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The high-frequency pole of the reference CTLE in Annex 120E (comment #r03-12)

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IEEE P802.3bs 200GbE and 400GbE Task Force
Electrical Ad Hoc, August 28, 2017

Overview

- A problem to realize stressed input test signal for 120E (C2M) was reported recently
- The high-frequency pole of the reference CTLE of 120E (C2M) is much lower than that of 120D (C2C)
- Aligning the high-frequency pole of 120E to that of 120D may resolve the problem

Unable to make Stressed Input Test Signal

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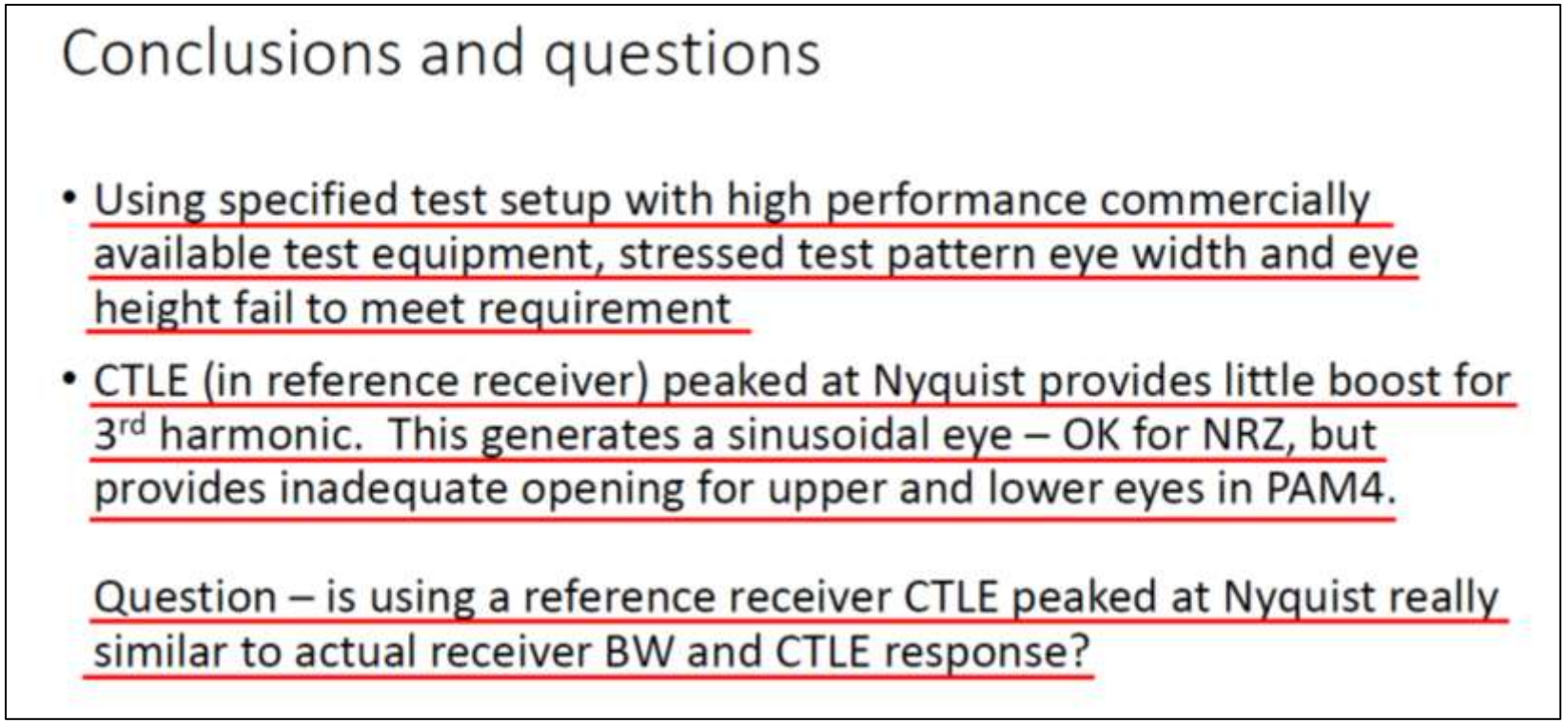
- Reported by Steve Sekel (Keysight) and discussed at June 28 Electrical Ad Hoc, joint with P802.3cd Task Force

  sekel_062817_3cd_adhoc.pdf, slide 11



Conclusions and questions

- Using specified test setup with high performance commercially available test equipment, stressed test pattern eye width and eye height fail to meet requirement
- CTLE (in reference receiver) peaked at Nyquist provides little boost for 3rd harmonic. This generates a sinusoidal eye – OK for NRZ, but provides inadequate opening for upper and lower eyes in PAM4.

Question – is using a reference receiver CTLE peaked at Nyquist really similar to actual receiver BW and CTLE response?

- This may be a serious problem as a standard, because nobody can generate a test signal to test Rx device

Reference CTLE in Annex 120E (C2M)

$$H(f) = \frac{GP_1P_2P_{LF}}{Z_1Z_{LF}} \times \frac{j2\pi f + Z_1}{(j2\pi f + P_1)(j2\pi f + P_2)} \times \frac{j2\pi f + Z_{LF}}{j2\pi f + P_{LF}}$$

Table 120E–2—Reference CTLE coefficients

Peaking (dB)	G	$\frac{P_1}{2\pi}$	$\frac{P_2}{2\pi}$	$\frac{Z_1}{2\pi}$	$\frac{P_{LF}}{2\pi}$	$\frac{Z_{LF}}{2\pi}$
1	0.89125	18.6	14.1	8.359	1.2	1.2
1.5	0.8414	18.6	14.1	8.159	1.2	1.15
2	0.79433	18.6	14.1	7.995	1.2	1.1
2.5	0.74989	18.6	14.1	7.604	1.2	1.075
3	0.70795	15.6	14.1	6.713	1.2	1.05
3.5	0.66834	15.6	14.1	6.421	1.2	1.025
4	0.63096	15.6	14.1	6.155	1.2	1
4.5	0.59566	15.6	14.1	5.733	1.2	1
5	0.56234	15.6	14.1	5.353	1.2	1
5.5	0.53088	15.6	14.1	5.007	1.2	1
6	0.50119	15.6	14.1	4.691	1.2	1
6.5	0.47315	15.6	14.1	4.399	1.2	1
7	0.44668	15.6	14.1	4.13	1.2	1
7.5	0.4217	15.6	14.1	3.88	1.2	1
8	0.39811	15.6	14.1	3.647	1.2	1
8.5	0.37584	15.6	14.1	3.43	1.2	1
9	0.35481	15.6	14.1	3.228	1.2	1

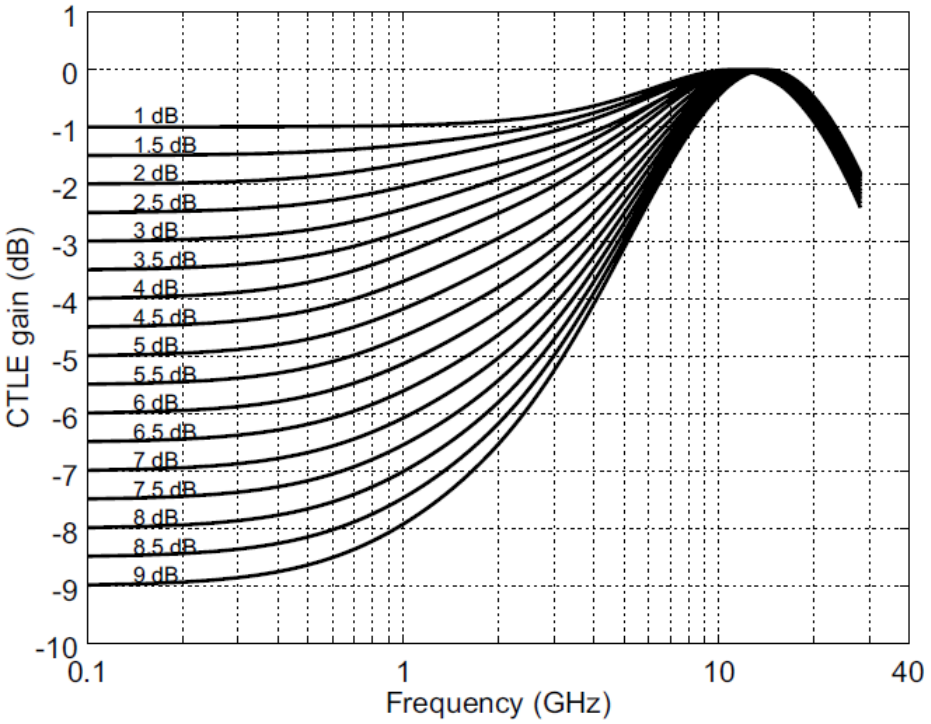


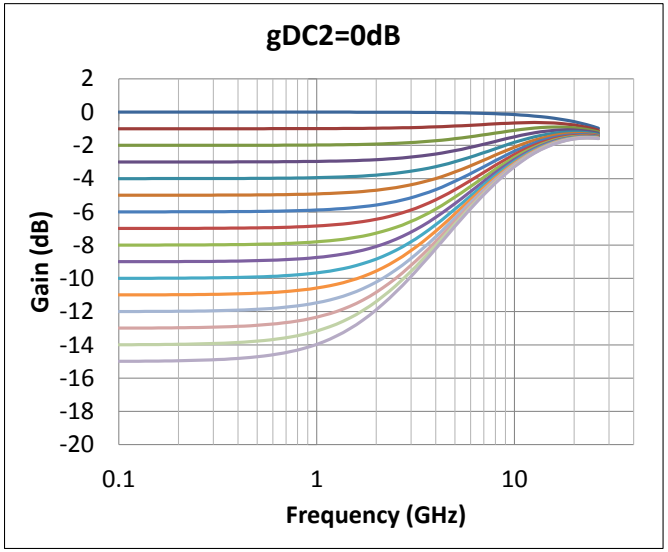
Figure 120E–9—Reference continuous time linear equalizer (CTLE) characteristic

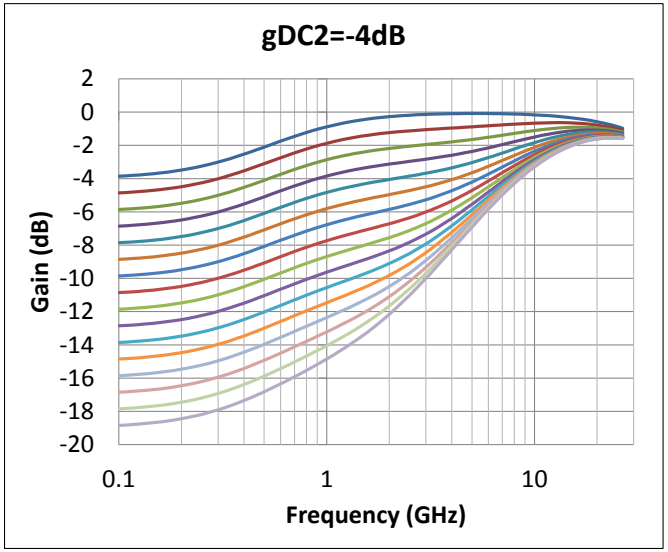
- High pole (P_1) is 15.6GHz (= $0.587f_b$) or 18.6GHz (= $0.7f_b$)
  - Medium pole (P_2) is 14.1GHz (= $0.531f_b$)

Reference CTLE in Annex 120D (C2C)

$$H_{ctf}(f) = \frac{\left(10^{\frac{g_{DC}}{20}} + j\frac{f}{f_z}\right)\left(10^{\frac{g_{DC2}}{20}} + j\frac{f}{f_{LF}}\right)}{\left(1 + j\frac{f}{f_{p1}}\right)\left(1 + j\frac{f}{f_{p2}}\right)\left(1 + j\frac{f}{f_{LF}}\right)}$$

f_b	26.5625	GBd
f_z	$0.4 \times f_b$	GHz
f_{p1}	$0.4 \times f_b$	GHz
f_{p2}	$2 \times f_b$	GHz
f_{LF}	$f_b/40$	GHz





- High pole (f_{p2}) is $2f_b$ (= 53.125GHz), much higher than 120E
  - Medium pole (f_{p1}) is $0.4f_b$ (= 10.625GHz), a little lower than 120E

Change History of Reference CTLE

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	Chip-to-module (Annex 83E, 120E)		Chip-to-chip (Annex 83D, 120D)	
	Architecture	High-freq pole (P_1)	Architecture	High-freq pole (f_{p2})
CAUI-4	2 poles, 1 zero	15.6 or 18.6GHz	2 poles, 1 zero	$1f_b$ (=25.78125GHz)
bs D1.0	2 poles, 1 zero	15.6 or 18.6GHz	2 poles, 1 zero	$1f_b$ (=26.5625GHz)
bs D1.1	2 poles, 1 zero	15.6 or 18.6GHz	2 poles, 2 zeroes	None
bs D1.2	3 poles, 2 zeroes	15.6 or 18.6GHz	2 poles, 2 zeroes	None
bs D1.3	3 poles, 2 zeroes	15.6 or 18.6GHz	2 poles, 2 zeroes	None
:	:	:	:	:
bs D3.0	3 poles, 2 zeroes	15.6 or 18.6GHz	2 poles, 2 zeroes	None
bs D3.1	3 poles, 2 zeroes	15.6 or 18.6GHz	3 poles, 2 zeroes	$2f_b$ (=53.125GHz)
bs D3.2	3 poles, 2 zeroes	15.6 or 18.6GHz	3 poles, 2 zeroes	$2f_b$ (=53.125GHz)
bs D3.3	3 poles, 2 zeroes	15.6 or 18.6GHz	3 poles, 2 zeroes	$2f_b$ (=53.125GHz)

- Reference spec in OIF
  - CEI-56G-VSR-PAM4 : High-frequency pole (P_1) is 15.6 or 18.6GHz
  - CEI-56G-MR-PAM4 : High-frequency pole (f_{p2}) is $1f_b$

4 Options Investigated

- Option 1
  - Increase $P_1/2\pi$ to $2 * fb$ (= f_{p2} of Annex 120D)
- Option 2
  - Increase $P_1/2\pi$ to $2 * fb$ (= f_{p2} of Annex 120D)
  - Reduce $P_2/2\pi$ to $0.4 * fb$ (= f_{p1} of Annex 120D)
- Option 3
  - Increase $P_1/2\pi$ to $1 * fb$ (= f_{p2} of CEI-56G-MR-PAM4)
- Option 4
  - Increase $P_1/2\pi$ to $1 * fb$ (= f_{p2} of CEI-56G-MR-PAM4)
  - Reduce $P_2/2\pi$ to $0.4 * fb$ (= f_{p1} of CEI-56G-MR-PAM4)

- Z_1 is also adjusted to force the peak gain always at 0dB
  - Formula of the exact Z_1 values for this is shown in a backup slide

Baseline: P802.3bs D3.3 Annex 120E

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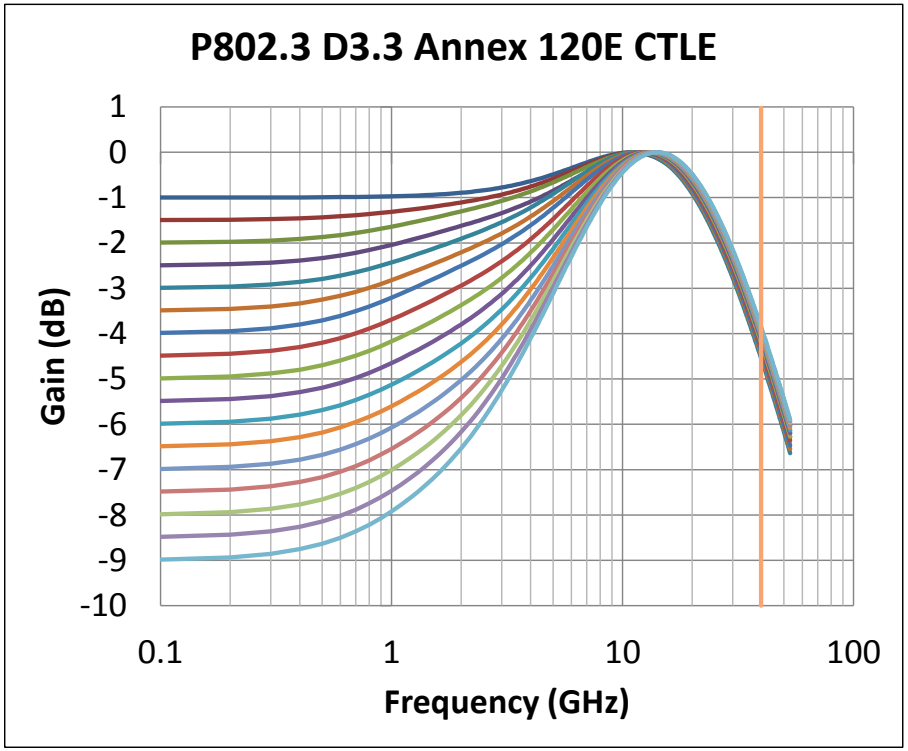
- Current draft
- Gain at $1.5 \times f_b = 39.8GHz$ is -4.3dB ~ -3.9dB

