

400GAUI-8 C2M TP1a Eye Measurement Data

Jane Lim, Cisco
Pirooz Tooyserkani, Cisco

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Aknowledgements

- Wei Yao
- Liehui Ren
- Matt Traverso
- Marco Mazzini
- Upen Reddy Kareti

Scope

- Investigate if current 400GAUI-8 C2M TP1a eye spec can be met over 10dB channel
- Check the impact of QSFPDD connector to the eye quality, 3 cases were studied:
 - Case 1: 2x1 stacked Upper port
 - Case 2: 2x1 stacked Lower port
 - Case 3: 1x1 SMT
- Different host Transmitters were used for data comparison
- Same TP1a setup was used in all measurements
 - Only QSFPDD legacy pair was measured, as the QSFPDD HCB with new pairs can't meet IL spec

Annex 120E, C2M Measurement at TP1a

- The electrical characteristics for 400GAUI-8 C2M interface is defined at TP1a for the host
- Host compliance board (HCB) is used to verify the host electrical signal at TP1a.

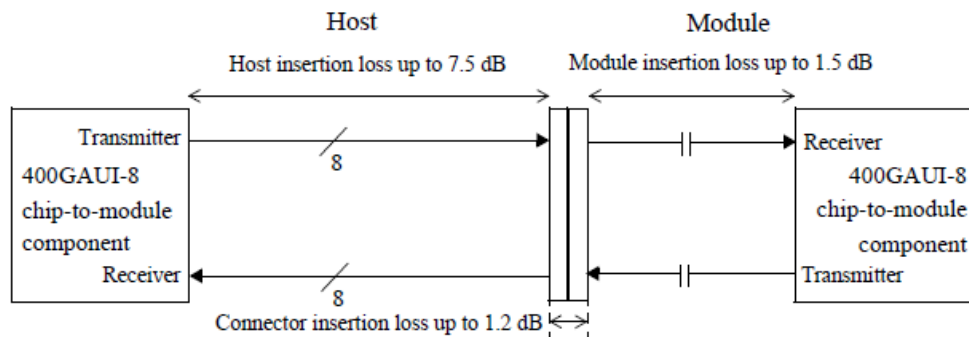


Figure 120E-3—400GAUI-8 chip-to-module insertion loss budget at 13.28 GHz

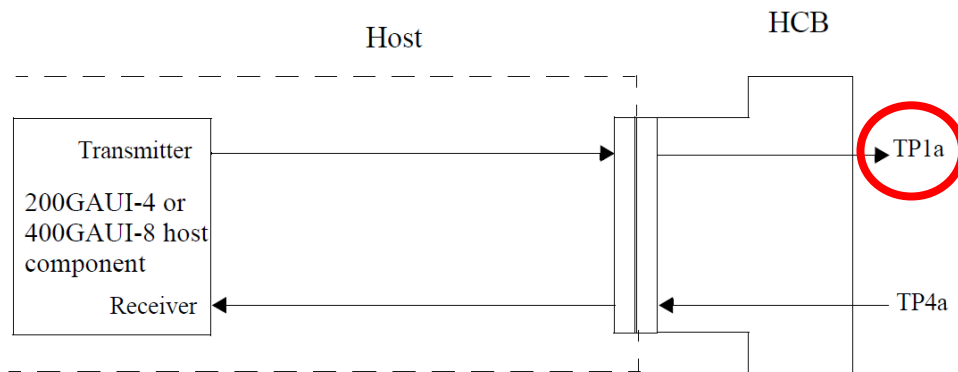


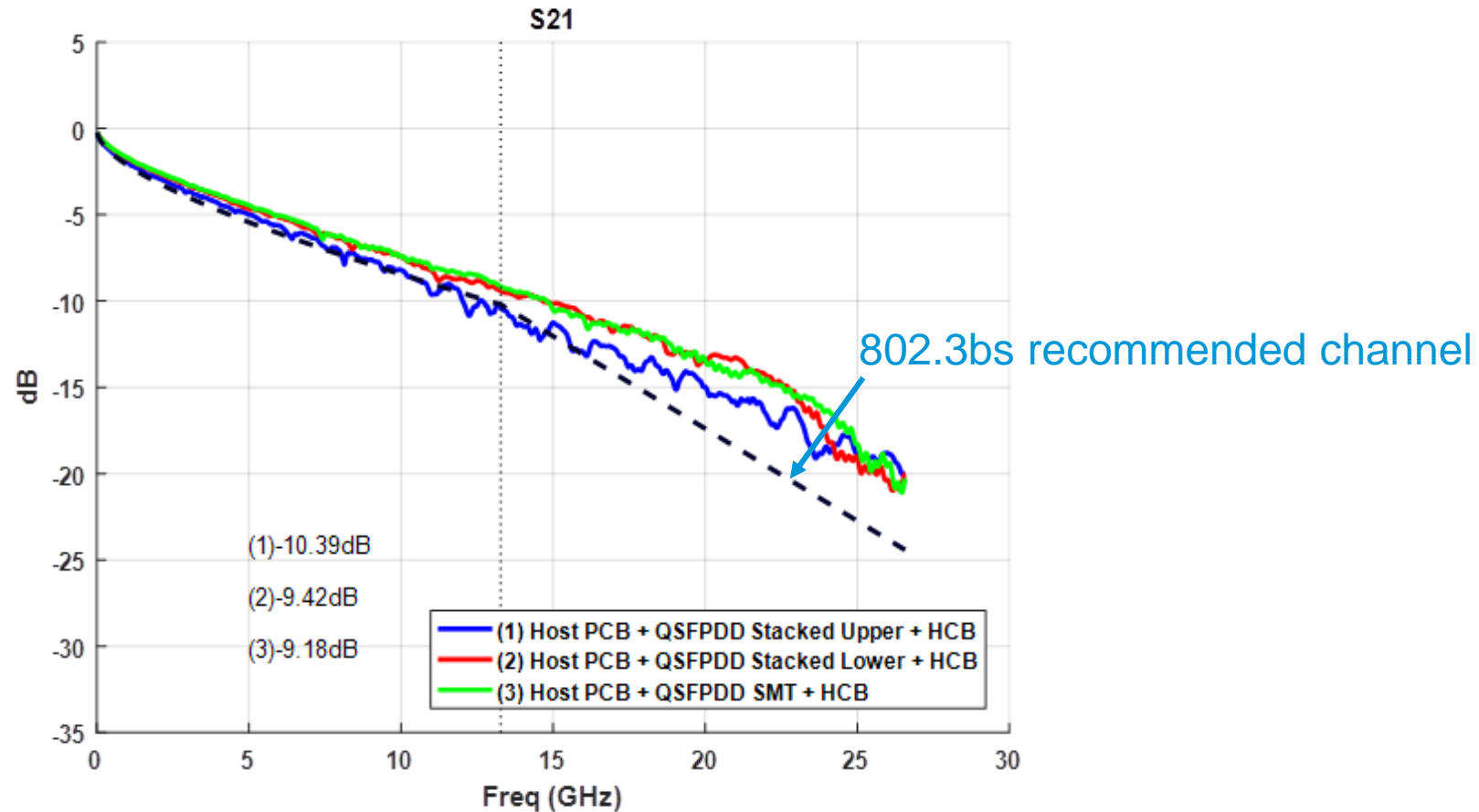
Figure 120E-5—Host 200GAUI-4 or 400GAUI-8 C2M compliance points

Table 120E-1—200GAUI-4 and 400GAUI-8 host output characteristics (at TP1a)

Parameter	Reference	Value	Units
Signaling rate per lane (range)	120E.3.1.1	26.5625 ± 100 ppm	GBd
DC common-mode output voltage (max)	120E.3.1.2	2.8	V
DC common-mode output voltage (min)	120E.3.1.2	-0.3	V
Single-ended output voltage (max)	120E.3.1.2	3.3	V
Single-ended output voltage (min)	120E.3.1.2	-0.4	V
AC common-mode output voltage (max, RMS)	120E.3.1.2	17.5	mV
Differential peak-to-peak output voltage (max)	120E.3.1.2	35 880	mV
<i>E_{SMW}</i> (Eye symmetry mask width)	120E.4.2	0.22	UI
Eye height, differential (min)	120E.4.2	32	mV
Differential output return loss (min)	83E.3.1.3	Equation (83E-2)	dB
Common to differential mode conversion return loss (min)	83E.3.1.3	Equation (83E-3)	dB
Differential termination mismatch (max)	120E.3.1.4	10	%
Transition time (min, 20% to 80%)	120E.3.1.5	10	ps

