  - The only choice is to change fp1 to low frequency
    - P802.3bj Rx may have LF-CTLE (or equivalent such as long-tail equalizer)
      - It was implementer's choice
    - We can earn actual margin, if Rx has LF-CTLE or equivalent
      - We will loose margin, only if Rx does not have LF-CTLE or equivalent

Change of Text (Revised Comment #174)

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- Add the following parameters to Table 110-10
  - Continuous time filter, zero frequency

	CA-N	CA-S	CA-L	
• fz	fb / 15	fb/4	fb/4	GHz

  - Continuous time filter, pole frequencies

	CA-N	CA-S	CA-L	
• fp1	fb / 15	fb/4	fb/4	GHz
• fp2	fb	fb	fb	

- Add the following parameters to Table 110-7
  - Continuous time filter, zero frequency

• fz	fb / 15	GHz

  - Continuous time filter, pole frequencies

• fp1	fb / 15	GHz
• fp2	fb	

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.

[4] T. Nakao, et al., “An Equalizer-Adaptation Logic for a 32Gb/s Wireline Receiver in 28nm CMOS,” ASSCC Dig. Tech. Papers, Nov. 2013.

[5] Y. Hidaka, “Low-Frequency Equalizer for High-Speed I/O,” The 11th International System-on-Chip (SoC) Conference, Irvine, CA, Oct. 2013.

References of Channel Data

FUJITSU

- ~ = 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