Table 120E-2

Peaking	G	P1/2pi	P2/2pi	Z1/2pi	PLF/2pi	ZLF/2pi
1.0	0.89125	18.6	14.1	8.359	1.2	1.2
1.5	0.8414	18.6	14.1	8.159	1.2	1.15
2.0	0.79433	18.6	14.1	7.995	1.2	1.1
2.5	0.74989	18.6	14.1	7.604	1.2	1.075
3.0	0.70795	15.6	14.1	6.713	1.2	1.05
3.5	0.66834	15.6	14.1	6.421	1.2	1.025
4.0	0.63096	15.6	14.1	6.155	1.2	1
4.5	0.59566	15.6	14.1	5.733	1.2	1
5.0	0.56234	15.6	14.1	5.353	1.2	1
5.5	0.53088	15.6	14.1	5.007	1.2	1
6.0	0.50119	15.6	14.1	4.691	1.2	1
6.5	0.47315	15.6	14.1	4.399	1.2	1
7.0	0.44668	15.6	14.1	4.13	1.2	1
7.5	0.4217	15.6	14.1	3.88	1.2	1
8.0	0.39811	15.6	14.1	3.647	1.2	1
8.5	0.37584	15.6	14.1	3.43	1.2	1
9.0	0.35481	15.6	14.1	3.228	1.2	1

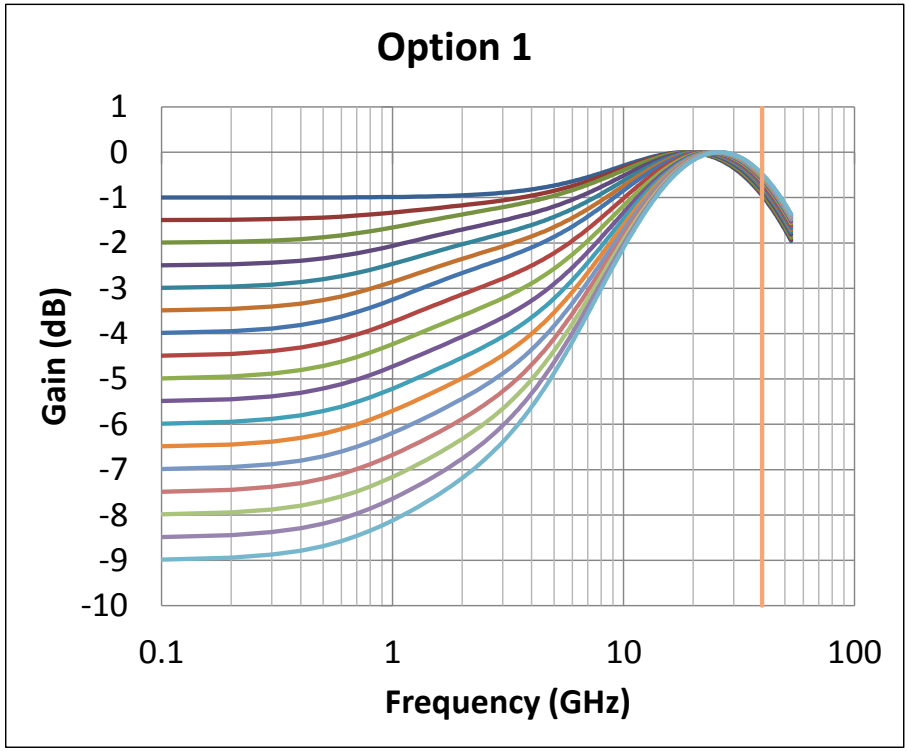
Figure 120E-9 plotted up to $2f_b$



Option 1

- Increase $P_1/2\pi$ to $2 * fb$ (align to f_{p2} of Annex 120D)
- Gain at $1.5 \times f_b = 39.8GHz$ is -1.0dB ~ -0.5dB

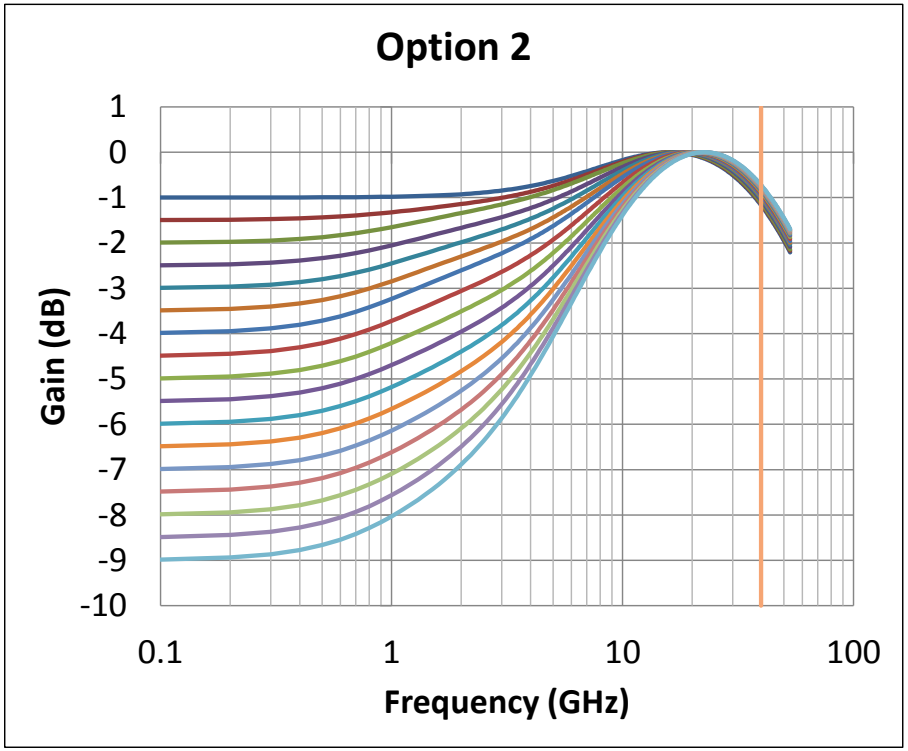
Peaking	G	P1/2pi	P2/2pi	Z1/2pi	PLF/2pi	ZLF/2pi
1.0	0.891251	53.125	14.1	10.974592	1.2	1.200
1.5	0.841395	53.125	14.1	10.756436	1.2	1.150
2.0	0.794328	53.125	14.1	10.573164	1.2	1.100
2.5	0.749894	53.125	14.1	10.117862	1.2	1.075
3.0	0.707946	53.125	14.1	9.702711	1.2	1.050
3.5	0.668344	53.125	14.1	9.320913	1.2	1.025
4.0	0.630957	53.125	14.1	8.967777	1.2	1.000
4.5	0.595662	53.125	14.1	8.393980	1.2	1.000
5.0	0.562341	53.125	14.1	7.868626	1.2	1.000
5.5	0.530884	53.125	14.1	7.384598	1.2	1.000
6.0	0.501187	53.125	14.1	6.936613	1.2	1.000
6.5	0.473151	53.125	14.1	6.520564	1.2	1.000
7.0	0.446684	53.125	14.1	6.133146	1.2	1.000
7.5	0.421697	53.125	14.1	5.771625	1.2	1.000
8.0	0.398107	53.125	14.1	5.433693	1.2	1.000
8.5	0.375837	53.125	14.1	5.117366	1.2	1.000
9.0	0.354813	53.125	14.1	4.820918	1.2	1.000



Option 2

- Increase $P_1/2\pi$ to $2 * fb$ (align to f_{p2} of Annex 120D)
- Reduce $P_2/2\pi$ to $0.4 * fb$ (align to f_{p1} of Annex 120D)
- Gain at $1.5 \times f_b = 39.8GHz$ is -1.2dB ~ -0.7dB

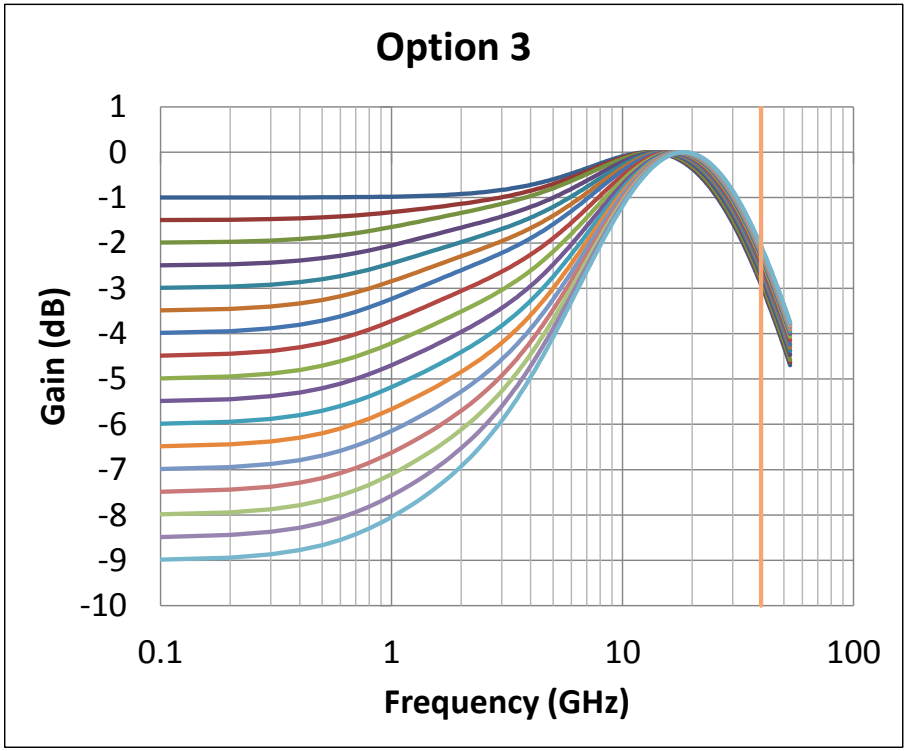
Peaking	G	P1/2pi	P2/2pi	Z1/2pi	PLF/2pi	ZLF/2pi
1.0	0.891251	53.125	10.625	8.568390	1.2	1.200
1.5	0.841395	53.125	10.625	8.406177	1.2	1.150
2.0	0.794328	53.125	10.625	8.269308	1.2	1.100
2.5	0.749894	53.125	10.625	7.927185	1.2	1.075
3.0	0.707946	53.125	10.625	7.612939	1.2	1.050
3.5	0.668344	53.125	10.625	7.322268	1.2	1.025
4.0	0.630957	53.125	10.625	7.052157	1.2	1.000
4.5	0.595662	53.125	10.625	6.610998	1.2	1.000
5.0	0.562341	53.125	10.625	6.204939	1.2	1.000
5.5	0.530884	53.125	10.625	5.829252	1.2	1.000
6.0	0.501187	53.125	10.625	5.480360	1.2	1.000
6.5	0.473151	53.125	10.625	5.155436	1.2	1.000
7.0	0.446684	53.125	10.625	4.852166	1.2	1.000
7.5	0.421697	53.125	10.625	4.568615	1.2	1.000
8.0	0.398107	53.125	10.625	4.303123	1.2	1.000
8.5	0.375837	53.125	10.625	4.054251	1.2	1.000
9.0	0.354813	53.125	10.625	3.820734	1.2	1.000



Option 3

- Increase $P_1/2\pi$ to $1 * fb$ (align to f_{p2} of CEI-56G-MR-PAM4)
- Gain at $1.5 \times f_b = 39.8GHz$ is -2.9dB ~ -2.1dB

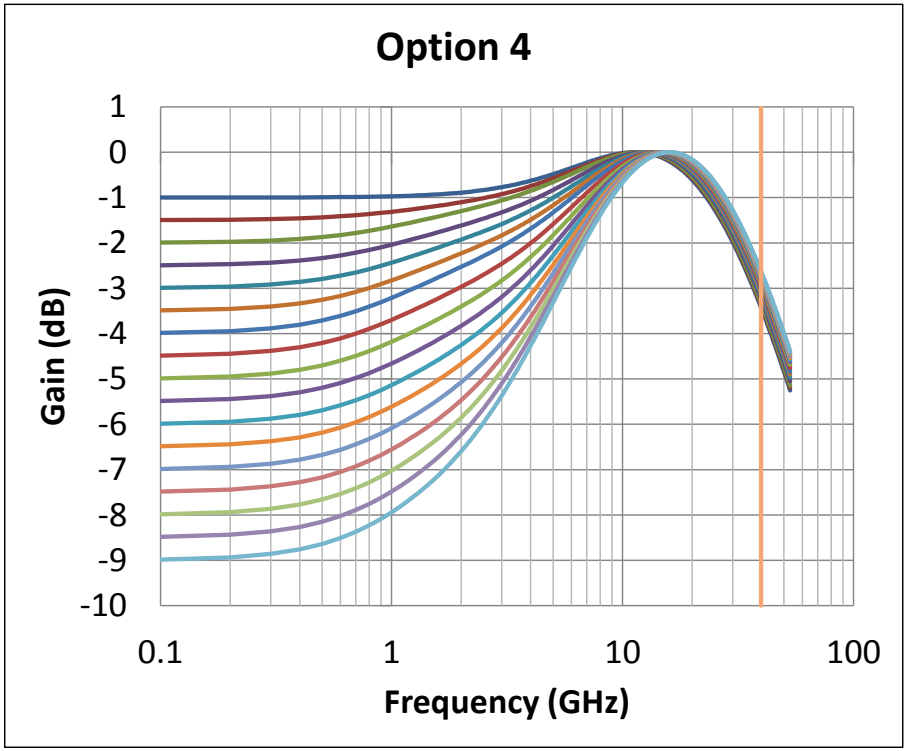
Peaking	G	P1/2pi	P2/2pi	Z1/2pi	PLF/2pi	ZLF/2pi
1.0	0.891251	26.5625	14.1	9.463748	1.2	1.200
1.5	0.841395	26.5625	14.1	9.252896	1.2	1.150
2.0	0.794328	26.5625	14.1	9.077589	1.2	1.100
2.5	0.749894	26.5625	14.1	8.648416	1.2	1.075
3.0	0.707946	26.5625	14.1	8.263874	1.2	1.050
3.5	0.668344	26.5625	14.1	7.915060	1.2	1.025
4.0	0.630957	26.5625	14.1	7.596006	1.2	1.000
4.5	0.595662	26.5625	14.1	7.083885	1.2	1.000
5.0	0.562341	26.5625	14.1	6.620838	1.2	1.000
5.5	0.530884	26.5625	14.1	6.198404	1.2	1.000
6.0	0.501187	26.5625	14.1	5.810522	1.2	1.000
6.5	0.473151	26.5625	14.1	5.452633	1.2	1.000
7.0	0.446684	26.5625	14.1	5.121171	1.2	1.000
7.5	0.421697	26.5625	14.1	4.813269	1.2	1.000
8.0	0.398107	26.5625	14.1	4.526563	1.2	1.000
8.5	0.375837	26.5625	14.1	4.259067	1.2	1.000
9.0	0.354813	26.5625	14.1	4.009088	1.2	1.000



Option 4

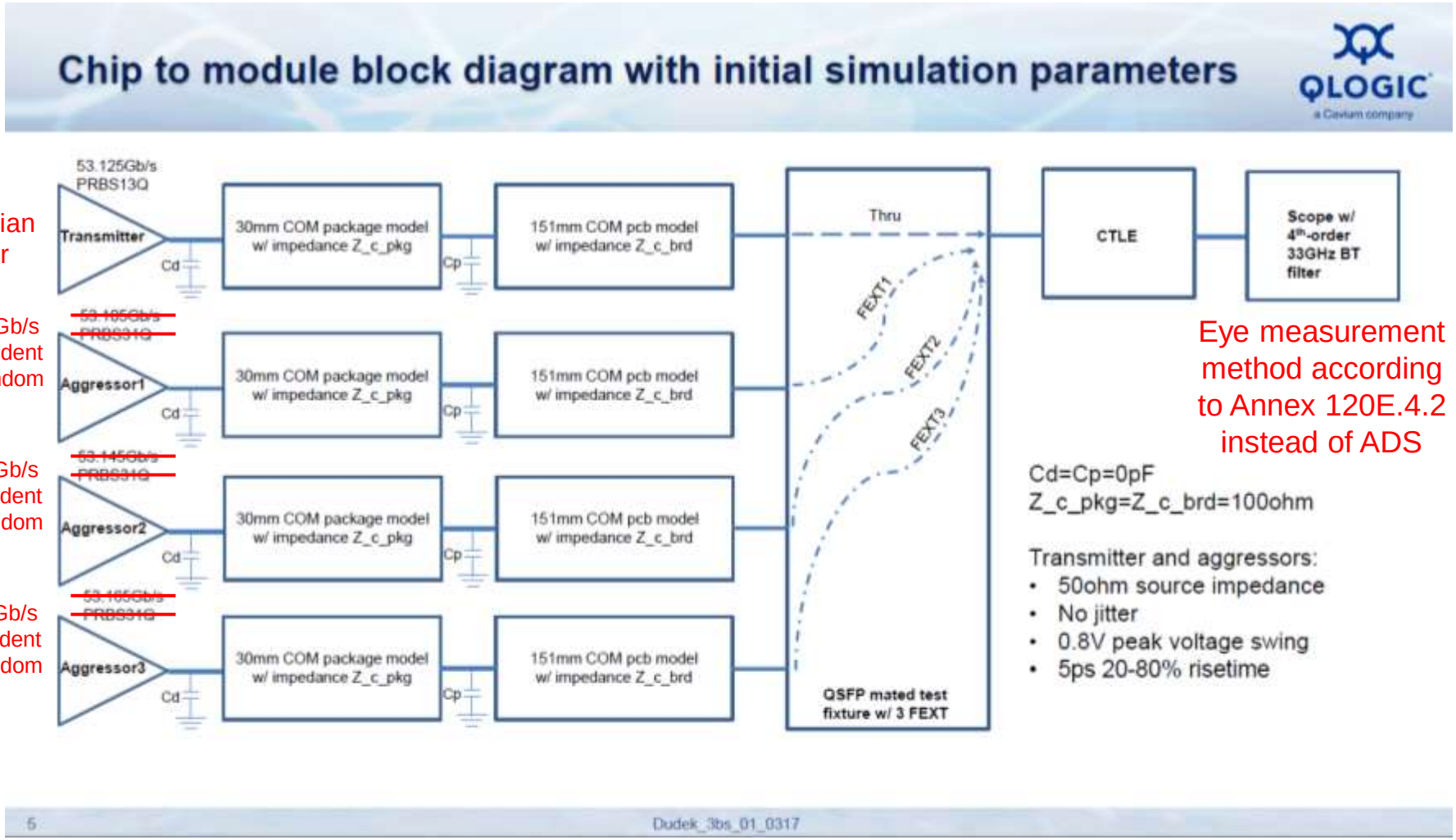
- Increase $P_1/2\pi$ to $1 * fb$ (align to f_{p2} of CEI-56G-MR-PAM4)
- Reduce $P_2/2\pi$ to $0.4 * fb$ (align to f_{p1} of CEI-56G-MR-PAM4)
- Gain at $1.5 \times f_b = 39.8GHz$ is -3.3dB ~ -2.5dB