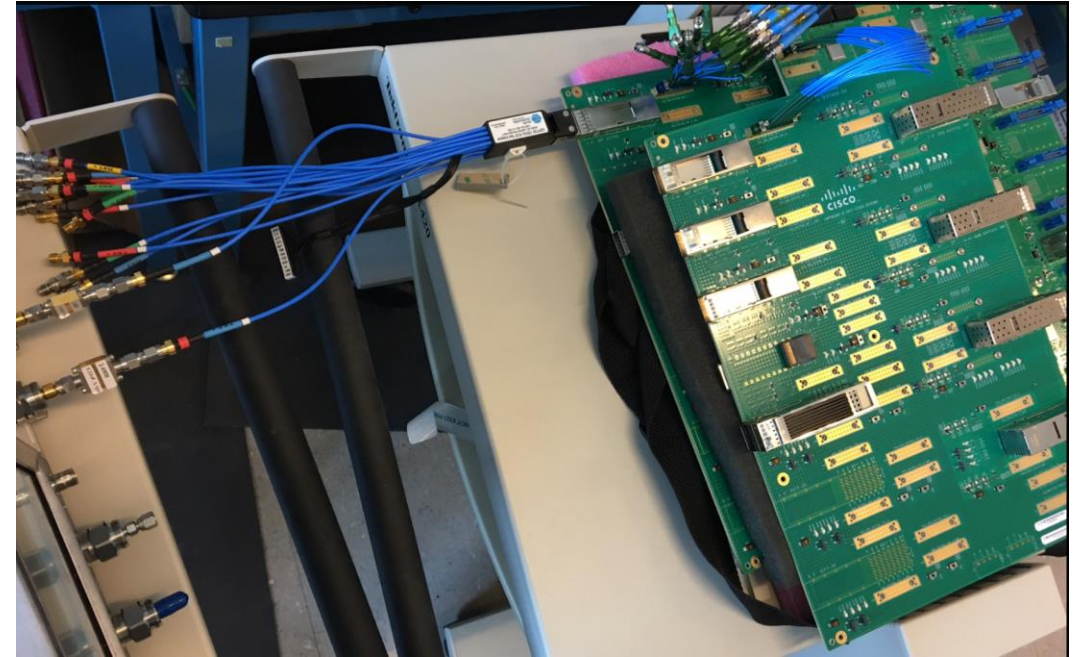
TP1a End to End Channel Insertion Loss

- Host PCB board with traces and QSFPDD connector mated with HCB



TP1a EH and EW Measurement Setup

- The host output eye is measured using reference receiver with a CTLE defined in 120E.3.1.7
- EH & EW measurement followed methodology defined in 120E.4.2
- Host TX equalization is optimized to meet eye requirements
- The peaking values from Table 120E-2 are selected based on maximum EW & EH
- Measurement is performed at room temp with typical Si & nominal voltage on all power supplies



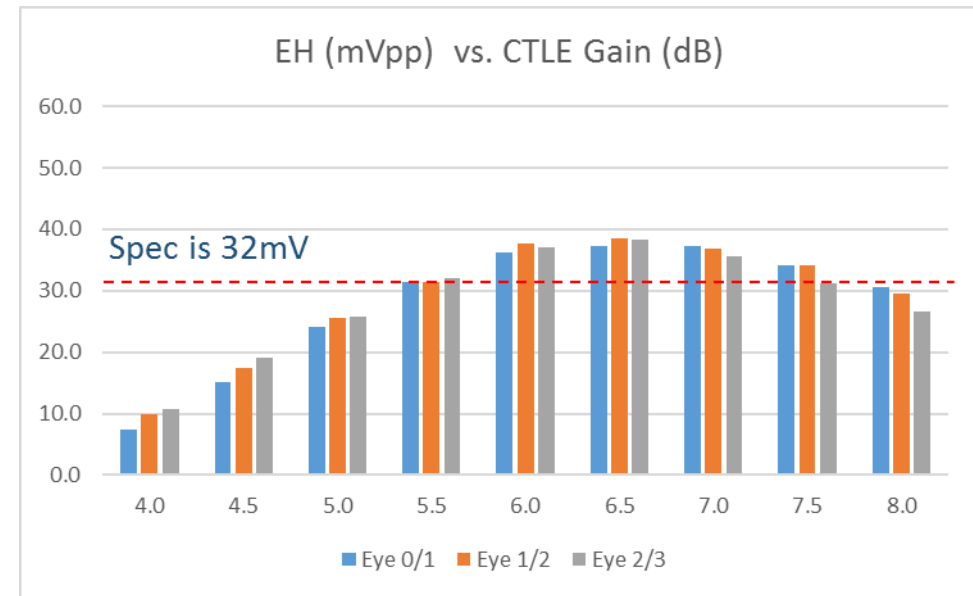
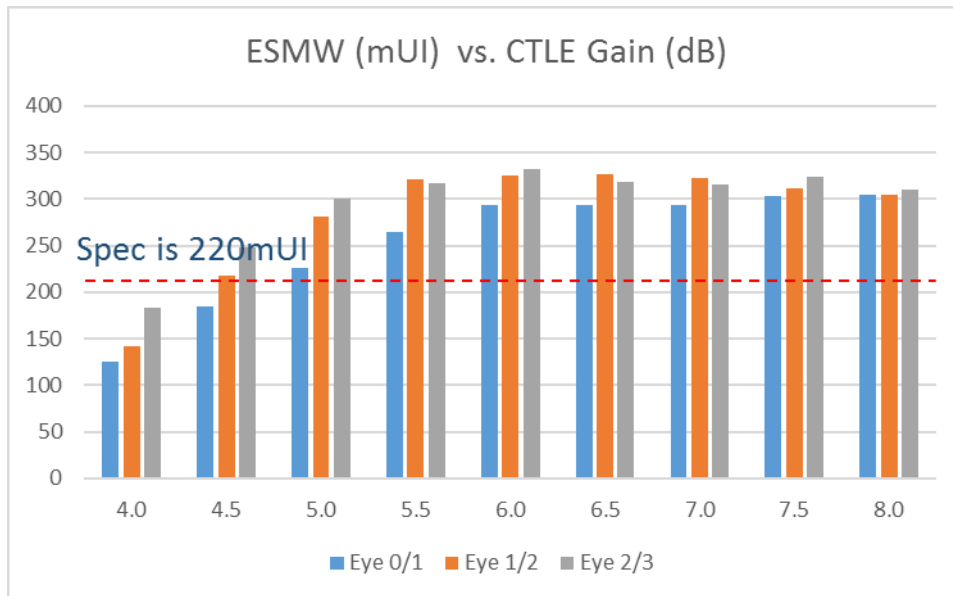
TP1a Eye Measurements Results @ Typical PVT

Serdes List	Channel	End to end loss @13.3 GHz (dB)	ESMW (mUI)	Eye height (mV)	Optimal CTLE Gain (dB)
Serdes A	Case 1: Host PCB + QDD Upper + HCB	10.4	293	37.2	6.5
Serdes A	Case 2: Host PCB + QDD Lower + HCB	9.5	314	44.4	6.0
Serdes A	Case 3: Host PCB + QDD SMT + HCB	9.2	301	45.6	6.0
Serdes B	Case 1: Host PCB + QDD Upper + HCB	10.4	233	32.5	7.0
Serdes B	Case 2: Host PCB + QDD Lower + HCB	9.5	263	41.9	6.5
Serdes B	Case 3: Host PCB + QDD SMT + HCB	9.2	306	52.3	6.5
Serdes C	Case 1: Host PCB + QDD Upper+HCB	10.4	248	45.7	5.0
Serdes C	Case 2: Host PCB + QDD Lower+HCB	9.5	278	55.1	4.5
Serdes C	Case 3: Host PCB + QDD SMT+HCB	9.2	287	58.0	4.5

- Results shown all 3 Serdes have low margin (<20%) meeting EW and/or EH specs: EW (min) = 0.22 mUI; EH (min) = 32 mV
- Measured values project that the worst PVT corner may violate the spec