Peaking	G	P1/2pi	P2/2pi	Z1/2pi	PLF/2pi	ZLF/2pi
1.0	0.891251	26.5625	10.625	7.673726	1.2	1.200
1.5	0.841395	26.5625	10.625	7.509911	1.2	1.150
2.0	0.794328	26.5625	10.625	7.373176	1.2	1.100
2.5	0.749894	26.5625	10.625	7.036567	1.2	1.075
3.0	0.707946	26.5625	10.625	6.732960	1.2	1.050
3.5	0.668344	26.5625	10.625	6.456124	1.2	1.025
4.0	0.630957	26.5625	10.625	6.201840	1.2	1.000
4.5	0.595662	26.5625	10.625	5.791795	1.2	1.000
5.0	0.562341	26.5625	10.625	5.419289	1.2	1.000
5.5	0.530884	26.5625	10.625	5.078193	1.2	1.000
6.0	0.501187	26.5625	10.625	4.764061	1.2	1.000
6.5	0.473151	26.5625	10.625	4.473509	1.2	1.000
7.0	0.446684	26.5625	10.625	4.203868	1.2	1.000
7.5	0.421697	26.5625	10.625	3.952967	1.2	1.000
8.0	0.398107	26.5625	10.625	3.719002	1.2	1.000
8.5	0.375837	26.5625	10.625	3.500446	1.2	1.000
9.0	0.354813	26.5625	10.625	3.295987	1.2	1.000



MATLAB Simulation Setup

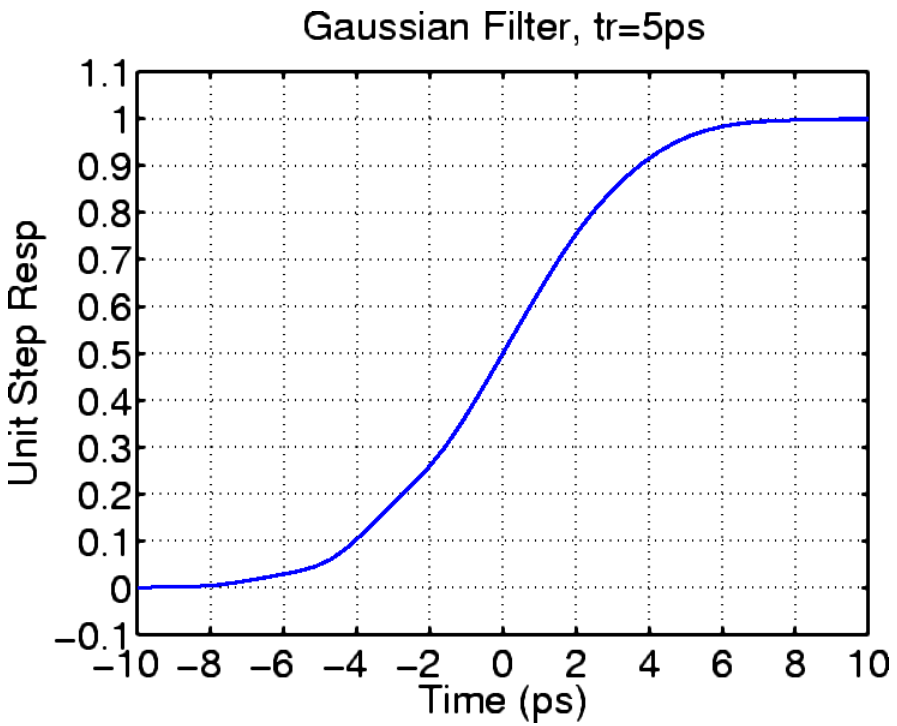
- Similar to dudek_3bs_01_0317.pdf, slide 5



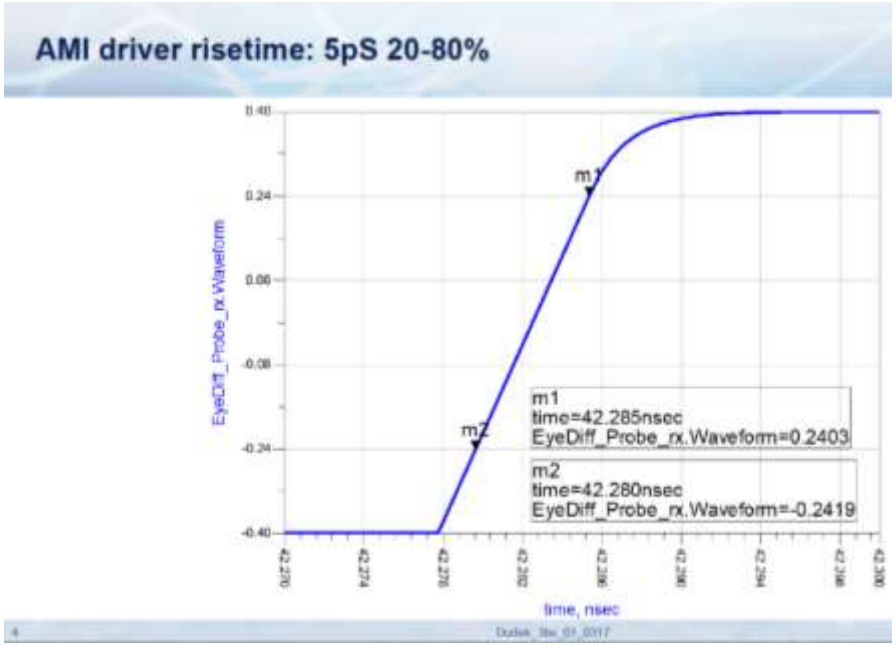
Gaussian Filter to Control 20-80% Risetime

- Same as Transition-Time Filter in P802.3by defined as
  - $H_t(f) = \exp(-\beta(\pi f T_r/1.6832)^2)$ (93A-46)
    - with $\beta = 2, T_r = 5ps$

Unit Step response of Gaussian Filter in this Simulation



dudek_3bs_01_0317.pdf, slide 4



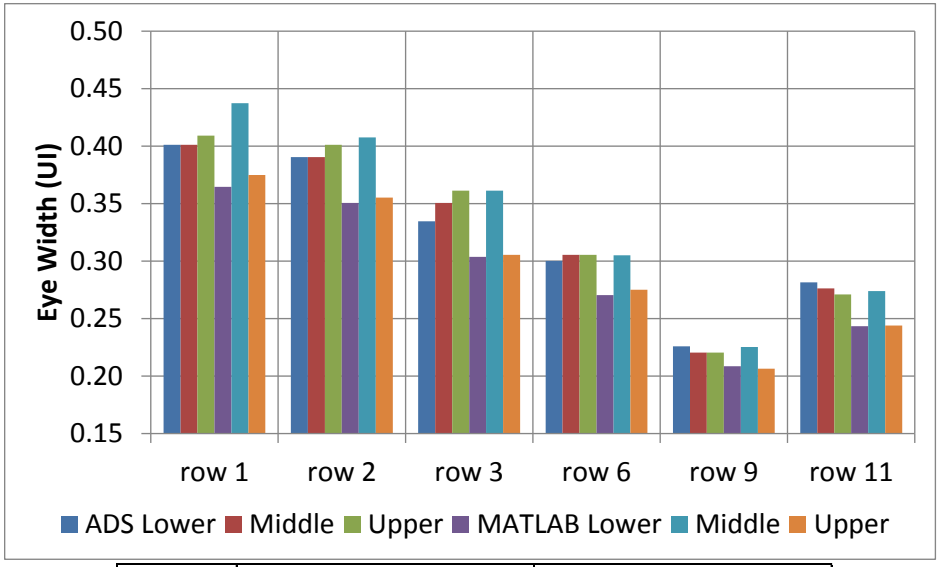
Simulated Conditions

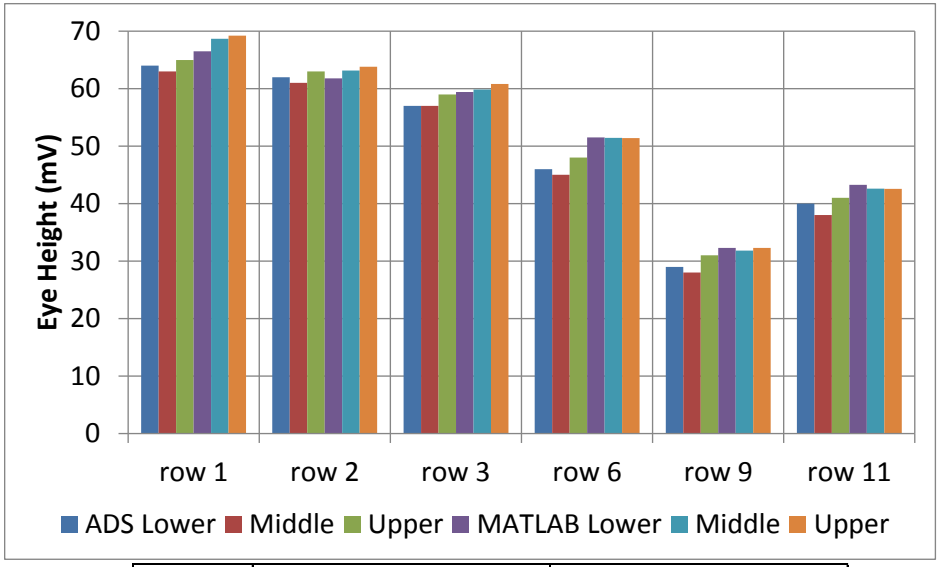
- Row 1-11 are same as dudek_3bs_01_0317.pdf, slide 17
- Row 12-14 are row 11 + more impairments (Tr and DJ)

Row	Av (V)	Rd (ohm)	Cd (pF)	Cp (pF)	Package Zc (ohm)	Board Zc (ohm)	SNR_TX (dB)	RJ (UI-rms)	DJ (UI-pp)	Xtalk	Tr (ps)	Note
1	0.4	50	0	0	100	100	100	0.00	0.00	No	5.0	Ideal Case
2	0.4	50	0	0	100	100	100	0.00	0.00	Yes	5.0	+ Xtalk
3	0.416	50	0	0	100	100	100	0.01	0.02	Yes	5.0	+ Jitter
6	0.442	55	0.18	0.11	90	109.8	100	0.01	0.02	Yes	5.0	+ Reflection
9	0.445	55	0.28	0.11	85	109.8	31	0.01	0.02	Yes	5.0	bs D3.0 A120D
11	0.442	55	0.18	0.11	90	109.8	32.5	0.01	0.02	Yes	5.0	cd D1.2 CL137
12	0.442	55	0.18	0.11	90	109.8	32.5	0.01	0.02	Yes	9.5	Tr = 9.5ps
13	0.442	55	0.18	0.11	90	109.8	32.5	0.01	0.02	Yes	13.5	Tr = 13.5ps
14	0.442	55	0.18	0.11	90	109.8	32.5	0.01	0.04	Yes	13.5	DJ = 0.04UI

Comparison with ADS's results

- Eye measurement method is different
  - ADS: ADS's method (results from dudek_3bs_01_0317.pdf, slide 17)
  - MATLAB: method in 120E.4.2 (new results performed by MATLAB)
    - With the same CTLE and Tx-FIR settings as dudek_3bs_01_0317.pdf, slide 17





width (ps)	ADS			MATLB		
	Lower	Middle	Upper	Lower	Middle	Upper
row 1	15.1	15.1	15.4	13.7	16.5	14.1
row 2	14.7	14.7	15.1	13.2	15.3	13.4
row 3	12.6	13.2	13.6	11.4	13.6	11.5
row 6	11.3	11.5	11.5	10.2	11.5	10.4
row 9	8.5	8.3	8.3	7.8	8.5	7.8
row 11	10.6	10.4	10.2	9.2	10.3	9.2

height (mV)	Dudek			Hidaka		
	Lower	Middle	Upper	Lower	Middle	Upper
row 1	64	63	65	66.5	68.7	69.2
row 2	62	61	63	61.8	63.1	63.8
row 3	57	57	59	59.4	59.8	60.8
row 6	46	45	48	51.5	51.4	51.4
row 9	29	28	31	32.3	31.8	32.3
row 11	40	38	41	43.3	42.6	42.6

Effects on Eye Width at BER=1E-05

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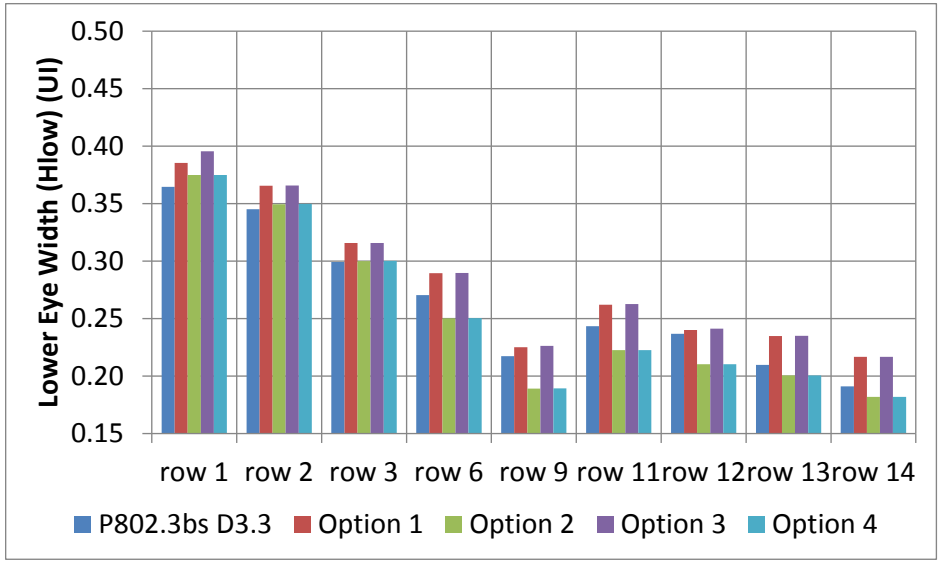
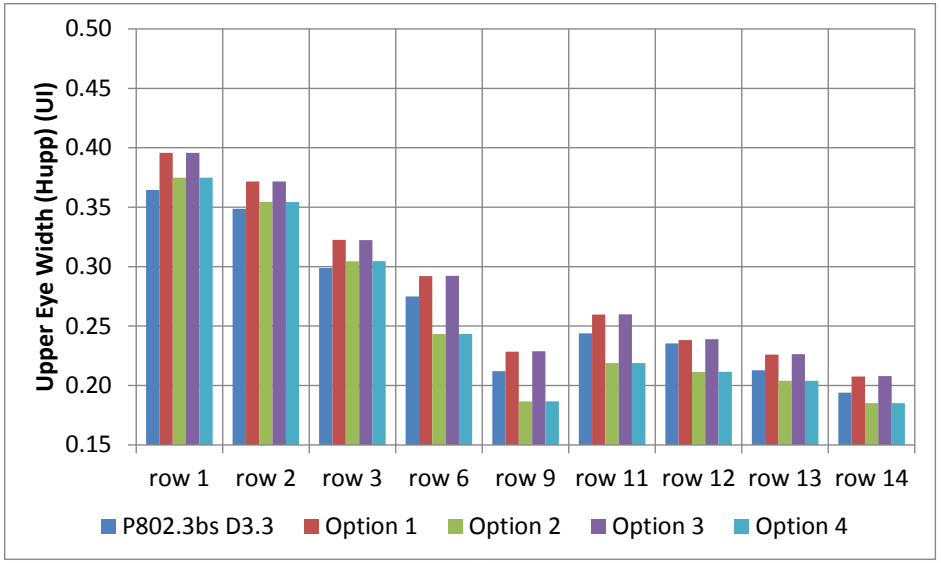
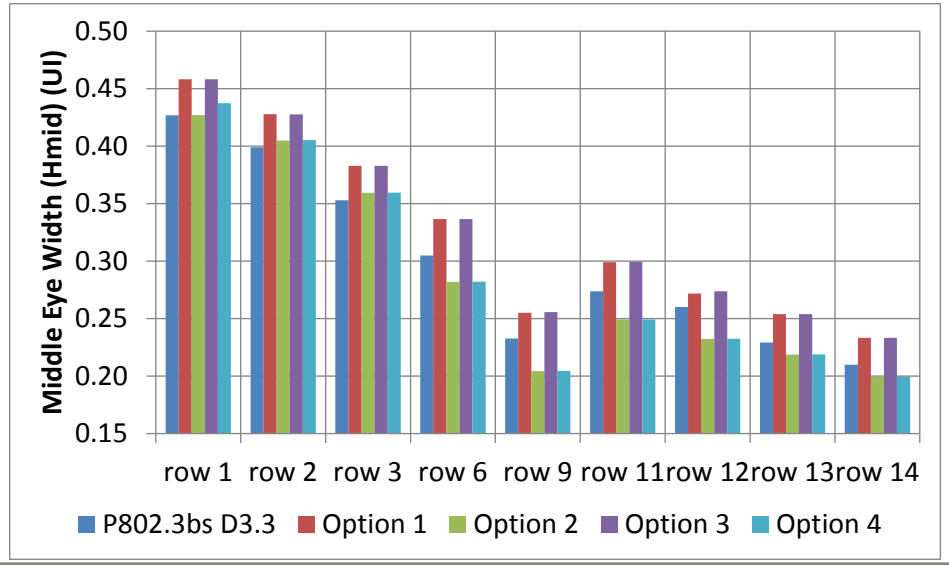
- Gets better with option 1 & 3, same or worse with option 2 & 4