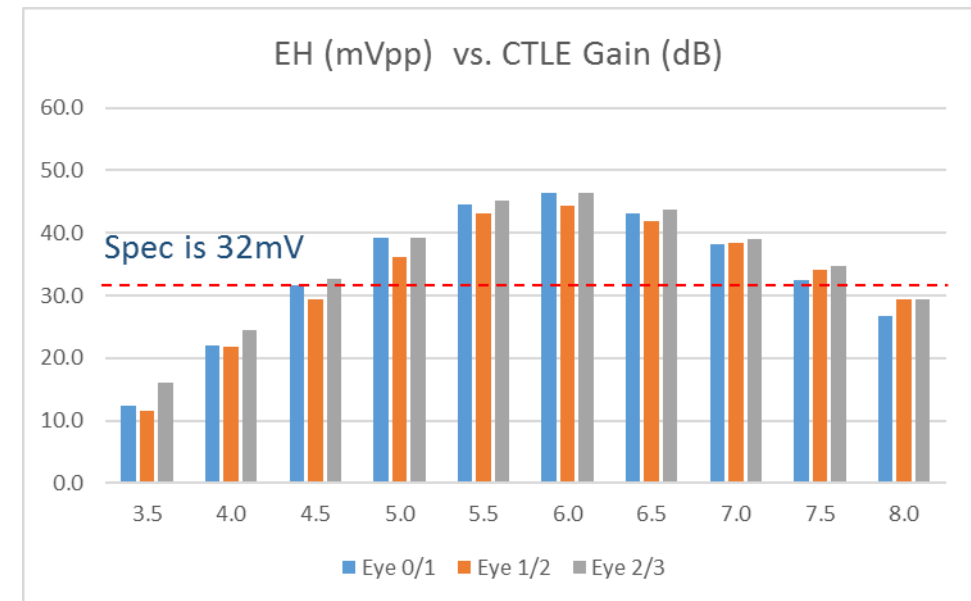
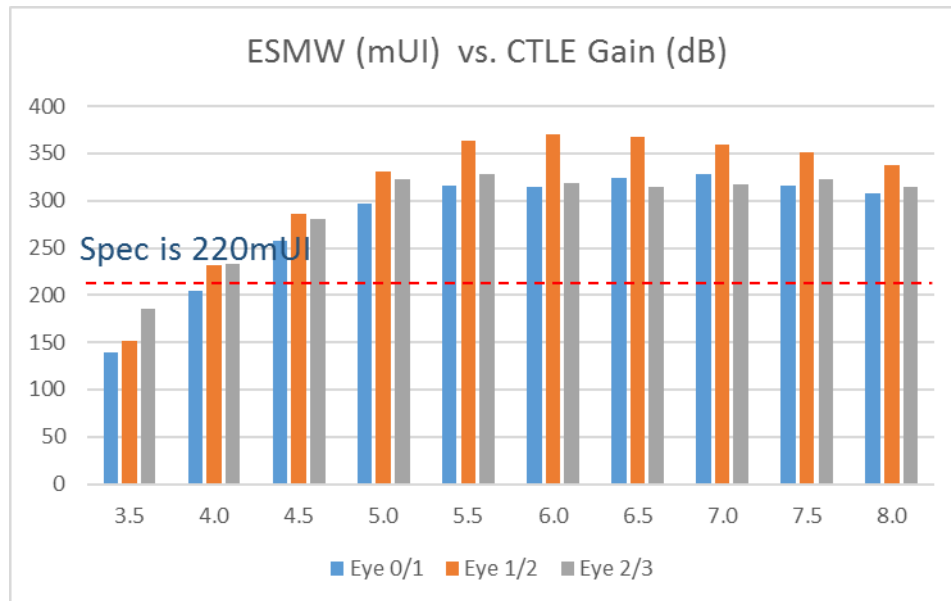
Serdes "A" TP1a Eye Results – Case 1

CTLE (dB)	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
4.0	126	7.3	142	9.8	183	10.7	126	7.3
4.5	184	15.2	218	17.5	248	19.0	184	15.2
5.0	226	24.1	281	25.6	301	25.7	226	24.1
5.5	264	31.4	321	31.4	317	32.1	264	31.4
6.0	293	36.3	325	37.6	332	37.0	293	36.3
6.5	293	37.2	326	38.5	319	38.4	293	37.2
7.0	293	37.4	322	36.9	316	35.7	293	35.7
7.5	303	34.1	312	34.1	324	31.2	303	31.2
8.0	305	30.5	304	29.5	310	26.7	304	26.7



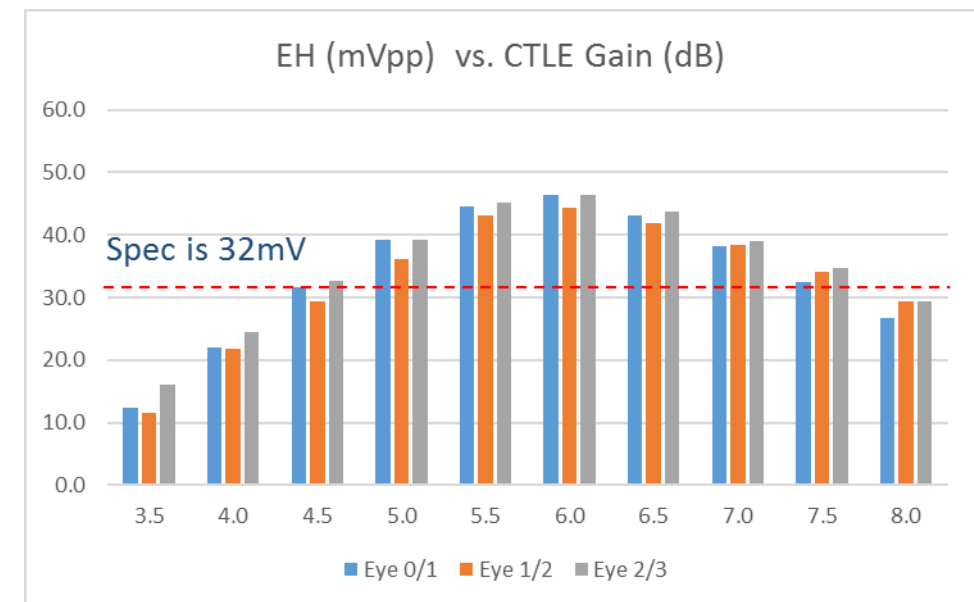
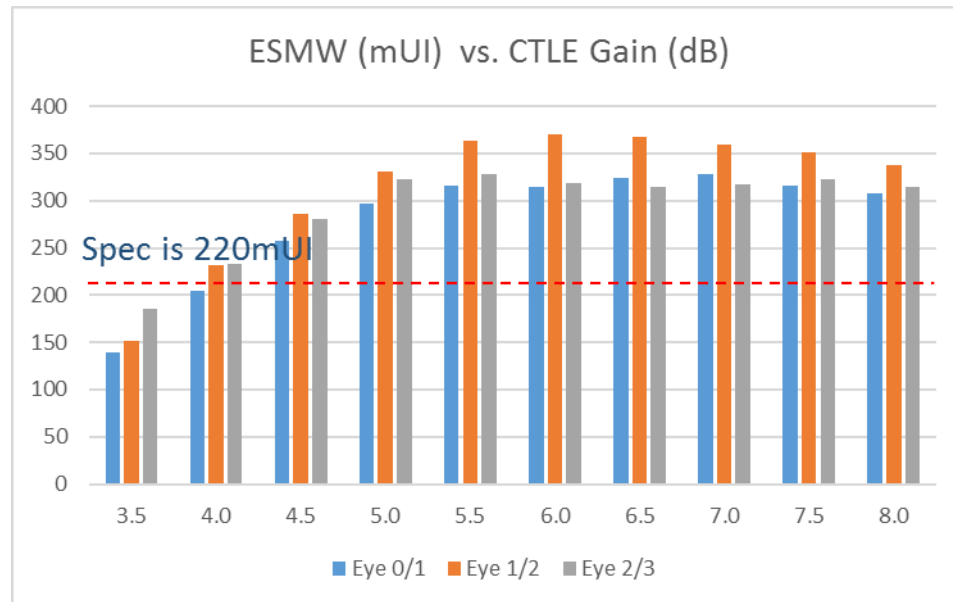
Serdes "A" TP1a Eye Results – Case 2

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	139	12.4	152	11.6	186	16.1	139	11.6
4.0	204	22.0	231	21.9	233	24.5	204	21.9
4.5	257	31.7	286	29.4	281	32.7	257	29.4
5.0	297	39.2	331	36.2	323	39.3	297	36.2
5.5	316	44.6	364	43.1	328	45.2	316	43.1
6.0	314	46.4	370	44.4	319	46.4	314	44.4
6.5	324	43.2	367	42.0	314	43.8	314	42.0
7.0	328	38.3	360	38.4	317	39.0	317	38.3
7.5	316	32.4	351	34.2	322	34.7	316	32.4
8.0	308	26.7	338	29.5	315	29.4	308	26.7



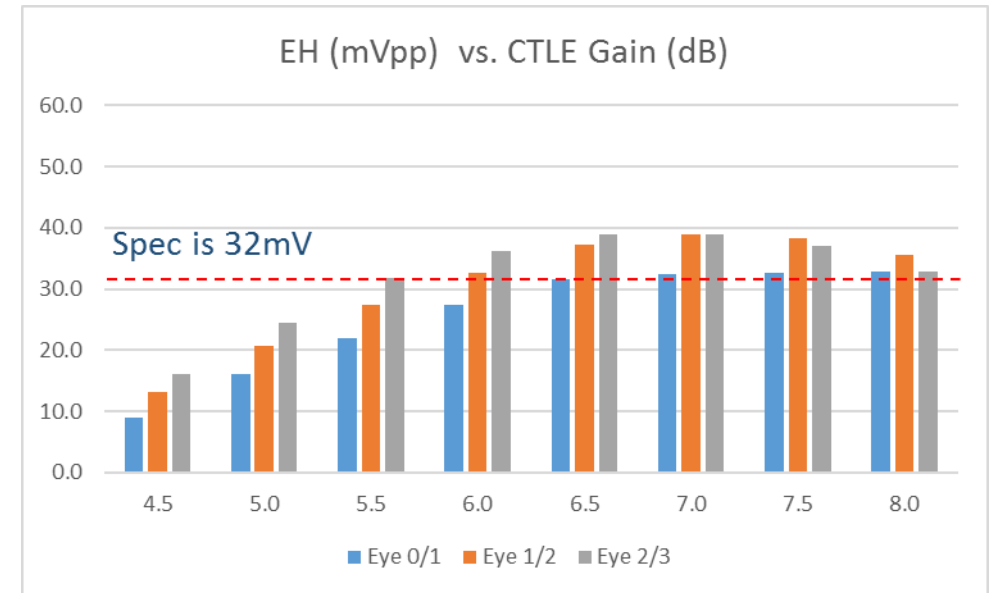
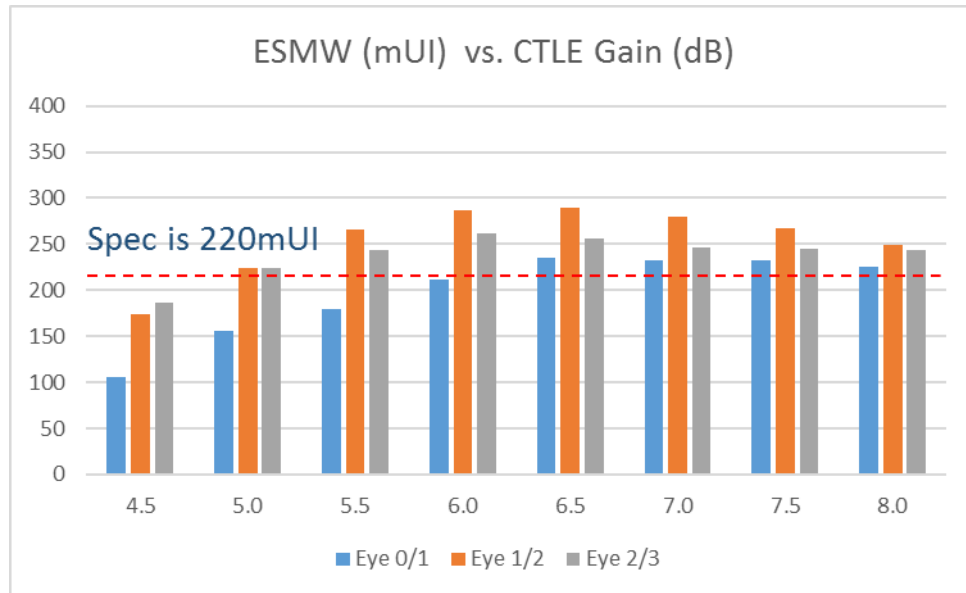
Serdes "A" TP1a Eye Results – Case 3

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	137	10.6	146	11.6	165	16.1	137	10.6
4.0	194	21.1	217	19.4	226	25.4	194	19.4
4.5	232	28.4	270	28.4	268	33.4	232	28.4
5.0	275	37.8	316	36.2	301	38.8	275	36.2
5.5	307	44.0	346	42.6	307	44.0	307	42.6
6.0	301	45.6	360	45.6	320	47.7	301	45.6
6.5	301	43.5	359	44.1	322	44.2	301	43.5
7.0	297	38.3	352	38.4	315	38.9	297	38.3
7.5	295	32.6	343	32.7	315	33.8	295	32.6
8.0	287	26.2	339	27.3	313	28.4	287	26.2



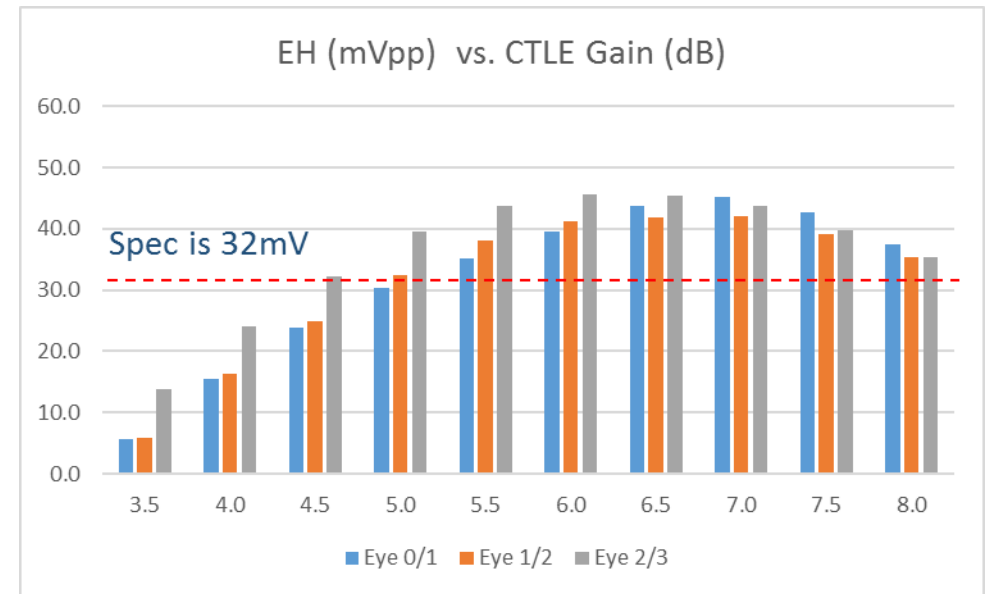
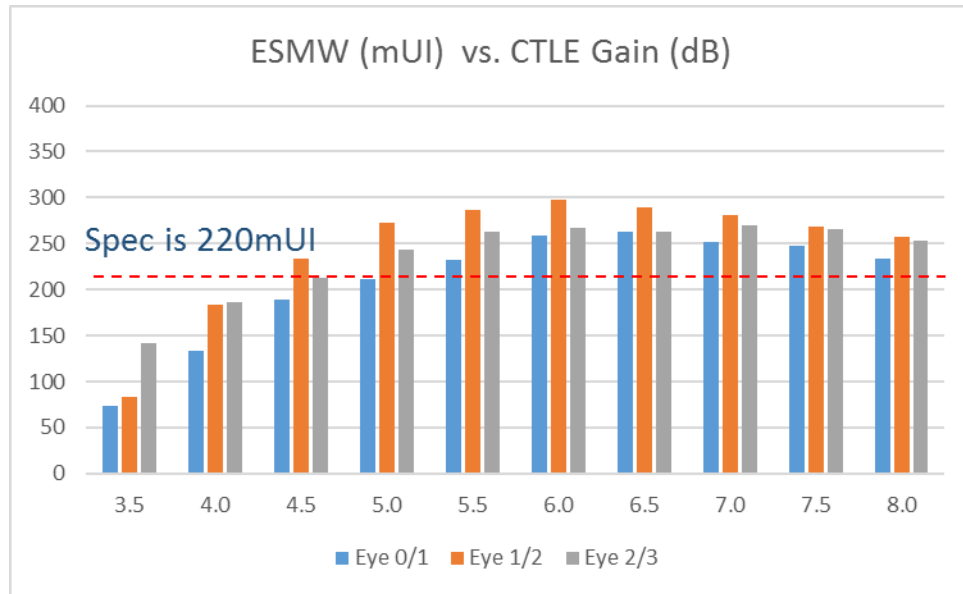
Serdes "B" TP1a Eye Results – Case 1

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
4.5	105	9.0	174	13.1	187	16.2	105	9.0
5.0	156	16.0	224	20.8	224	24.5	156	16.0
5.5	180	21.9	266	27.3	243	31.8	180	21.9
6.0	211	27.5	287	32.6	262	36.1	211	27.5
6.5	235	31.6	289	37.3	256	38.9	235	31.6
7.0	233	32.5	280	38.9	247	38.9	233	32.5
7.5	233	32.6	267	38.4	245	37.0	233	32.6
8.0	225	32.8	249	35.5	243	32.9	225	32.8