Lower (ps)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	13.7	14.5	14.1	14.9	14.1
row 2	13.0	13.8	13.2	13.8	13.2
row 3	11.3	11.9	11.3	11.9	11.3
row 6	10.2	10.9	9.4	10.9	9.4
row 9	8.2	8.5	7.1	8.5	7.1
row 11	9.2	9.9	8.4	9.9	8.4
row 12	8.9	9.0	7.9	9.1	7.9
row 13	7.9	8.8	7.6	8.8	7.6
row 14	7.2	8.2	6.8	8.2	6.8

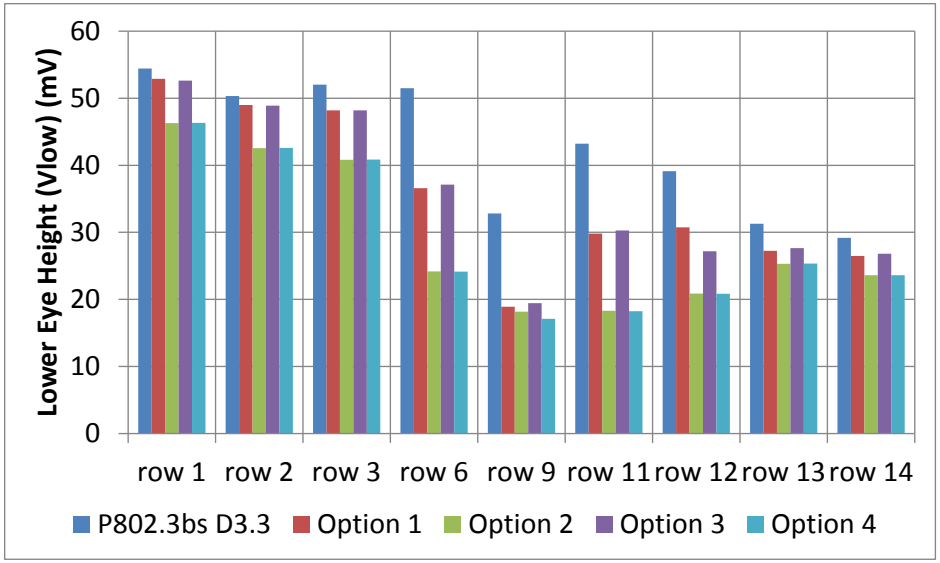
Upper (ps)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	13.7	14.9	14.1	14.9	14.1
row 2	13.1	14.0	13.3	14.0	13.3
row 3	11.2	12.1	11.5	12.1	11.5
row 6	10.4	11.0	9.2	11.0	9.2
row 9	8.0	8.6	7.0	8.6	7.0
row 11	9.2	9.8	8.2	9.8	8.2
row 12	8.9	9.0	8.0	9.0	8.0
row 13	8.0	8.5	7.7	8.5	7.7
row 14	7.3	7.8	7.0	7.8	7.0

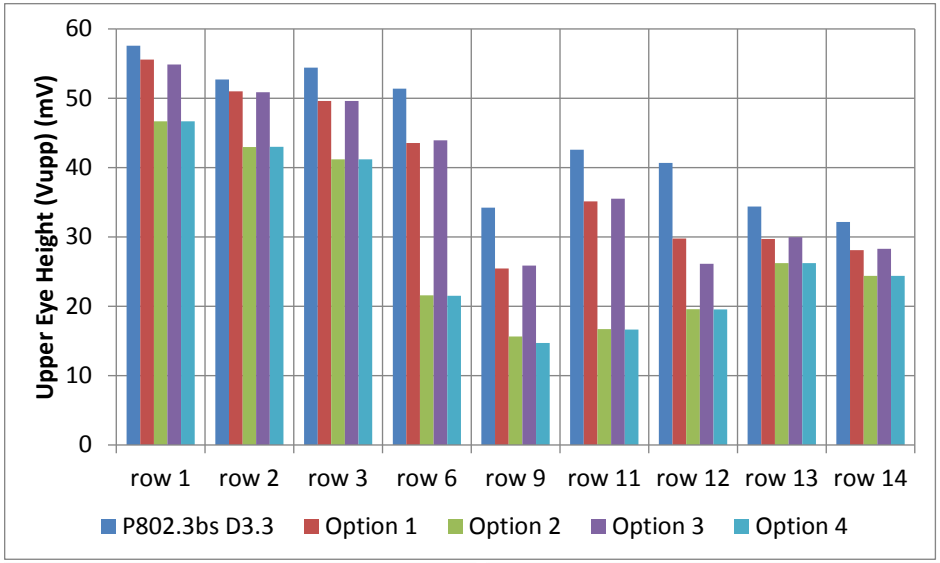
Middle (ps)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	16.1	17.3	16.1	17.3	16.5
row 2	15.0	16.1	15.2	16.1	15.3
row 3	13.3	14.4	13.5	14.4	13.5
row 6	11.5	12.7	10.6	12.7	10.6
row 9	8.8	9.6	7.7	9.6	7.7
row 11	10.3	11.3	9.4	11.3	9.4
row 12	9.8	10.2	8.7	10.3	8.7
row 13	8.6	9.6	8.2	9.6	8.2
row 14	7.9	8.8	7.5	8.8	7.5

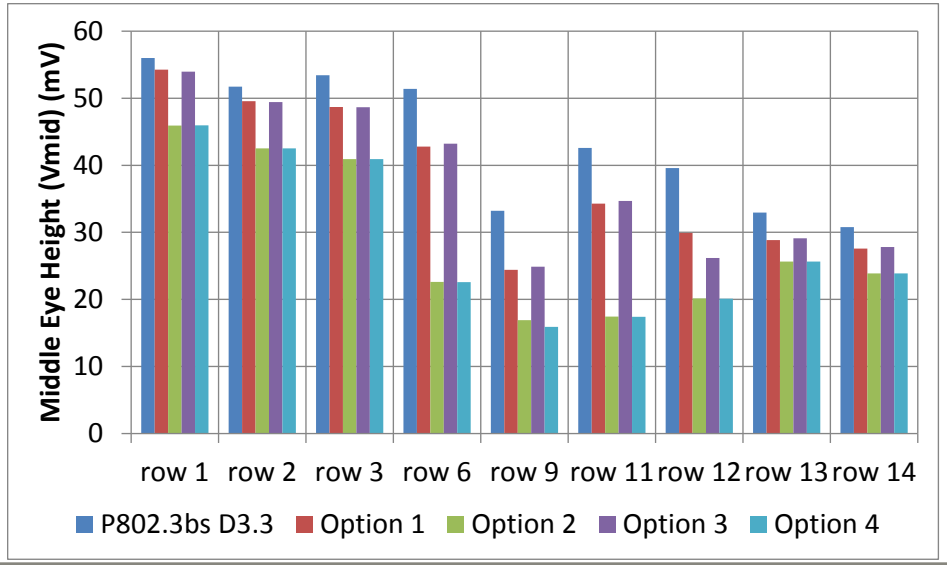
Eye diagrams for each case are shown in back-up slides.

Effects on Eye Height at BER=1E-05

- Small drop with option 1 & 3, large drop with option 2 & 4







Lower (mV)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	54.4	52.9	46.3	52.6	46.3
row 2	50.3	49.0	42.6	48.9	42.6
row 3	52.0	48.2	40.8	48.2	40.8
row 6	51.5	36.6	24.2	37.1	24.1
row 9	32.8	18.9	18.2	19.4	17.1
row 11	43.2	29.8	18.3	30.3	18.2
row 12	39.1	30.7	20.9	27.2	20.8
row 13	31.3	27.2	25.3	27.6	25.3
row 14	29.2	26.5	23.6	26.8	23.6

Middle (mV)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	56.0	54.2	45.9	54.0	45.9
row 2	51.7	49.6	42.5	49.4	42.5
row 3	53.4	48.7	40.9	48.7	40.9
row 6	51.4	42.8	22.6	43.2	22.6
row 9	33.2	24.4	16.9	24.9	15.9
row 11	42.6	34.3	17.4	34.7	17.4
row 12	39.6	29.9	20.1	26.2	20.1
row 13	33.0	28.8	25.6	29.1	25.7
row 14	30.8	27.6	23.9	27.8	23.9

Upper (mV)	D3.3	Opt1	Opt2	Opt3	Opt4
row 1	57.6	55.6	46.7	54.9	46.7
row 2	52.7	51.0	43.0	50.9	43.0
row 3	54.4	49.6	41.2	49.6	41.2
row 6	51.4	43.5	21.6	43.9	21.5
row 9	34.2	25.4	15.6	25.9	14.7
row 11	42.6	35.1	16.7	35.5	16.6
row 12	40.7	29.8	19.6	26.1	19.6
row 13	34.4	29.7	26.2	29.9	26.2
row 14	32.2	28.1	24.4	28.3	24.4

Eye diagrams for each case are shown in back-up slides.

CTLE Peaking and TX FIR coefficients

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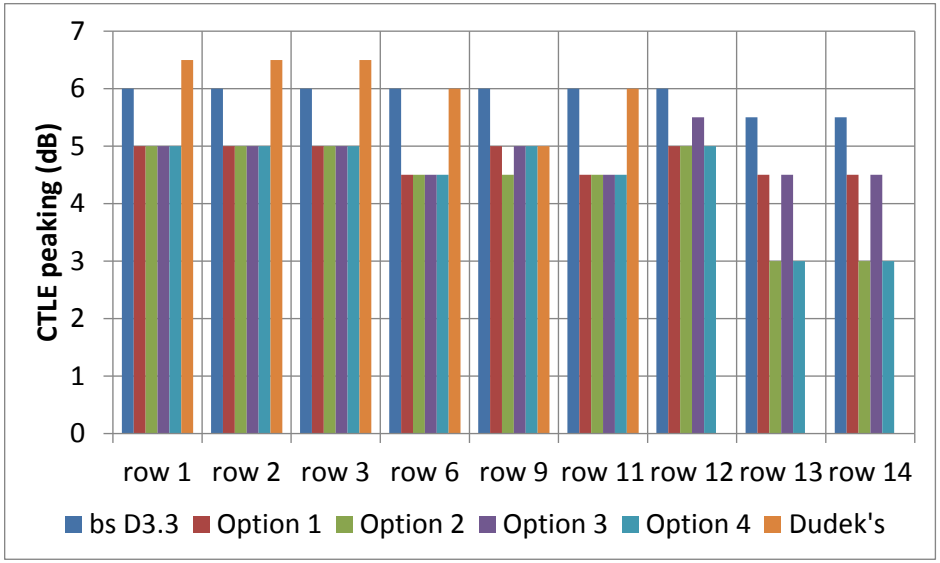
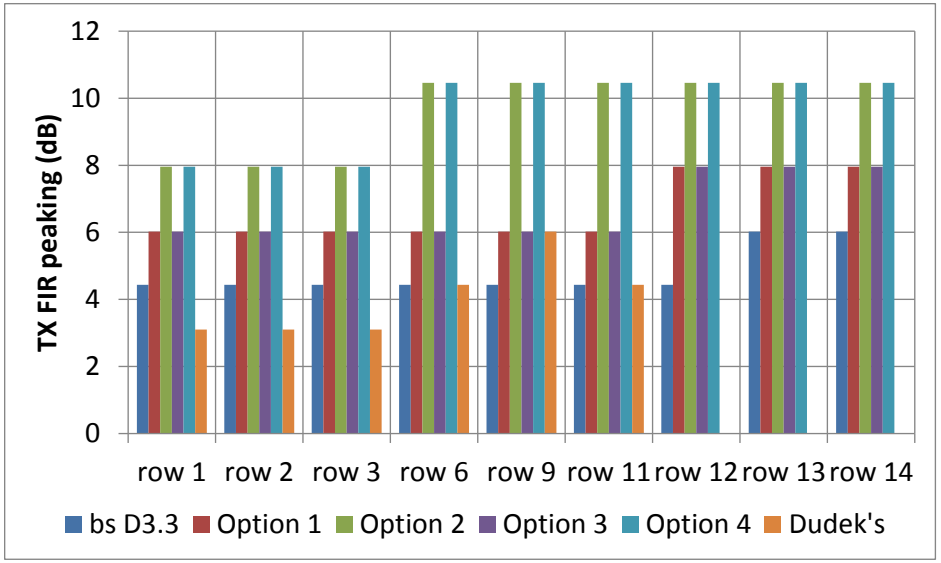
- Automatically adapted
  - Drop of eye height is due to TX FIR
    - Eye comparison with Dudek's parameters is shown in back up slides

$$\text{TX FIR peaking(dB)} = 20\log_{10}\left(\frac{|C_{-1}| + |C_0| + |C_1|}{C_{-1} + C_0 + C_1}\right)$$





CTLE	bs D3.3	Option 1	Option 2	Option 3	Option 4	Dudek's
row 1	6.0	5.0	5.0	5.0	5.0	6.5
row 2	6.0	5.0	5.0	5.0	5.0	6.5
row 3	6.0	5.0	5.0	5.0	5.0	6.5
row 6	6.0	4.5	4.5	4.5	4.5	6.0
row 9	6.0	5.0	4.5	5.0	5.0	5.0
row 11	6.0	4.5	4.5	4.5	4.5	6.0
row 12	6.0	5.0	5.0	5.5	5.0	
row 13	5.5	4.5	3.0	4.5	3.0	
row 14	5.5	4.5	3.0	4.5	3.0	

Tx FIR	bs D3.3	Option 1	Option 2	Option 3	Option 4	Dudek's
row 1	[-0.1 0.8 -0.1]	[-0.1 0.8 -0.1]	[-0.1 0.8 -0.1]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.85 -0.05]
row 2	[-0.1 0.8 -0.1]	[-0.1 0.8 -0.1]	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.85 -0.05]
row 3	[-0.1 0.8 -0.1]	[-0.1 0.8 -0.1]	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.85 -0.05]
row 6	[-0.1 0.8 -0.1]	[-0.1 0.8 -0.1]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.1 0.8 -0.1]
row 9	[-0.1 0.8 -0.1]	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.1 0.75 -0.15]
row 11	[-0.1 0.8 -0.1]	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.1 0.8 -0.1]
row 12	[-0.1 0.8 -0.1]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.05 0.7 -0.25]	
row 13	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.05 0.7 -0.25]	
row 14	[-0.1 0.75 -0.15]	[-0.05 0.75 -0.2]	[-0.05 0.75 -0.2]	[-0.1 0.7 -0.2]	[-0.05 0.7 -0.25]	

Recommendation

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- Either option 1 or 3 is recommended
  - Both of option 1 and 3 will improve the eye width
    - No significant difference between option 1 and 3
  - Align the high-frequency pole P_1 of 120E to f_{p2} of 120D
- Neither option 2 nor 4 is recommended
  - It will degrade the eye width, in particular with more impairments
  - Do not align the medium-frequency pole P_2 of 120E to f_{p1} of 120D
- Instead, shall we align f_{p1} of 120D to P_2 of 120E?
  - Not necessary, and it depends
    - Need to check its effects on the COM value for C2C channels

Simulation of Effects on COM for C2C Channels

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4 Options Investigated

	f_{p1}	f_{p2}	Note
Option 1	$0.531 \times f_b = 14.1GHz$	$2 \times f_b = 53.125GHz$	Good for 120E
Option 2	$0.4 \times f_b = 10.625GHz$	$2 \times f_b = 53.125GHz$	bs D3.3 120D
Option 3	$0.531 \times f_b = 14.1GHz$	$1 \times f_b = 26.5625GHz$	Good for 120E
Option 4	$0.4 \times f_b = 10.625GHz$	$1 \times f_b = 26.5625GHz$	CEI-56G-MR-PAM4

Evaluated Channels

- 10 C2C channels in P802.3bs Task Force channel data area
  - CH1-7: 7 Intel chip-to-chip channels (mellitz_3bs_0[2-8]_0714.zip)
  - CH8-9: 2 improved Intel chip-to-chip channels (mellitz_3bs_0[36]a_0315.zip)
  - CH10: TEC, Medium Reach / C2C with Armor Connector (shanbhag_01_0914.zip)

Channel	1	2	3	4	5	6	7	8	9	10
IL at Nyquist	19.63dB	14.72dB	6.92dB	19.49dB	17.41dB	10.99dB	9.18dB	19.10dB	17.43dB	18.64dB

COM Parameters Other than f_{p1} or f_{p2}

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Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	26.5625	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1.8e-4 1.8e-4]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 12]	mm	[test cases]
z_p (FEXT)	[12 30]	mm	[test cases]
z_p (RX)	[12 30]	mm	[test cases]
C_p	[1.1e-4 1.1e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[50 50]	Ohm	[TX RX]
f_r	0.75	*fb	
c(0)	0.6		min
c(-1)	[-0.15:0.05:0]		[min:step:max]
c(1)	[-0.25:0.05:0]		[min:step:max]
g_DC	[-15:1:0]	dB	[min:step:max]
f_z	10.625	GHz	
f_p1	10.625	GHz	
f_p2	53.125	GHz	
A_v	0.418	V	
A_fe	0.418	V	
A_ne	0.63	V	
L	4		
M	32		
N_b	10	UI	
b_max(1)	0.5		
b_max(2..N_b)	0.2		
sigma_RJ	0.01	UI	
A_DD	0.02	UI	
eta_0	2.60E-08	V^2/GHz	
SNR_TX	31	dB	
R_LM	0.95		
DER_0	1.00E-05		
Operational control			
COM Pass threshold	3	dB	
Include PCB	0	Value	0, 1, 2
g_DC_HP	[-4:1:0]		[min:step:max]
f_HP_PZ	0.6640625	GHz	