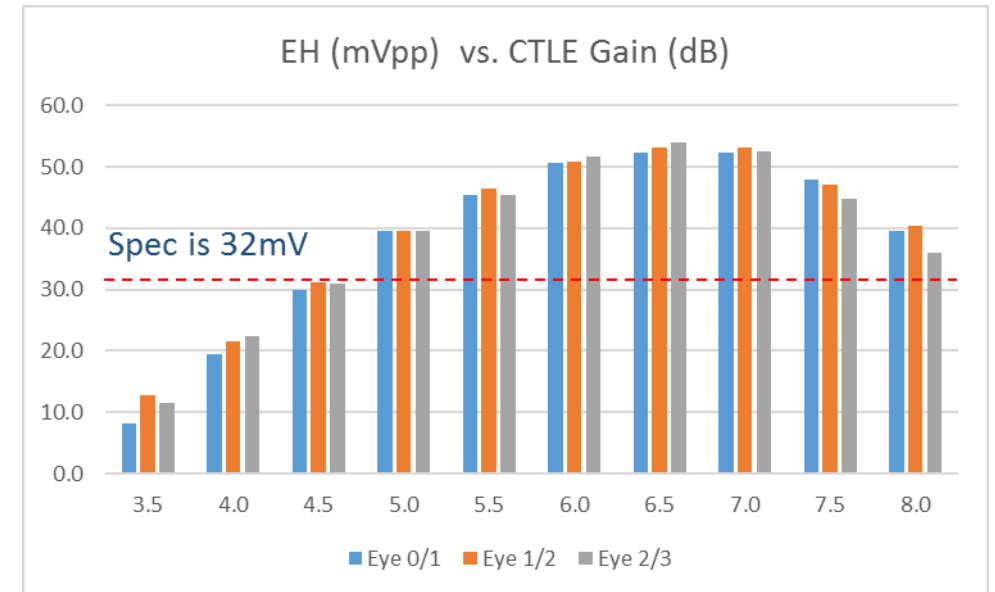
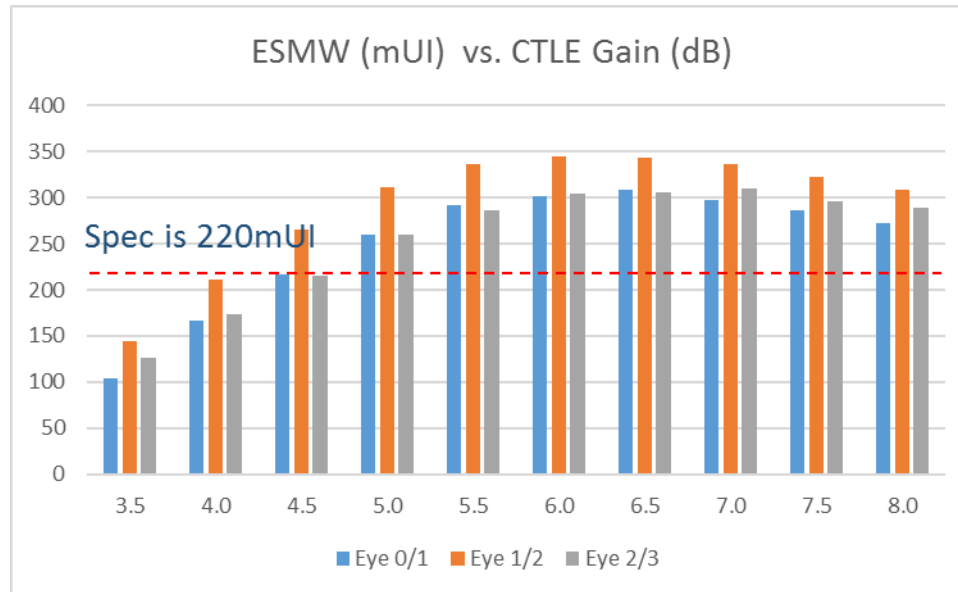
Serdes "B" TP1a Eye Results – Case 2

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	74	5.6	83	5.8	142	13.9	74	5.6
4.0	133	15.4	183	16.4	187	24.1	133	15.4
4.5	189	23.8	234	24.8	213	32.2	189	23.8
5.0	212	30.4	273	32.5	244	39.5	212	30.4
5.5	232	35.2	286	38.1	263	43.7	232	35.2
6.0	259	39.6	298	41.3	267	45.6	259	39.6
6.5	263	43.7	290	41.9	263	45.4	263	41.9
7.0	252	45.3	281	42.1	270	43.7	252	42.1
7.5	248	42.6	268	39.1	265	39.8	248	39.1
8.0	233	37.6	258	35.4	253	35.4	233	35.4



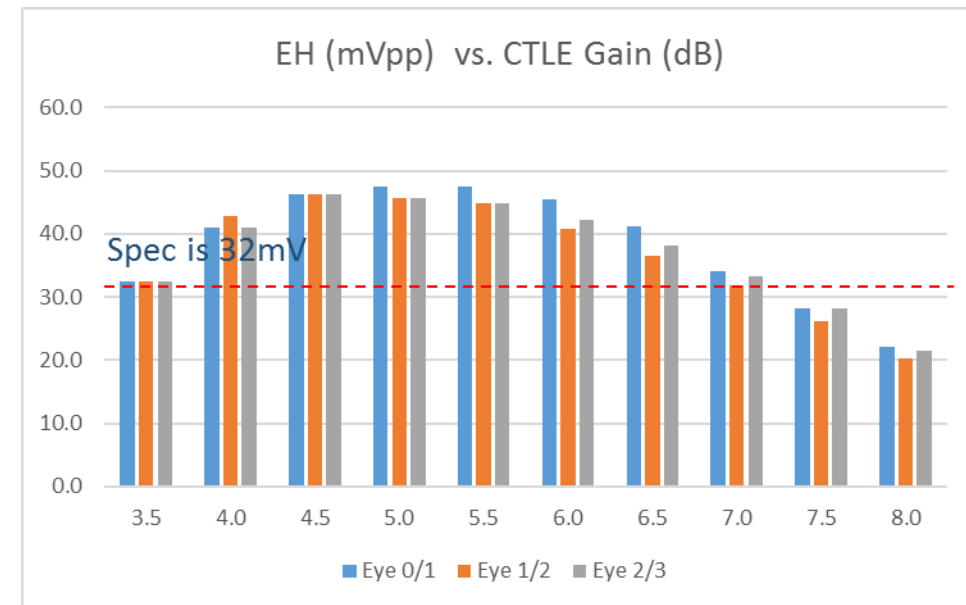
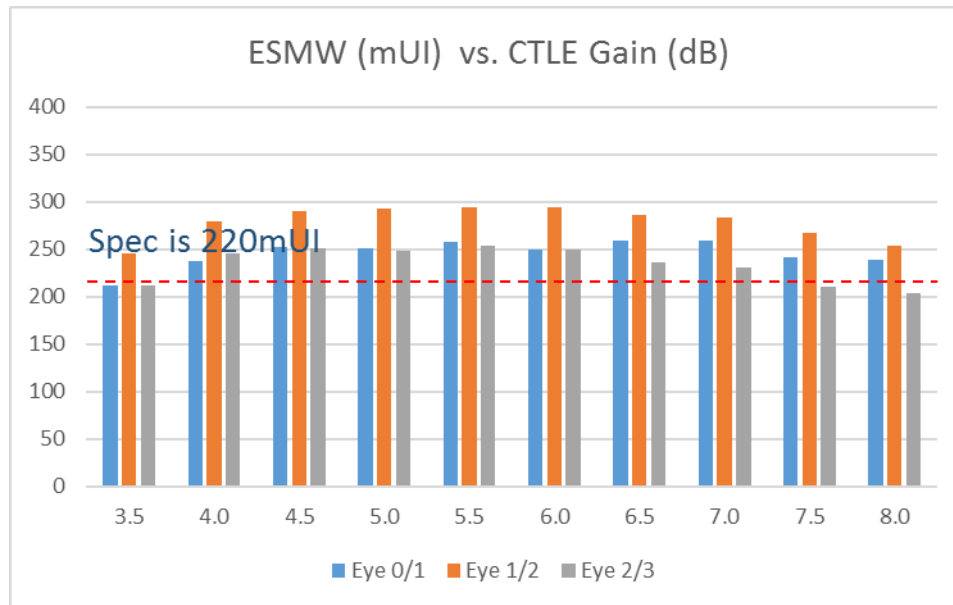
Serdes "B" TP1a Eye Results – Case 3

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	104	8.1	145	12.7	126	11.6	104	8.1
4.0	167	19.4	211	21.6	173	22.5	167	19.4
4.5	217	30.0	266	31.1	216	31.0	216	30.0
5.0	260	39.5	311	39.6	260	39.5	260	39.5
5.5	292	45.5	336	46.4	286	45.5	286	45.5
6.0	301	50.7	345	50.8	304	51.6	301	50.7
6.5	308	52.3	344	53.2	306	54.0	306	52.3
7.0	298	52.4	337	53.2	310	52.5	298	52.4
7.5	286	47.9	323	47.2	296	44.9	286	44.9
8.0	272	39.6	309	40.3	289	36.0	272	36.0