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
Display frequency domain	1	logical
CSV_REPORT	1	logical
RESULT_DIR	\results\D3p3_120D_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	C2C_	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
IDEAL_TX_TERM	0	logical
T_r	1.30E-02	ns
FORCE_TR	1	logical
Non standard control options		
COM_CONTRIBUTION	0	logical
TDR	1	logical
ERL	1	logical
Z_t	50	ohms
ERL_ONLY	0	logical
TR_TDR	0.0189	ns
TDR_duration	5	
TDR_f_BT_3db	19.921875	GHz
TDR_Butterworth	1	logical

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 1.734e-3 1.455e-4]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	95	Ohm

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	[0 4.114e-4 2.547e-4]	
board_tl_tau	6.191E-03	ns/mm
board_Z_c	110	Ohm
z_bp (TX)	151	mm
z_bp (NEXT)	72	mm
z_bp (FEXT)	72	mm
z_bp (RX)	151	mm

Effects on COM for C2C Channels

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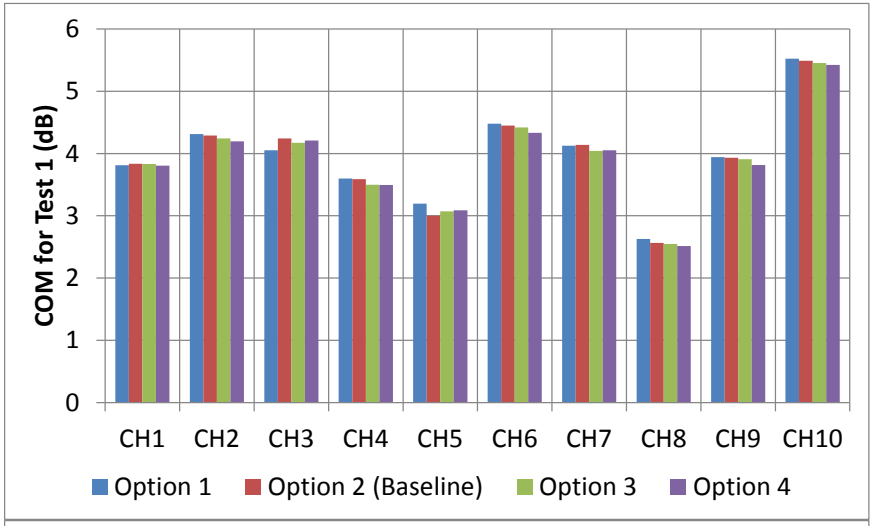
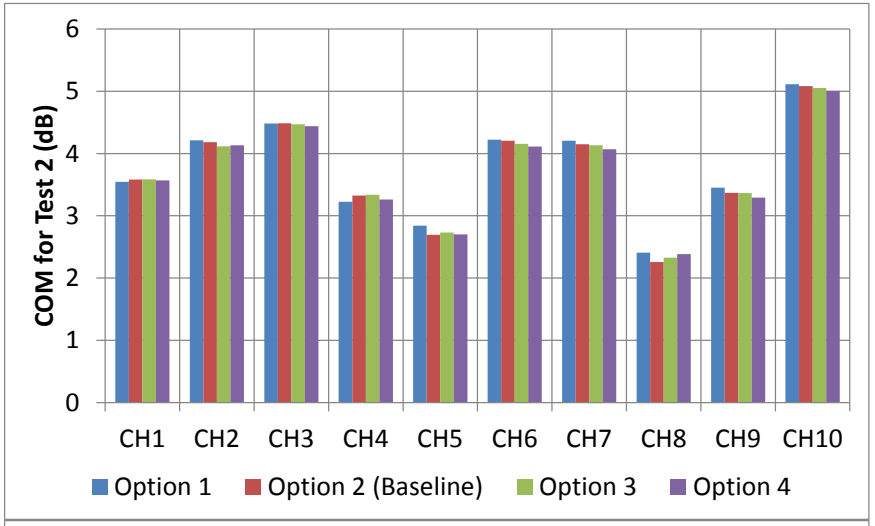
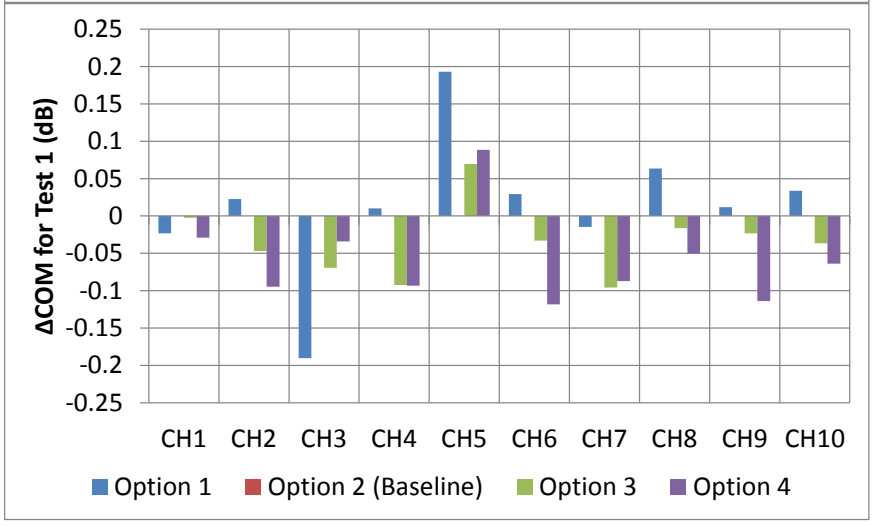
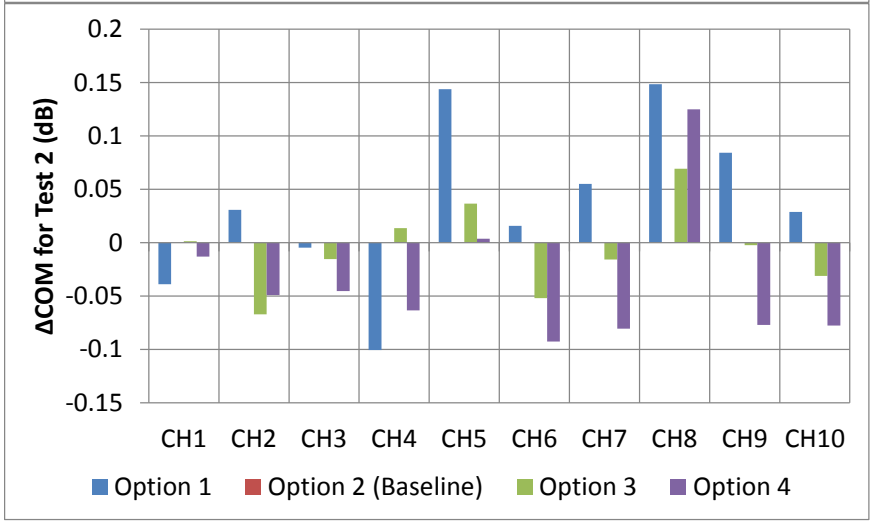
- Goes up or down a little, depending on the channel
  - Any option seems acceptable









Distinction of Reference CTLE

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- Reference CTLE in 120E
  - Used for observation of Tx output
    - Cancels insertion loss in the measurement path from Tx to scope
  - Does not necessarily model the actual CTLE in Rx
    - If they are matched, we can estimate Rx internal eye, but it is not primary use
  - Bandwidth is critical, and should be sufficiently high
    - CTLE bandwidth should not limit the Tx performance
- Reference CTLE in 120D
  - Used for channel specification (COM) and Rx specification (Rx ITT)
  - Models the actual CTLE in Rx
  - Bandwidth is not critical, because DFE is used together
- Bandwidth of 120E Ref CTLE should be higher than 120D
  - Or, at least same as 120D, but currently it is lower than 120D

Conclusion

- For 120E, either option 1 or option 3 is recommended
  - Namely, increase the bandwidth of reference CTLE
- For 120D, no change is required
  - If alignment to 120E is preferred, same option as 120E is also OK
  - If alignment to OIF is preferred, option 4 is also OK

Back up Slides

- Formula of exact Z_1 for unity peak gain of ref CTLE
- Eye diagrams
  - Comparison between P802.3bs D3.3 and proposed option 1-4
  - Comparison between Dudek's and adapted parameters

Formula of Z_1 for unity peak gain of CTLE

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- Transfer function of CTLE in Annex 120E

$$H(f) = \frac{GP_1P_2P_{LF}}{Z_1Z_{LF}} \times \frac{j2\pi f + Z_1}{(j2\pi + P_1)(j2\pi + P_2)} \times \frac{j2\pi f + Z_{LF}}{j2\pi + P_{LF}}$$

- Let $|H_0|$ represents the peak gain at the peak-gain frequency f_0
- Define

$$A \equiv \left(\frac{2\pi}{Z_1}\right)^2, \quad B \equiv \left(\frac{2\pi}{Z_{LF}}\right)^2, \quad C \equiv \left(\frac{2\pi}{P_1}\right)^2, \quad D \equiv \left(\frac{2\pi}{P_2}\right)^2, \quad E \equiv \left(\frac{2\pi}{P_{LF}}\right)^2$$

$$A_0 = Af_0{}^2 + 1, \quad B_0 = Bf_0{}^2 + 1, \quad C_0 = Cf_0{}^2 + 1, \quad D_0 = Df_0{}^2 + 1, \quad E_0 = Ef_0{}^2 + 1$$

- For $\left.\frac{\partial |H|}{\partial f}\right|_{f=f_0} = 0$,

$$A = \frac{-BC_0D_0E_0 + CB_0D_0E_0 + DB_0C_0E_0 + EB_0C_0D_0}{B_0C_0D_0E_0 + f_0{}^2BC_0D_0E_0 - f_0{}^2CB_0D_0E_0 - f_0{}^2DB_0C_0E_0 - f_0{}^2EB_0C_0D_0}$$

- For $|H(f_0)| = |H_0|$,

$$|H(f_0)|^2 = \frac{G^2A_0B_0}{C_0D_0E_0} = \frac{G^2B_0B_0}{B_0\left(2 + (C + D + E)f_0{}^2 - CDEf_0{}^6\right) - C_0D_0E_0} = |H_0|^2$$

- For $|H_0| = 1$,

$$\left(f_0{}^2\right)^4 + \frac{2}{B}\left(f_0{}^2\right)^3 + \frac{B(G^2B - C - D - E) + CD + DE + CE}{BCDE}\left(f_0{}^2\right)^2 + \frac{2(G^2 - 1)}{CDE}\left(f_0{}^2\right) + \frac{G^2 - 1}{BCDE} = 0$$

- Solve this quartic equation of $f_0{}^2$, and take its positive real root as $f_0{}^2$.
- Take the square root of $f_0{}^2$ as f_0. Calculate A. $Z_1 = 2\pi/\sqrt{A}$.

Eye Diagrams (Row 1: Ideal)

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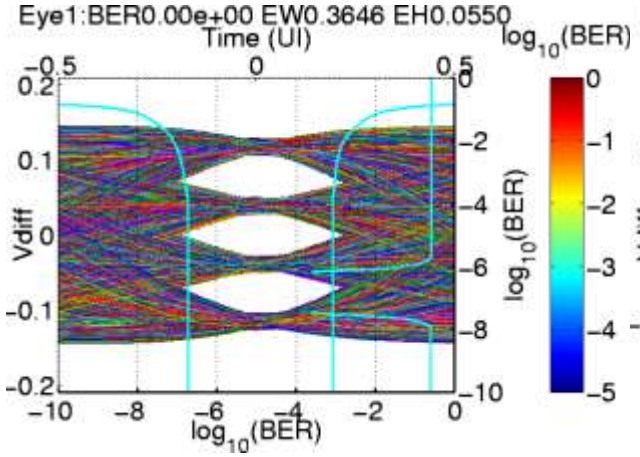
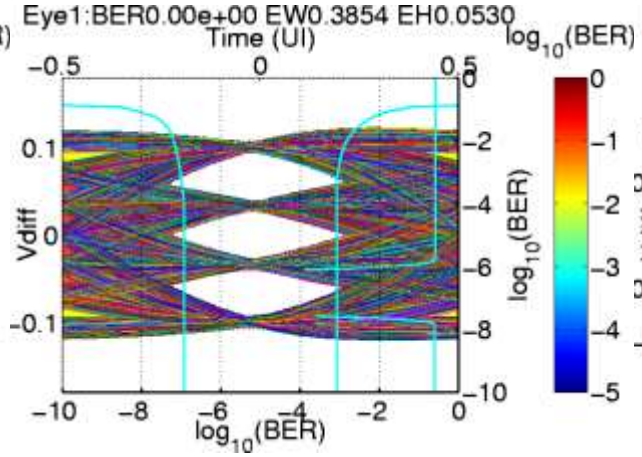
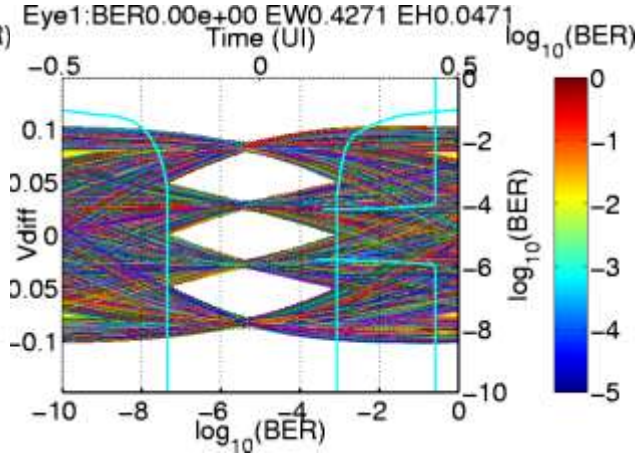
P802.3bs D3.3



Option 1



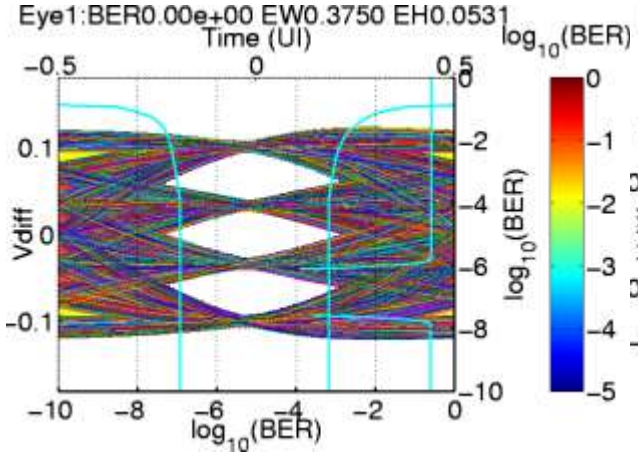
Option 2



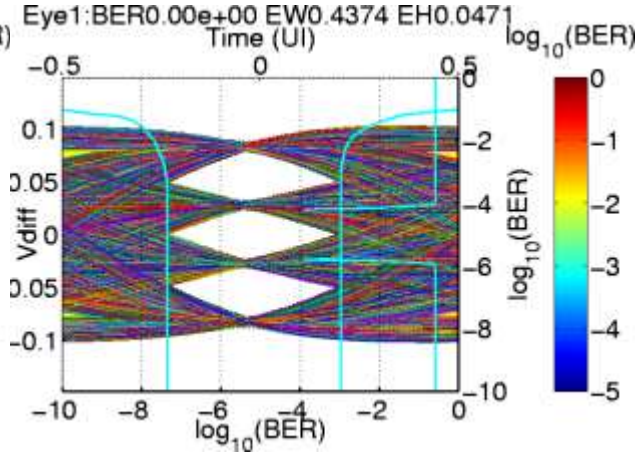
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.365	0.427	0.364
Option 1	0.385	0.458	0.396
Option 2	0.375	0.427	0.375
Option 3	0.396	0.458	0.396
Option 4	0.375	0.437	0.375

Option 3



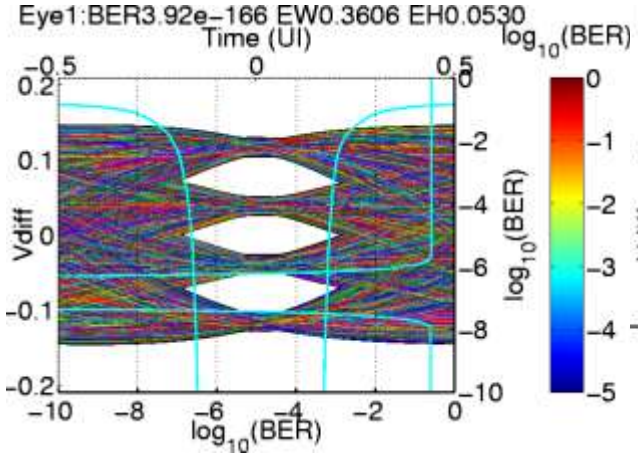
Option 4



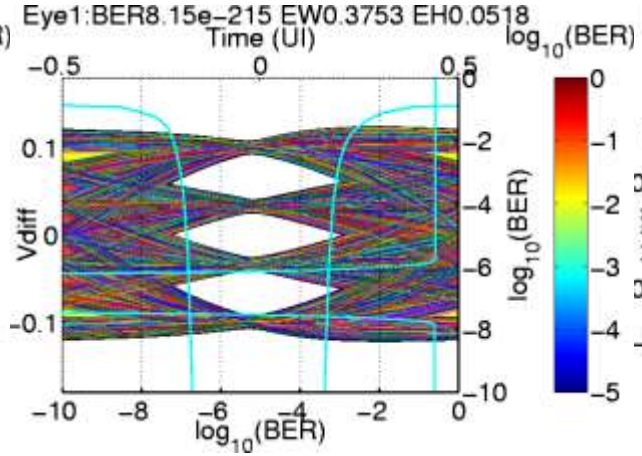
Eye Diagrams (Row 2: Row 1 + Xtalk)