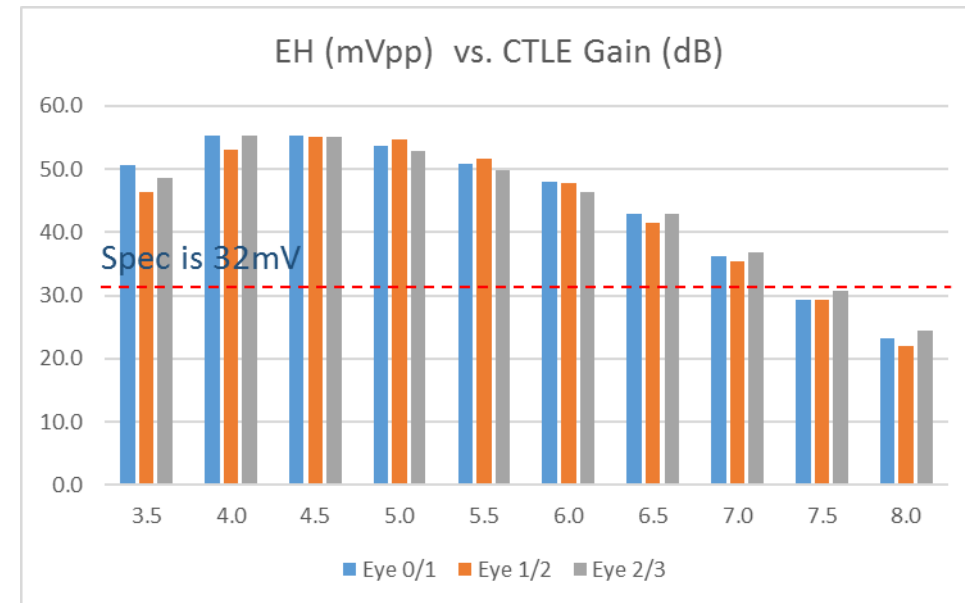
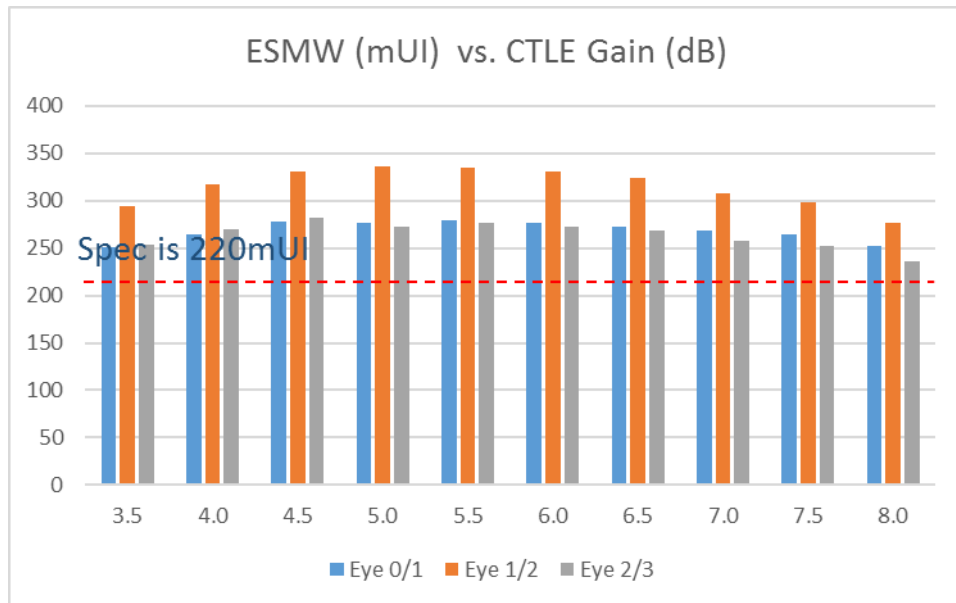
Serdes "C" TP1a Eye Results – Case 1

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	212	32.5	246	32.5	212	32.4	212	32.4
4.0	237	40.9	279	42.9	246	41.0	237	40.9
4.5	252	46.3	290	46.3	251	46.3	251	46.3
5.0	251	47.5	292	45.7	248	45.7	248	45.7
5.5	257	47.4	294	44.8	254	44.8	254	44.8
6.0	250	45.5	294	40.7	249	42.3	249	40.7
6.5	259	41.3	286	36.5	236	38.1	236	36.5
7.0	259	34.1	283	31.9	231	33.4	231	31.9
7.5	241	28.2	267	26.2	210	28.2	210	26.2
8.0	239	22.2	254	20.2	203	21.5	203	20.2



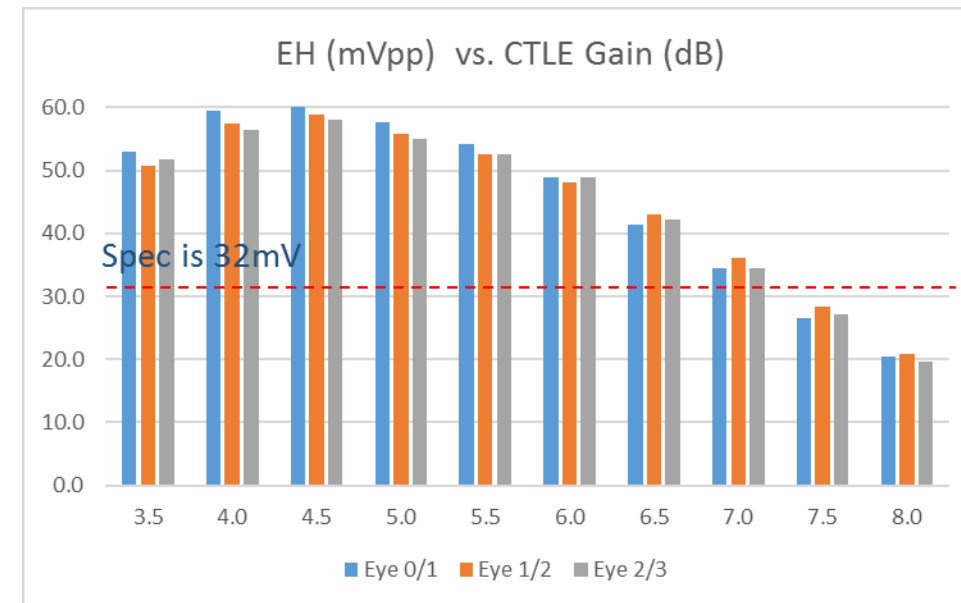
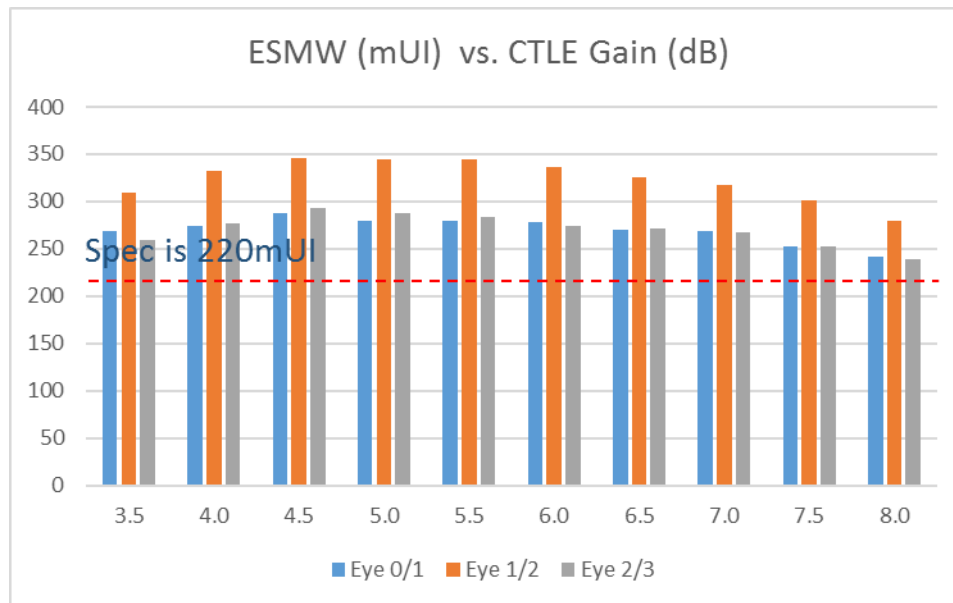
Serdes "C" TP1a Eye Results – Case 2

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	251	50.7	294	46.3	254	48.6	251	46.3
4.0	265	55.2	317	53.1	270	55.3	265	53.1
4.5	278	55.2	331	55.1	282	55.1	278	55.1
5.0	277	53.7	336	54.6	273	52.9	273	52.9
5.5	279	50.8	335	51.7	277	49.9	277	49.9
6.0	276	47.9	331	47.8	273	46.3	273	46.3
6.5	273	42.9	324	41.4	268	43.0	268	41.4
7.0	269	36.2	308	35.4	257	36.9	257	35.4
7.5	265	29.3	298	29.2	252	30.7	252	29.2
8.0	252	23.2	277	21.9	236	24.5	236	21.9



Serdes "C" TP1a Eye Results – Case 3

CTLE	Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
3.5	268	52.9	309	50.7	259	51.8	259	50.7
4.0	274	59.5	332	57.4	277	56.3	274	56.3
4.5	287	60.8	346	58.9	293	58.0	287	58.0
5.0	280	57.6	345	55.8	287	54.9	280	54.9
5.5	280	54.2	344	52.5	283	52.6	280	52.5
6.0	278	48.9	337	48.1	274	48.8	274	48.1
6.5	270	41.4	325	43.0	272	42.2	270	41.4
7.0	268	34.5	318	36.0	267	34.5	267	34.5
7.5	253	26.5	301	28.5	252	27.1	252	26.5
8.0	241	20.4	280	21.0	239	19.7	239	19.7



Reference CTLE Bandwidth Measurements

- Ref: Comment # r03-12 by Yasuo Hidaka from Fujitsu, 4 options were investigated
- Serdes A with case 1 used in this experiment