FUJITSU

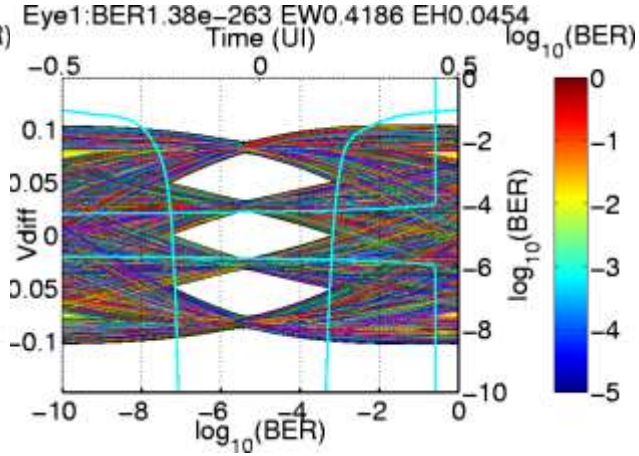
P802.3bs D3.3



Option 1



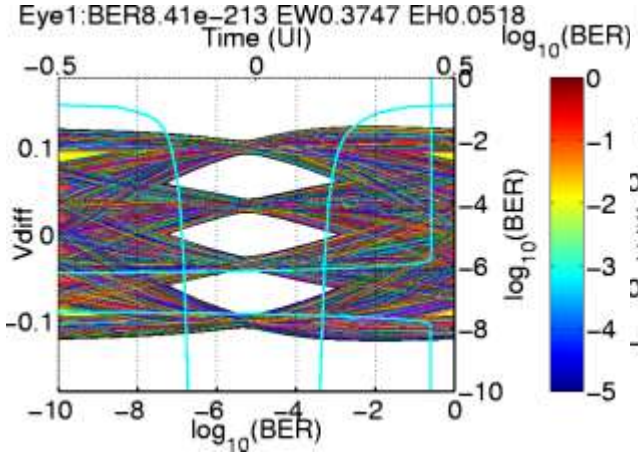
Option 2



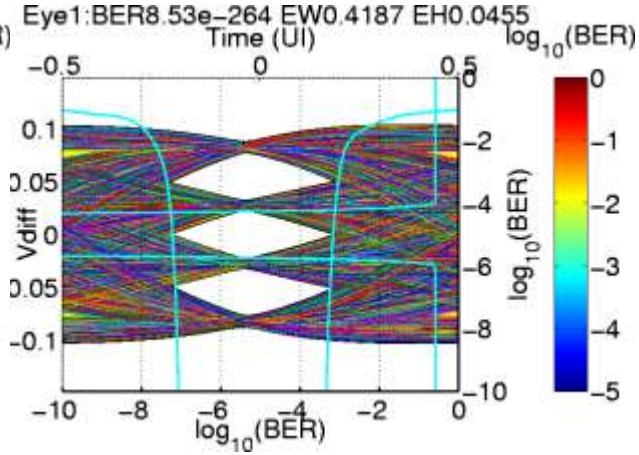
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.345	0.399	0.349
Option 1	0.366	0.428	0.372
Option 2	0.349	0.405	0.354
Option 3	0.366	0.428	0.372
Option 4	0.350	0.405	0.354

Option 3



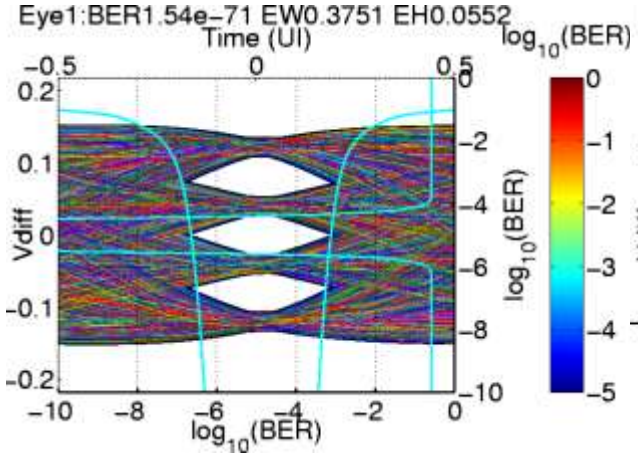
Option 4



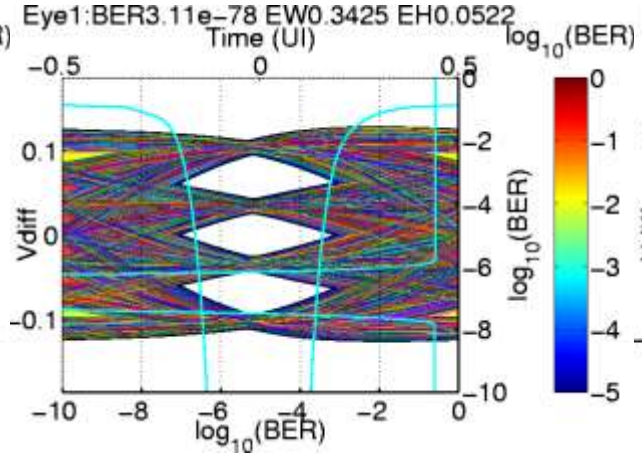
Eye Diagrams (Row 3: Row 2 + Jitter)

FUJITSU

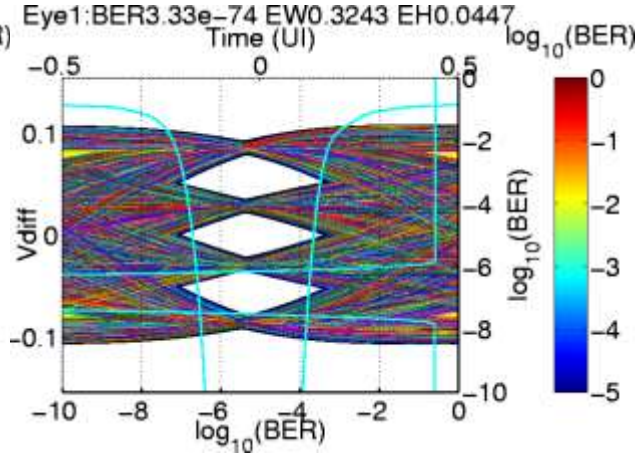
P802.3bs D3.3



Option 1



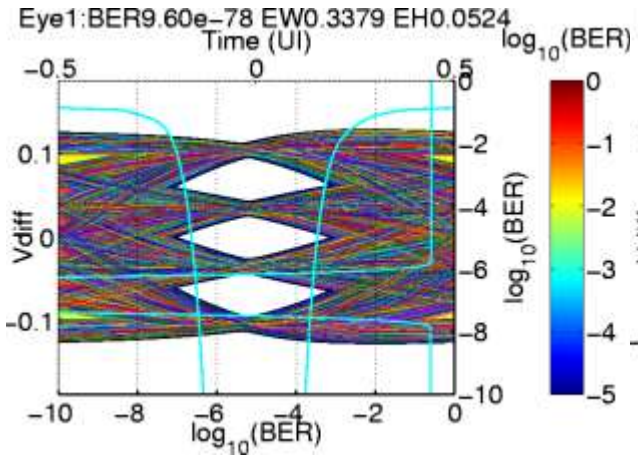
Option 2



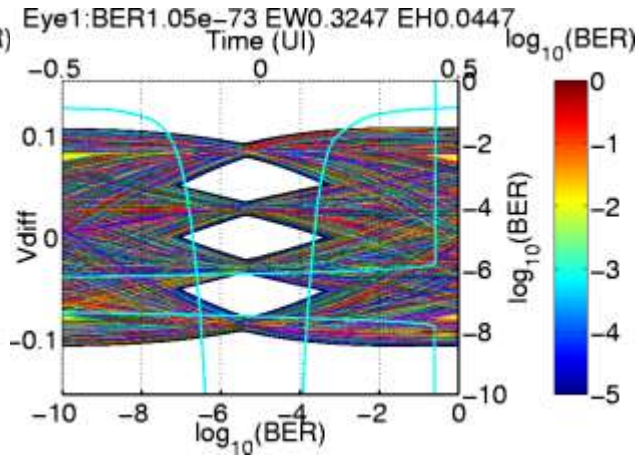
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.299	0.353	0.299
Option 1	0.316	0.383	0.323
Option 2	0.300	0.359	0.304
Option 3	0.316	0.383	0.323
Option 4	0.300	0.360	0.305

Option 3



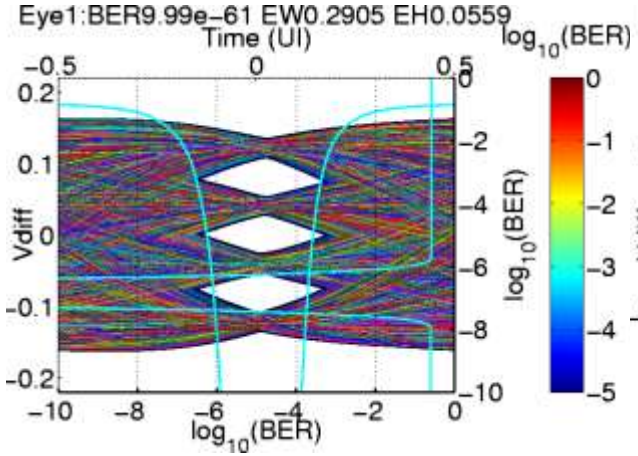
Option 4



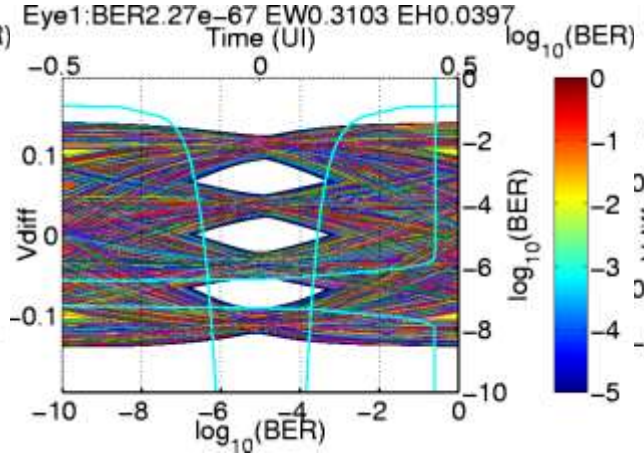
Eye Diagrams (Row 6: Row 3 + Reflection)

FUJITSU

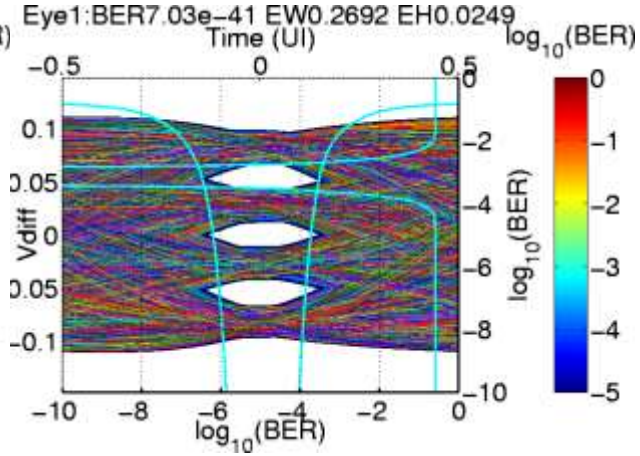
P802.3bs D3.3



Option 1



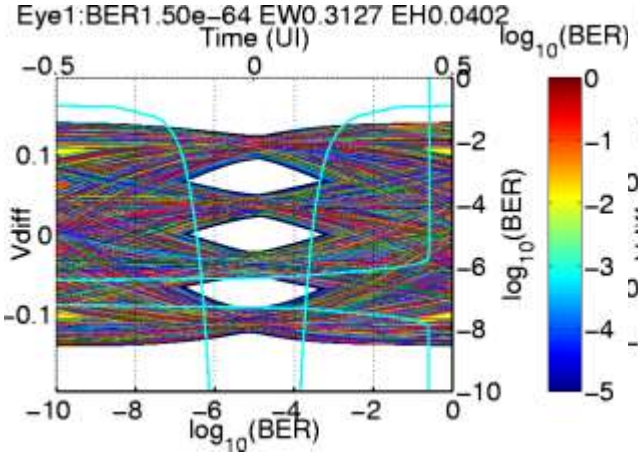
Option 2



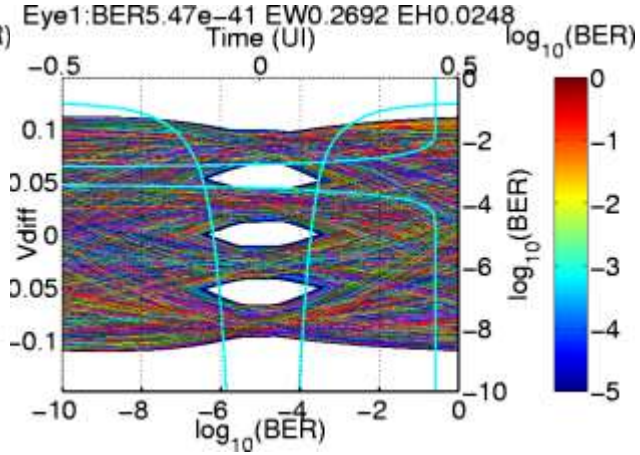
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.270	0.305	0.275
Option 1	0.289	0.337	0.292
Option 2	0.250	0.282	0.243
Option 3	0.290	0.336	0.292
Option 4	0.250	0.282	0.243

Option 3



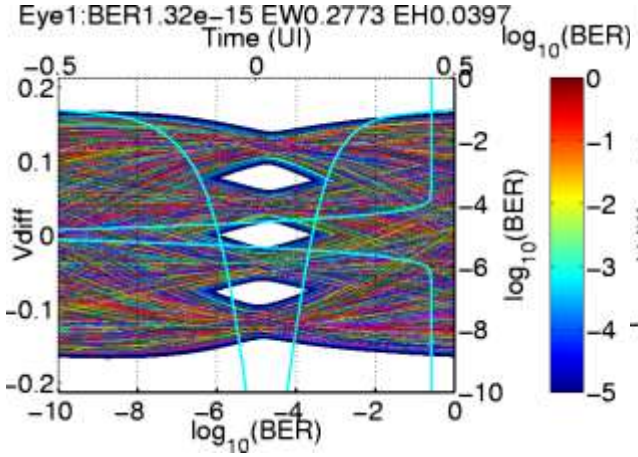
Option 4



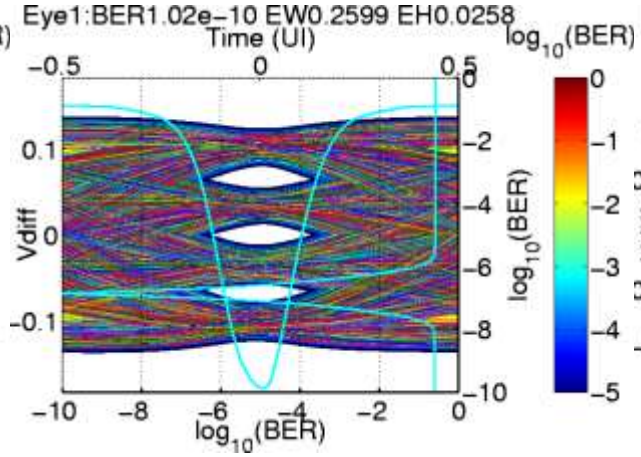
Eye Diagrams (Row 9: bs D3.0 A120D)

FUJITSU

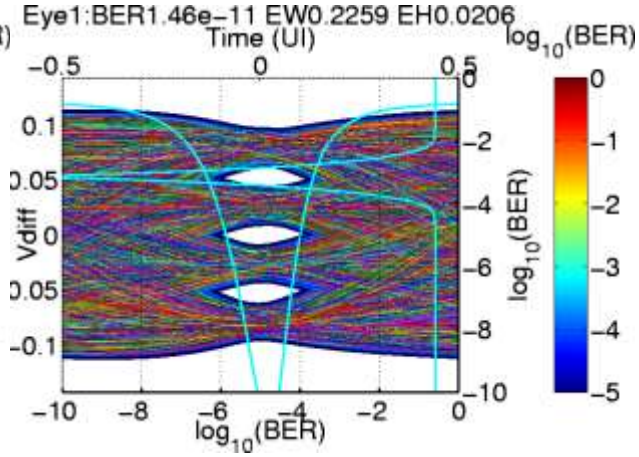
P802.3bs D3.3



Option 1



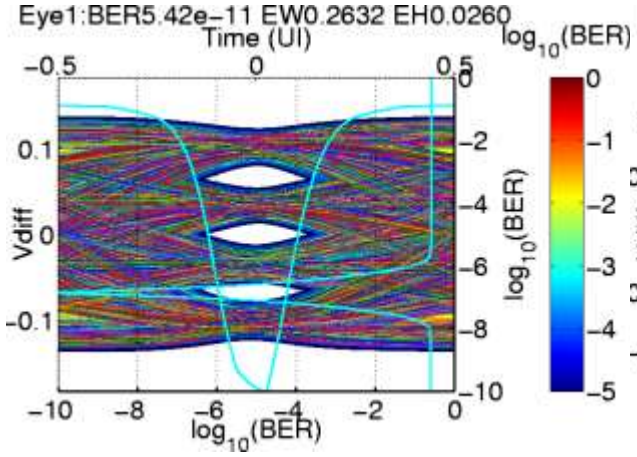
Option 2



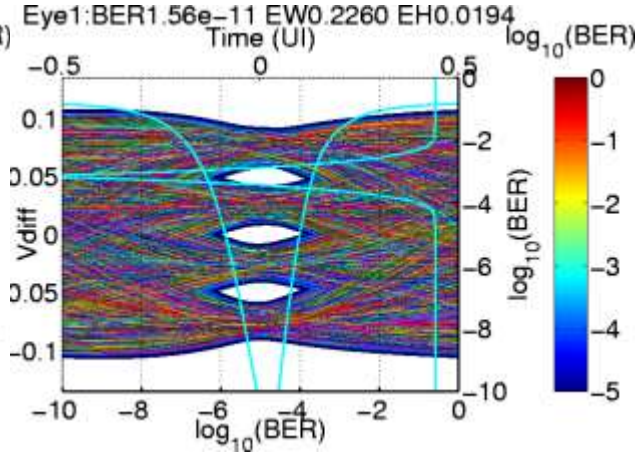
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.217	0.233	0.212
Option 1	0.225	0.255	0.228
Option 2	0.189	0.204	0.187
Option 3	0.226	0.256	0.229
Option 4	0.189	0.204	0.187