	Reference CTLE							TX FIR			Eye 0/1		Eye 1/2		Eye 2/3		Overall Min.	
	Peaking	DC Gain	P1 freq	Z1 freq	P2 freq	Z2 freq	P3 freq	Pre	Main	Post	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)	ESMW (mUI)	EH (mV)
Baseline	6.5	0.473	15.600	4.399	14.100	1.000	1.200	-0.11	0.83	-0.06	300	37.3	315	36.0	290	37.3	290	36.0
	7.5	0.422	15.600	3.880	14.100	1.000	1.200	-0.11	0.89	0	332	38.6	331	38.5	317	40.4	317	38.5
	8.0	0.398	15.600	3.647	14.100	1.000	1.200	-0.11	0.89	0	301	40.4	329	37.9	315	39.8	301	37.9
Option 1	4.5	0.596	53.125	8.394	14.100	1.000	1.200	-0.11	0.76	-0.13	265	28.5	254	24.7	244	25.9	244	24.7
	5.5	0.531	53.125	7.385	14.100	1.000	1.200	-0.11	0.79	-0.11	283	27.0	288	24.5	257	24.6	257	24.5
	6.5	0.473	53.125	6.521	14.100	1.000	1.200	-0.11	0.83	-0.06	263	24.8	258	21.6	235	20.4	235	20.4
	7.5	0.422	53.125	5.772	14.100	1.000	1.200	-0.11	0.86	-0.03	292	26.5	272	24.1	264	23.5	264	23.5
	8.0	0.398	53.125	5.434	14.100	1.000	1.200	-0.11	0.89	0	307	29.5	312	28.4	270	27.4	270	27.4
	8.5	0.376	53.125	5.117	14.100	1.000	1.200	-0.11	0.89	0	310	27.6	332	29.3	306	28.8	306	27.6
Option 2	4.5	0.596	53.125	6.611	10.625	1.000	1.200	-0.11	0.76	-0.13	292	32.5	293	29.3	281	28.0	281	28.0
	5.5	0.531	53.125	5.829	10.625	1.000	1.200	-0.11	0.79	-0.11	295	31.6	308	29.3	269	29.8	269	29.3
	6.5	0.473	53.125	5.155	10.625	1.000	1.200	-0.11	0.83	-0.06	297	31.1	320	31.1	275	29.9	275	29.9
	7.5	0.422	53.125	4.569	10.625	1.000	1.200	-0.11	0.86	-0.03	324	36.0	339	34.2	308	33.5	308	33.5
	8.0	0.398	53.125	4.303	10.625	1.000	1.200	-0.11	0.89	0	338	34.1	361	34.1	325	34.7	325	34.1
	8.5	0.376	53.125	4.054	10.625	1.000	1.200	-0.11	0.89	0	352	35.9	373	37.7	331	37.7	331	35.9
Option 3	4.5	0.596	26.5625	7.084	14.100	1.000	1.200	-0.11	0.76	-0.13	283	31.3	282	28.0	273	29.3	273	28.0
	5.5	0.531	26.5625	6.198	14.100	1.000	1.200	-0.11	0.79	-0.11	272	30.7	274	27.0	257	28.8	257	27.0
	6.5	0.473	26.5625	5.453	14.100	1.000	1.200	-0.11	0.83	-0.06	309	32.3	309	30.5	282	29.2	282	29.2
	7.5	0.422	26.5625	4.813	14.100	1.000	1.200	-0.11	0.86	-0.03	321	35.1	339	34.6	308	32.8	308	32.8
	8.0	0.398	26.5625	4.527	14.100	1.000	1.200	-0.11	0.89	0	332	35.2	356	36.3	331	35.8	331	35.2
	8.5	0.376	26.5625	4.259	14.100	1.000	1.200	-0.11	0.89	0	335	36.4	365	36.4	336	38.1	335	36.4
Option 4	4.5	0.596	26.5625	5.792	10.625	1.000	1.200	-0.11	0.76	-0.13	295	34.8	310	31.6	286	31.6	286	31.6
	5.5	0.531	26.5625	5.078	10.625	1.000	1.200	-0.11	0.79	-0.11	290	34.0	309	32.8	280	33.4	280	32.8
	6.5	0.473	26.5625	4.474	10.625	1.000	1.200	-0.11	0.83	-0.06	312	36.9	315	35.1	286	35.1	286	35.1
	7.5	0.422	26.5625	3.953	10.625	1.000	1.200	-0.11	0.86	-0.03	301	36.9	307	33.9	312	38.7	301	33.9
	8.0	0.398	26.5625	3.719	10.625	1.000	1.200	-0.11	0.89	0	337	40.6	351	39.9	331	41.2	331	39.9
	8.5	0.376	26.5625	3.500	10.625	1.000	1.200	-0.11	0.89	0	327	39.1	342	37.9	339	39.1	327	37.9
	9.0	0.355	26.5625	3.296	10.625	1.000	1.200	-0.11	0.89	0	320	34.9	326	33.8	331	35.4	320	33.8

Best results
• EW +5% better

Conclusions

- It is challenging to meet current 400GAUI-8 TP1a eye specs even at typ. PVT
 - ESMW & EH suffer lower margin (< 20%)
 - 100G CAUI-4 has much better eye margin (> 50%)
- Measurements were done using legacy HCB
 - QSFPDD HCB with new pairs could further reduce the margin
- Upper & lower eyes have worse EW than the middle eye due to the CTLE imposed BW limitation
- Adjusting reference CTLE bandwidth can improve ESMW by ~5% with Option 2, 3, 4
 - Option 3 seems to be the best compromise with the least change to CTLE pole freq

Recommendations

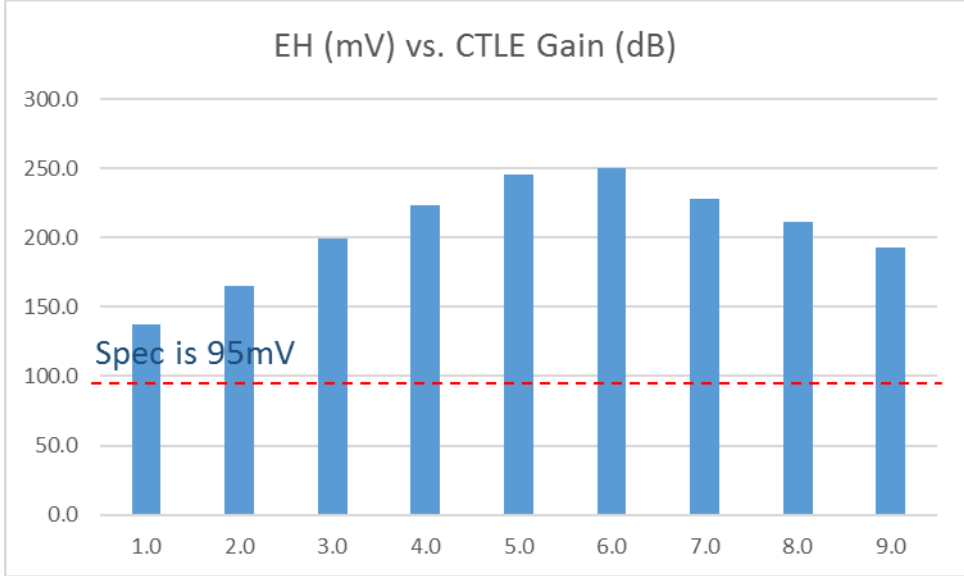
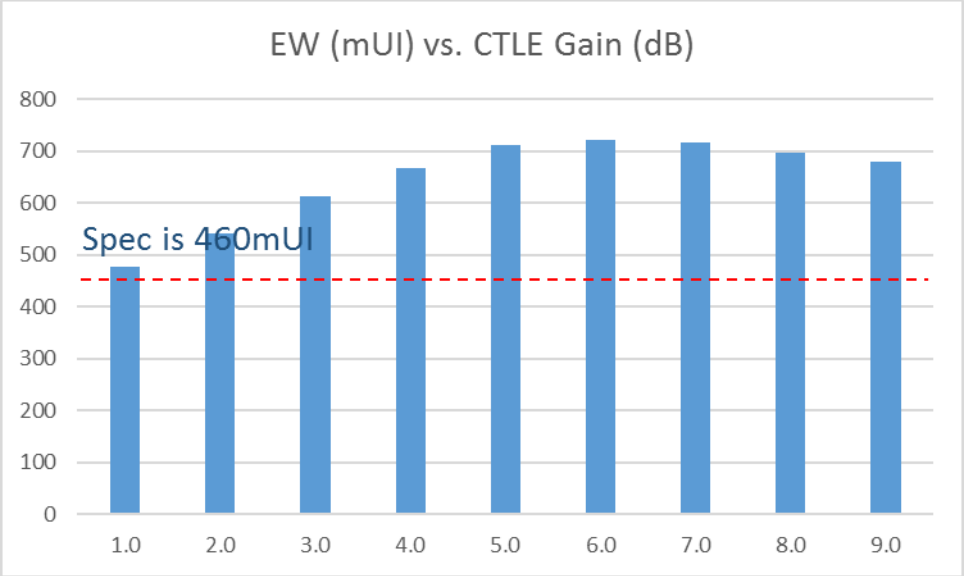
- Improve robustness of module receiver input from host to meet $1E-5$ BER
 - module VSR receiver adds the capability to adjust the sampling point of each PAM4 eyes
- Host VSR transmitter adds the capability to adjust the inner eye levels
 - with same level separation mismatch ratio RLM(min) of 0.95 as per C2C specs of Table 120D–1
- Modify reference CTLE pole value to better resemble the actual module receiver behavior
- The data shown PAM4 signaling is very sensitive to channel variation
 - continuously adaptive CTLE is a must!
- Future work:
 - Measure channels at different voltage and temperature corners
 - Characterization with QSFPDD new pairs when the HCB is available
 - More measurements with different CTLE poles values to increase the eye margin