Option 3



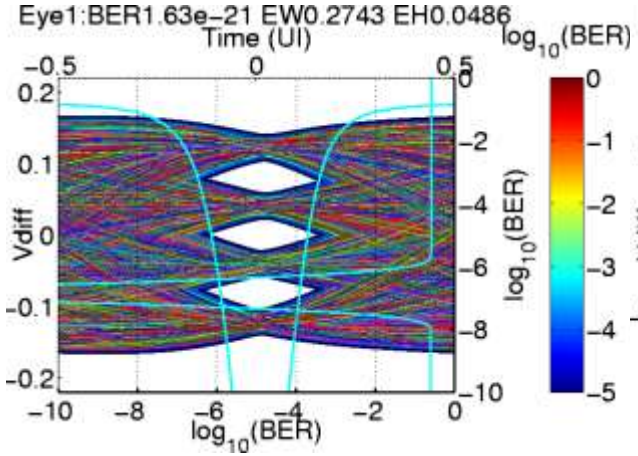
Option 4



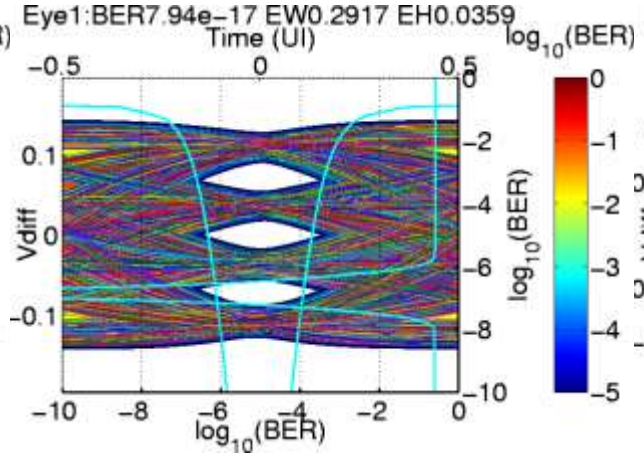
Eye Diagrams (Row 11: cd D1.2 CL137)

FUJITSU

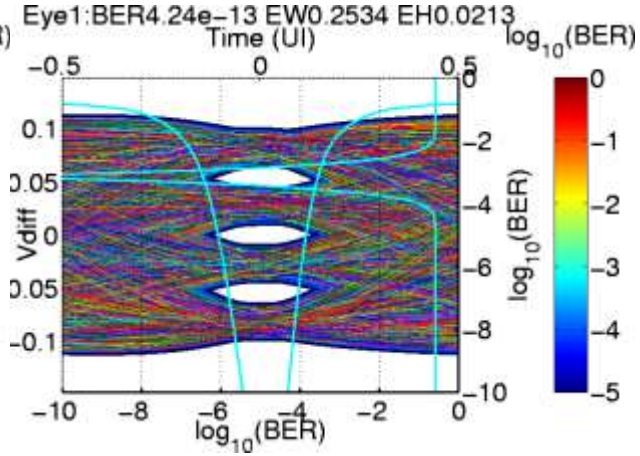
P802.3bs D3.3



Option 1



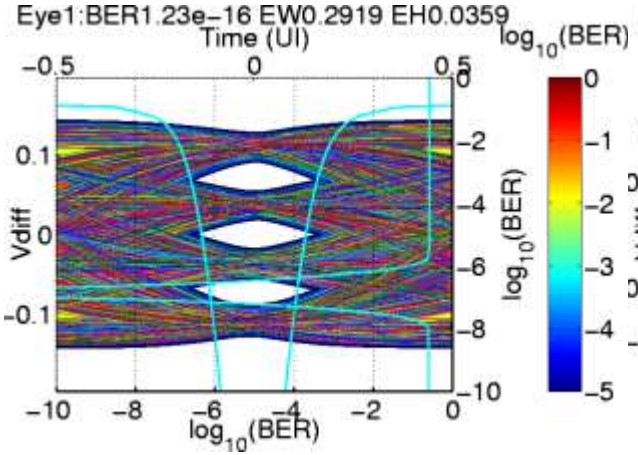
Option 2



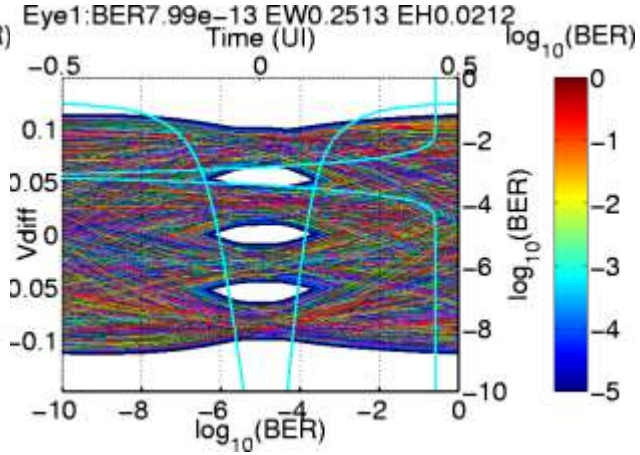
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.243	0.274	0.244
Option 1	0.262	0.299	0.260
Option 2	0.222	0.249	0.219
Option 3	0.263	0.299	0.260
Option 4	0.223	0.249	0.219

Option 3



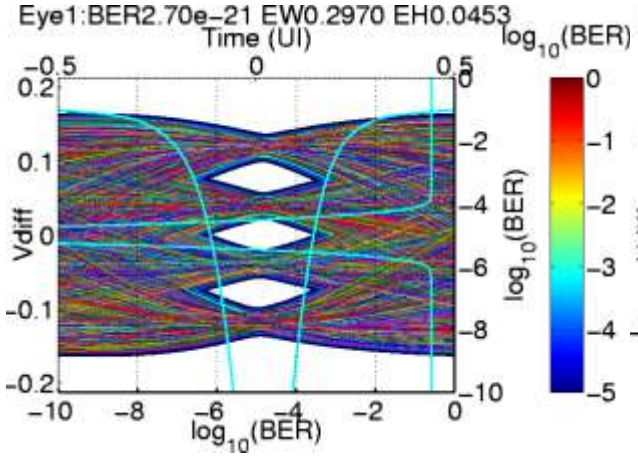
Option 4



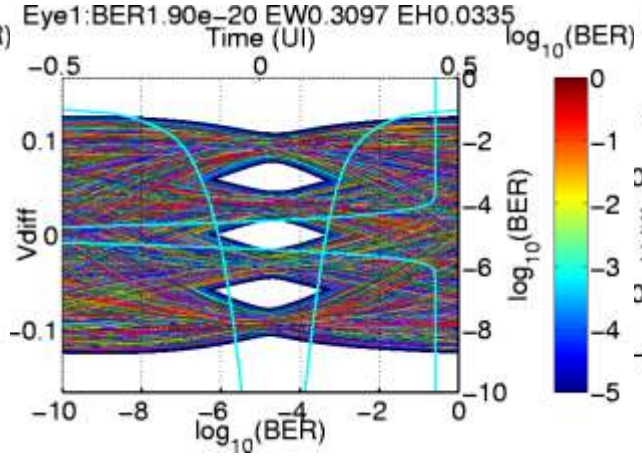
Eye Diagrams (Row 12: Row 11+Tr 9.5ps)

FUJITSU

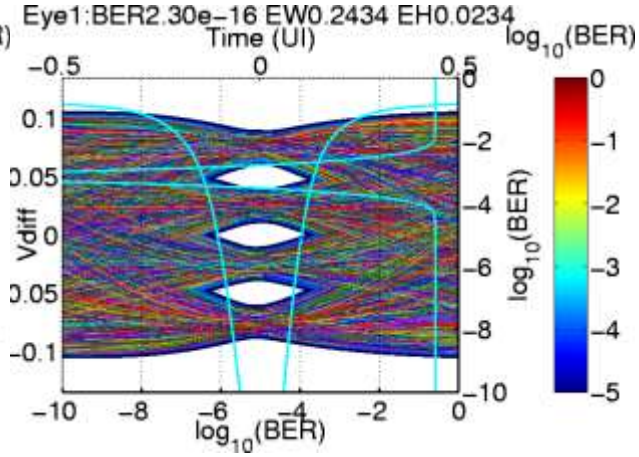
P802.3bs D3.3



Option 1



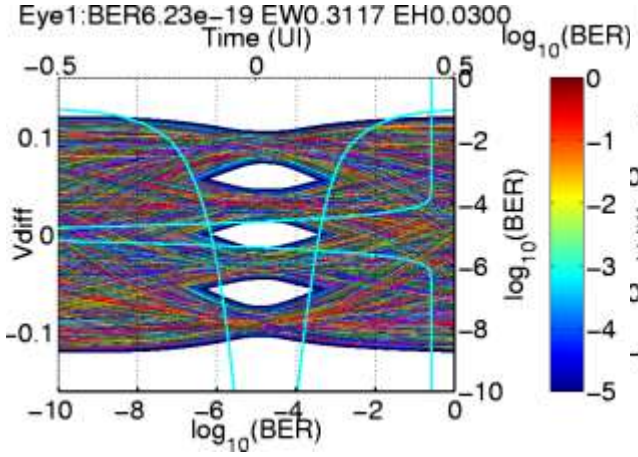
Option 2



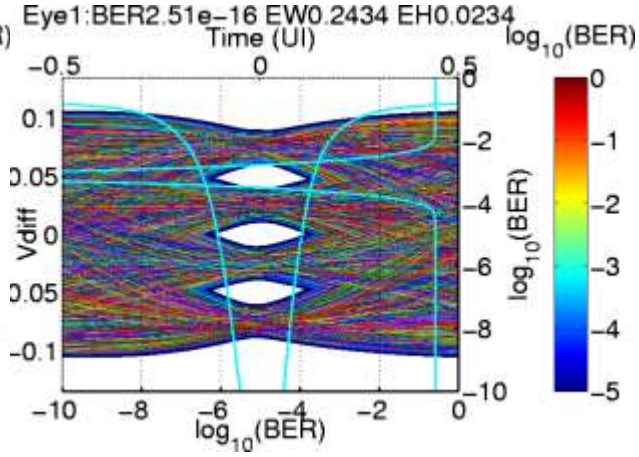
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.237	0.260	0.235
Option 1	0.240	0.272	0.238
Option 2	0.210	0.232	0.211
Option 3	0.241	0.274	0.239
Option 4	0.210	0.232	0.211

Option 3



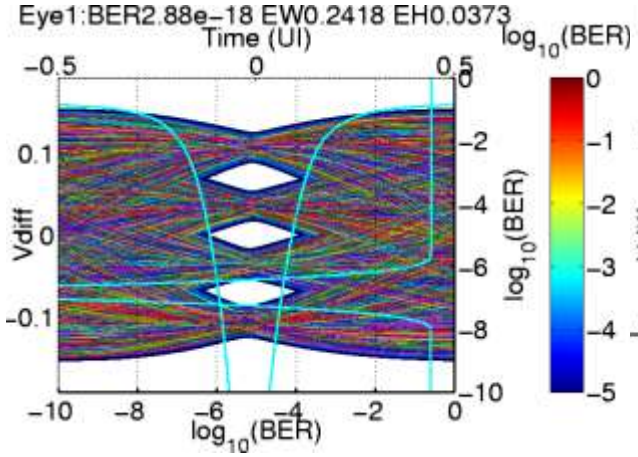
Option 4



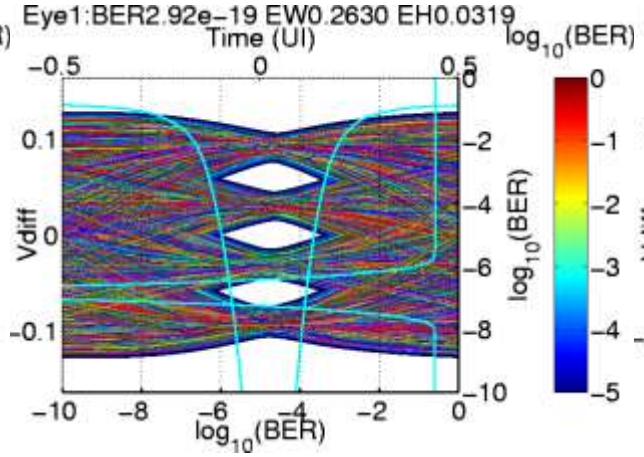
Eye Diagrams (Row 13:Row 11+Tr 13.5ps)

FUJITSU

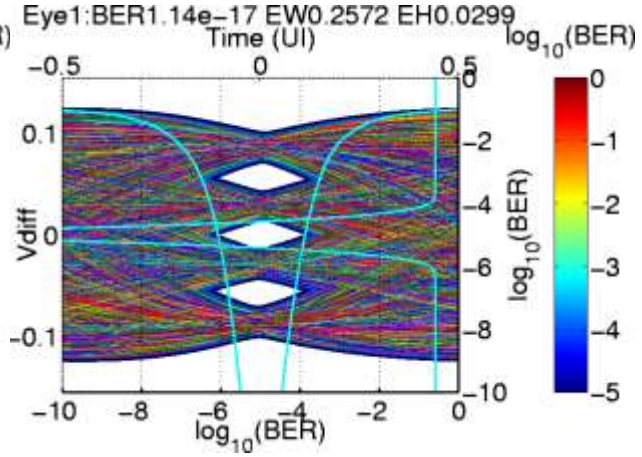
P802.3bs D3.3



Option 1



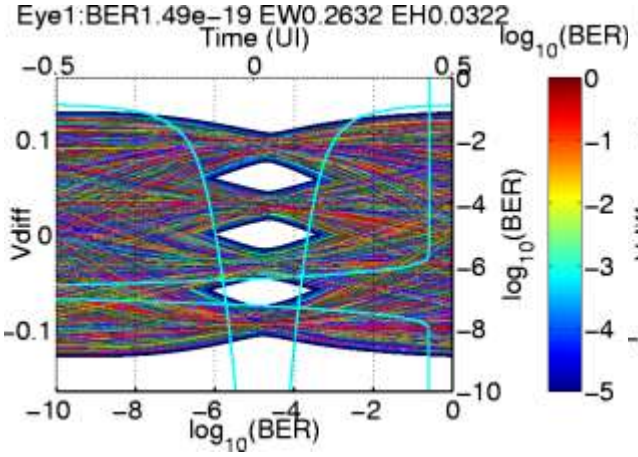
Option 2



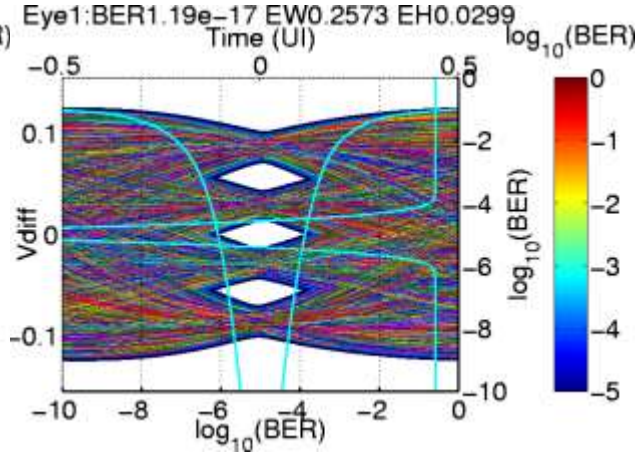
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.210	0.229	0.213
Option 1	0.235	0.254	0.226
Option 2	0.201	0.219	0.204
Option 3	0.235	0.254	0.226
Option 4	0.201	0.219	0.204