Backup Slides

100G CAUI4 Eye Results (1)

- Same TP1a channel setup
- Use 28nm 25G NRZ host serdes

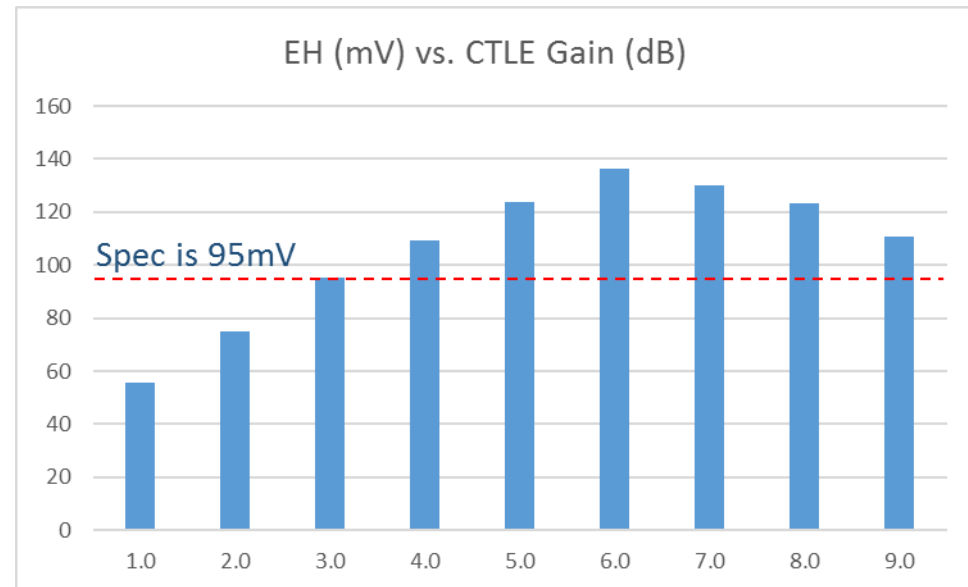
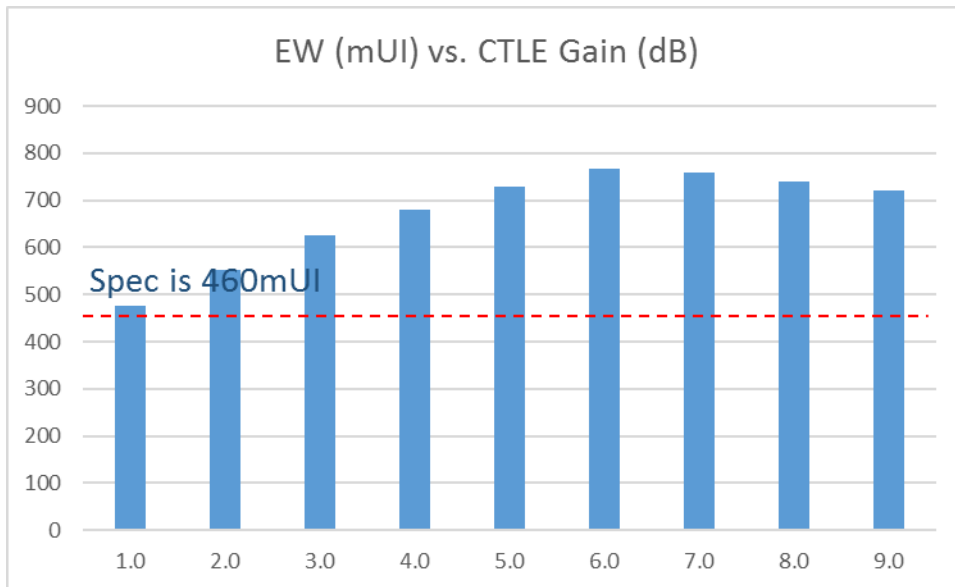
CTLE	EW (ps)	EW (mUI)	EH (mV)
1.0	18.5	476	137.0
2.0	21.0	542	165.5
3.0	23.8	613	199.0
4.0	25.9	668	223.4
5.0	27.6	712	246.0
6.0	28.0	722	250.4
7.0	27.8	716	228.4
8.0	27.0	697	211.8
9.0	26.4	679	193.0



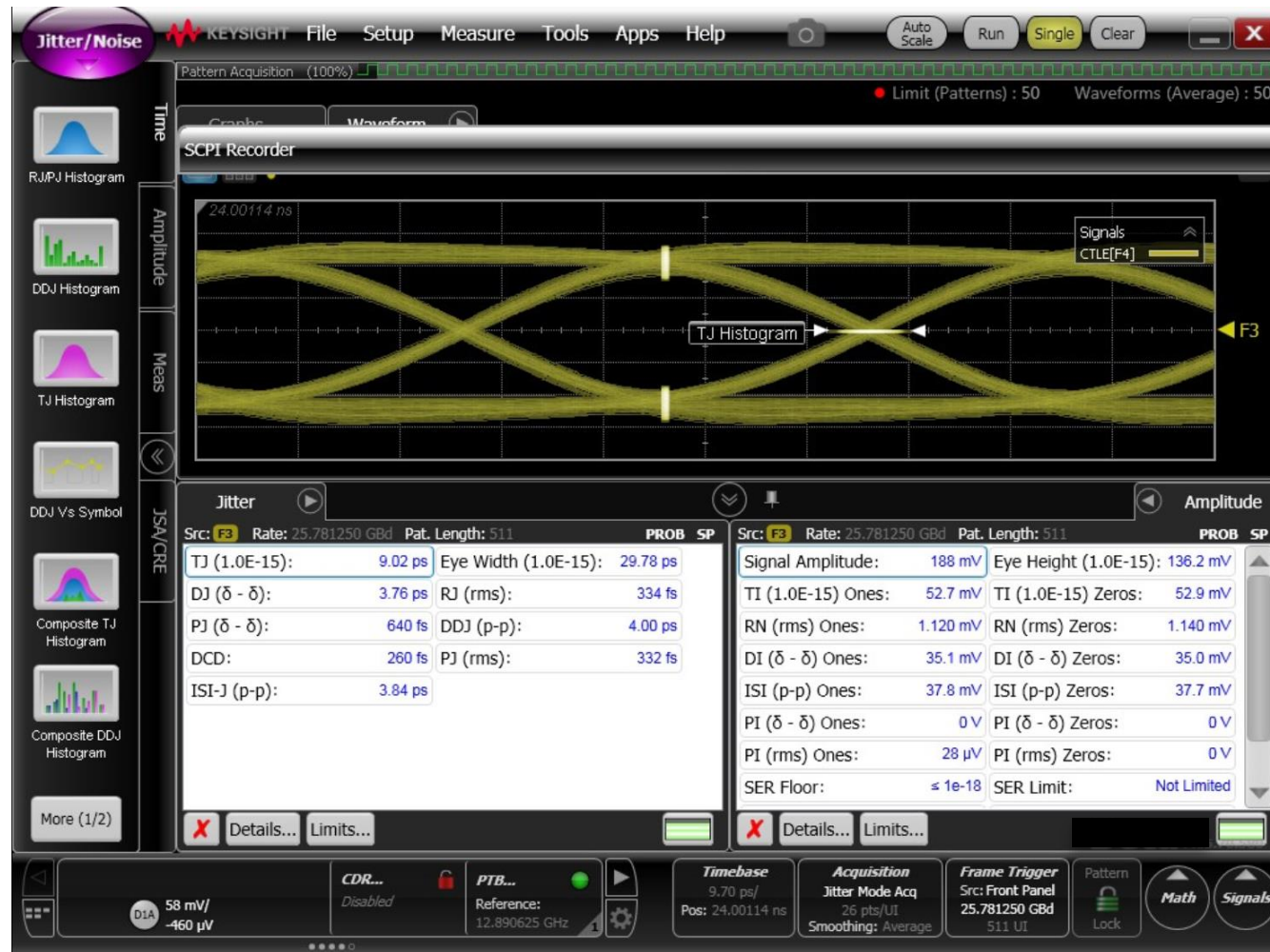
100G CAUI4 Eye Results (2)

- Same TP1a channel setup
- Use 16nm 56G PAM4 host serdes configured in 25G NRZ mode

CTLE	EW (ps)	EW (mUI)	EH (mV)
1.0	18.48	476	55.6
2.0	21.38	551	75
3.0	24.3	626	95.2
4.0	26.36	679	109.4
5.0	28.26	728	124
6.0	29.78	768	136.2
7.0	29.48	760	130
8.0	28.72	740	123.5
9.0	27.98	721	110.7



Representative 100G CAUI-4 TP1a Eye Plot



Representative 400GAUI-8 TP1a Eye Plot



Thank You !