Option 3



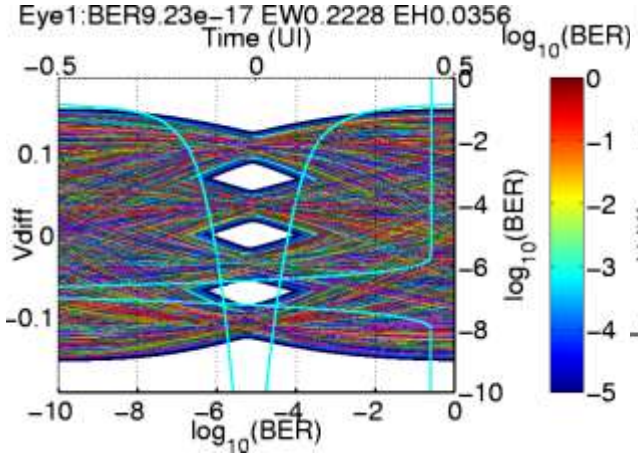
Option 4



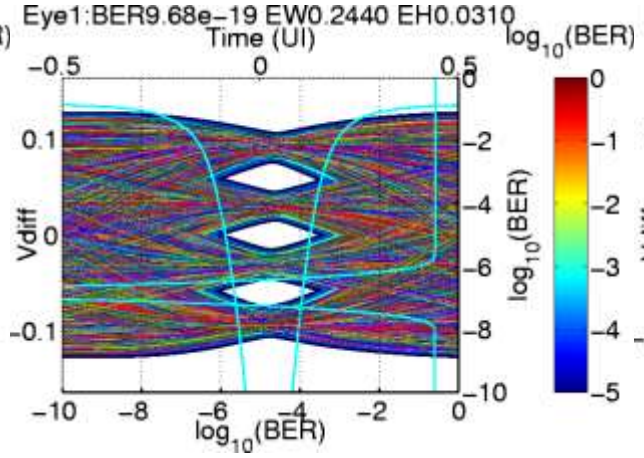
Eye Diagrams (Row 14:Row 13+DJ 0.04UI)

FUJITSU

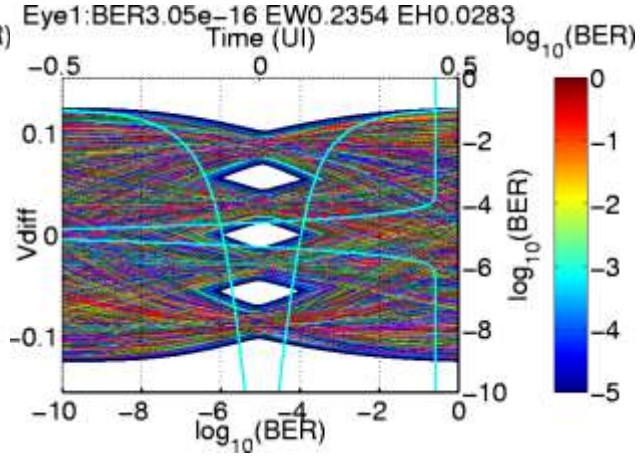
P802.3bs D3.3



Option 1



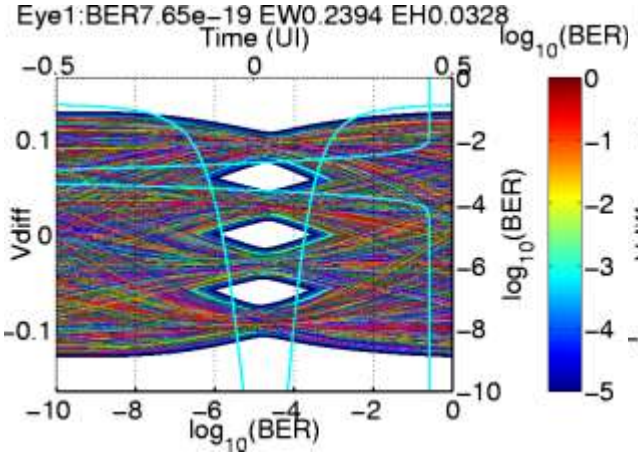
Option 2



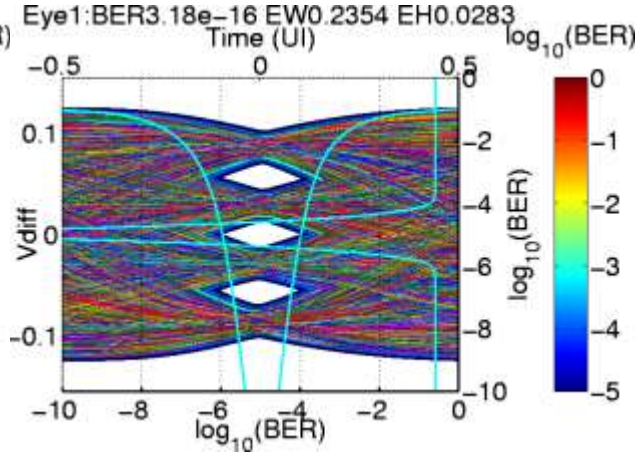
120E.4.2 Eye width @ 1E-5 (UI)

	Lower	Middle	Upper
D3.3	0.191	0.210	0.194
Option 1	0.217	0.233	0.207
Option 2	0.182	0.199	0.185
Option 3	0.217	0.233	0.208
Option 4	0.182	0.200	0.185

Option 3



Option 4

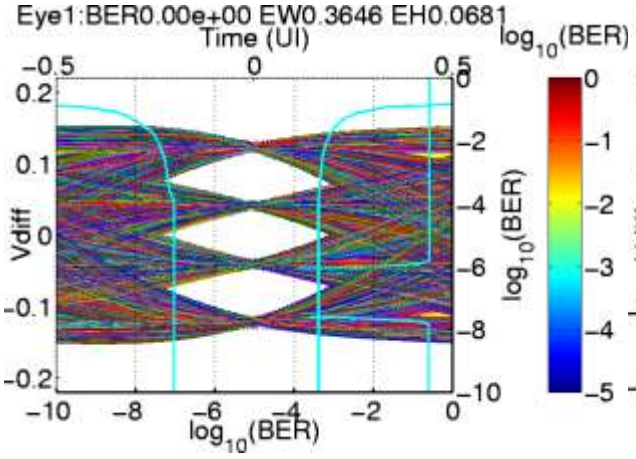


Eye Diagrams (Row 1,2: Dudek's vs Adapted)

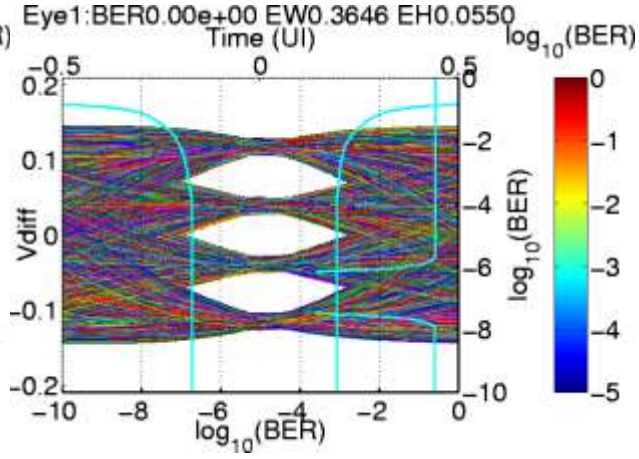
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.365	0.437	0.375
Adapted	0.365	0.427	0.364
EH (mV)	Lower	Middle	Upper
Dudek's	66.5	68.7	69.2
Adapted	54.4	56.0	57.6

Row 1: Dudek's



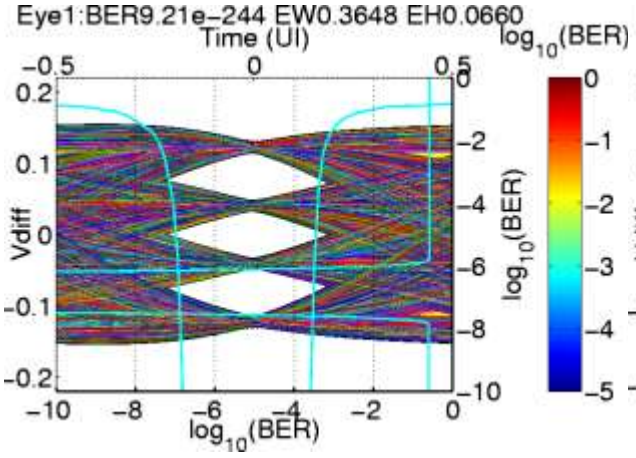
Row 1: Adapted



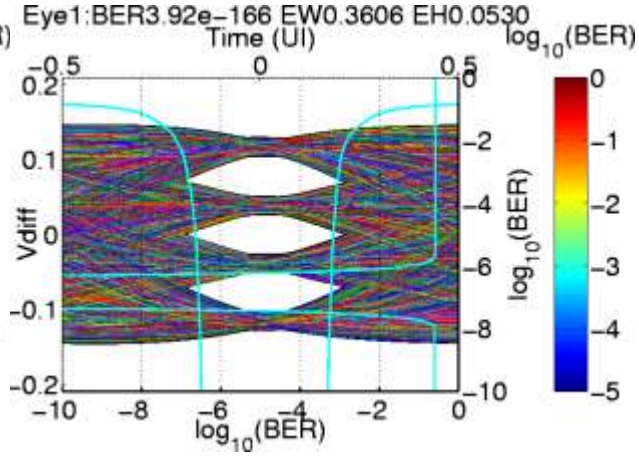
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.351	0.408	0.355
Adapted	0.345	0.399	0.349
EH (mV)	Lower	Middle	Upper
Dudek's	61.8	63.1	63.8
Adapted	50.3	51.7	52.7

Row 2: Dudek's



Row 2: Adapted



Eye Diagrams (Row 3,6: Dudek's vs Adapted)

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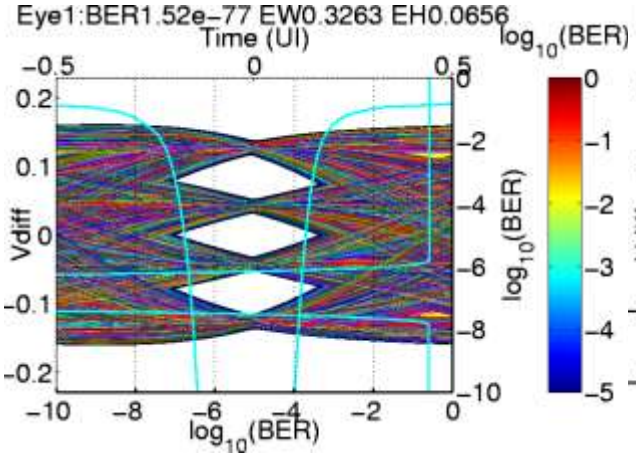
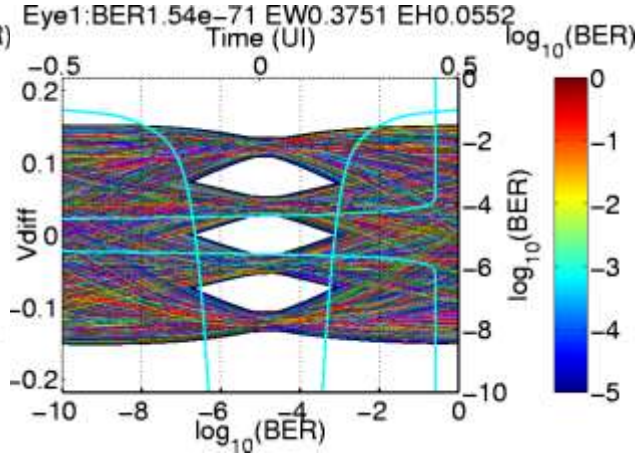
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.304	0.361	0.305
Adapted	0.299	0.353	0.299
EH (mV)	Lower	Middle	Upper
Dudek's	59.4	59.8	60.8
Adapted	52.0	53.4	54.4

Row 3: Dudek's



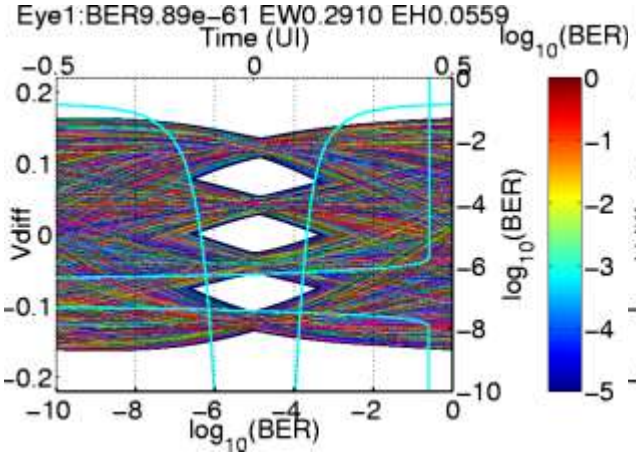
Row 3: Adapted



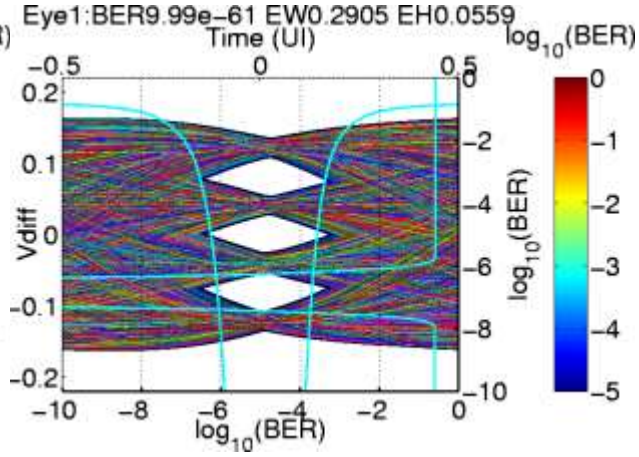
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.270	0.305	0.275
Adapted	0.270	0.305	0.275
EH (mV)	Lower	Middle	Upper
Dudek's	51.5	51.4	51.4
Adapted	51.5	51.4	51.4

Row 6: Dudek's



Row 6: Adapted

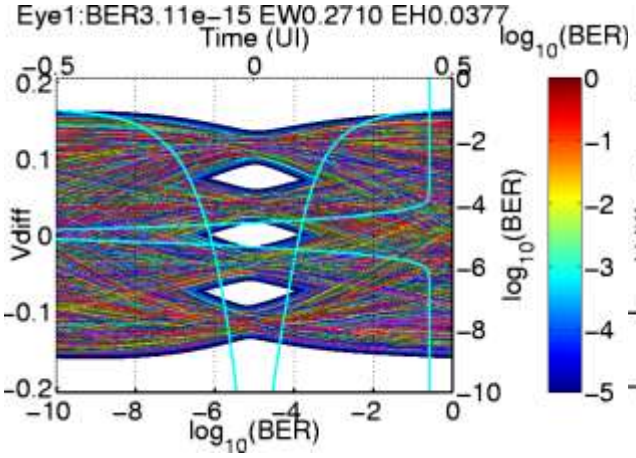


Eye Diagrams (Row 9,11: Dudek's vs Adapted)

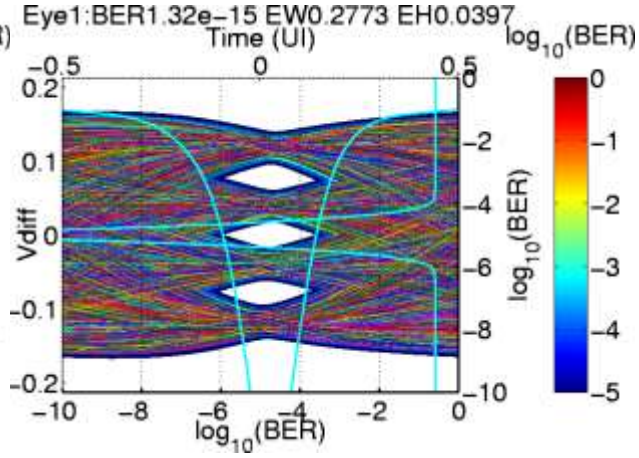
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.208	0.225	0.206
Adapted	0.217	0.233	0.212
EH (mV)	Lower	Middle	Upper
Dudek's	32.3	31.8	32.3
Adapted	32.8	33.2	34.2

Row 9: Dudek's



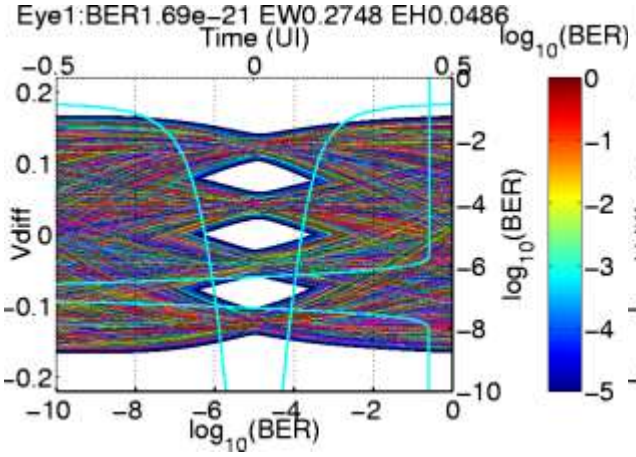
Row 9: Adapted



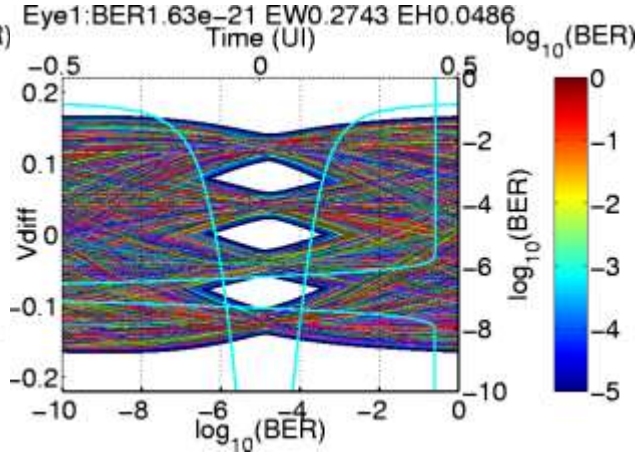
120E.4.2 Eye width/height @ 1E-5

EW (UI)	Lower	Middle	Upper
Dudek's	0.243	0.274	0.244
Adapted	0.243	0.274	0.244
EH (mV)	Lower	Middle	Upper
Dudek's	43.3	42.6	42.6
Adapted	43.2	42.6	42.6

Row 11: Dudek's



Row 11: Adapted



FUJITSU

Thank you