Proposed reference equalizer change in Clause 124.

Comment r01-21 supporting material

May 2017, New Orleans, LA, USA

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Supporters

- Atul Gupta - Macom
- Bharat Tailor - Semtech
- Dave Lewis - Lumentum
- Greg LeCheminant - Keysight
- Francesco Caggioni – Macom
- Frank Chang - Inphi
- Kohichi Tamura – Oclaro
- Mark Kimber - Semtech
- Pavel Zivny - Tektronix
- Rajiv Pancholy - Broadcom
- Sacha Corbeil – Lumentum
- Vasudevan Parthasarathy – Broadcom
- Winston Way – Neophotonics
- Ali Ghiasi – Ghiasi Quantum
- Hai-Feng Liu – Intel

Pre-Introduction

- Transmitters which demonstrate good sensitivity have failing TDECQ
  - See our ad hoc presentation (mazzini_01a_0517_smf), and way_3bs_01_0517
- First gen products will likely all be “long” T-spaced equalizer receivers whereas TDECQ is currently a short (5x) T/2-spaced receiver
- Possible interop “hole in standard” due to high diversity of transmitter technologies
  - No publicly available EML based waveforms
  - No publicly available DML based waveforms

Introduction

Several contributions are looking into possible changes for TDECQ reference equalizer for 400GBASE-DR4 (and in general, for link based on 53GBaud).

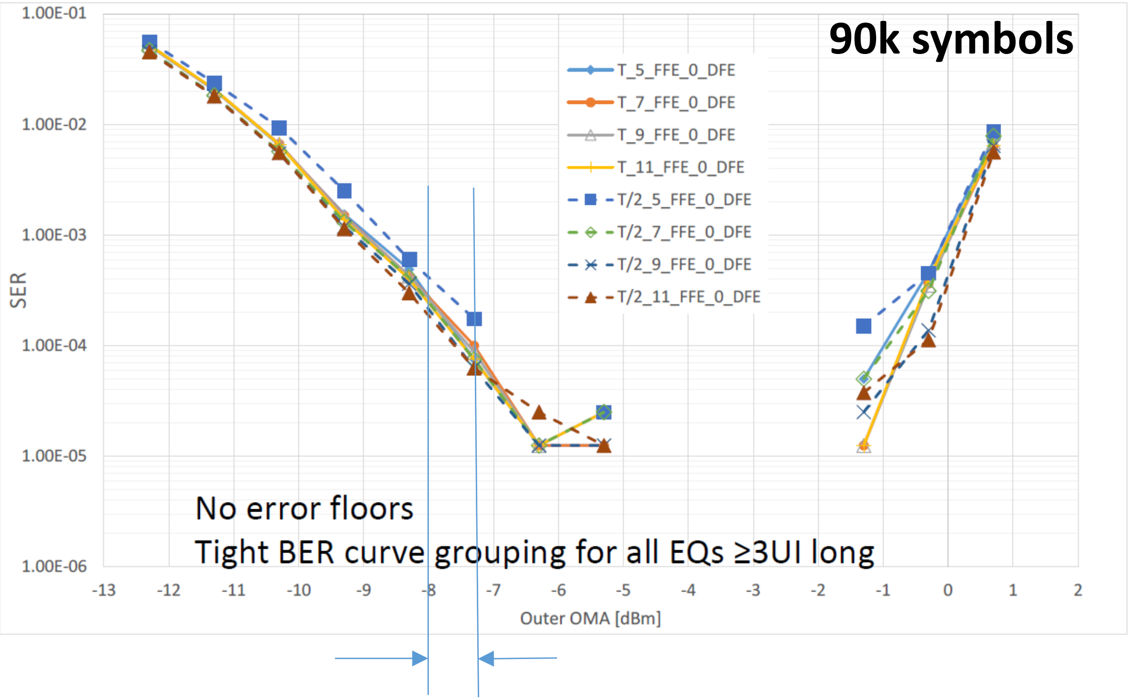
In proposal we'll:

1. Show sensitivity plot versus equalizer over waveforms acquired in Cisco labs.
   - Verified correlation with other works.
2. Show Cisco Lab Tx: TDECQ versus equalizer type and length.
   - RX sensitivity does not properly scale with TDECQ trends and maximum limits.
3. Show calculated and measured deltaOMA/delta SNR (Cisco_Lab_Tx/Rx) between T/2 & T spaced equalizers.
4. Calculated deltaOMA/deltaSNR over EML transmitter case between T/2 & T spaced equalizers.

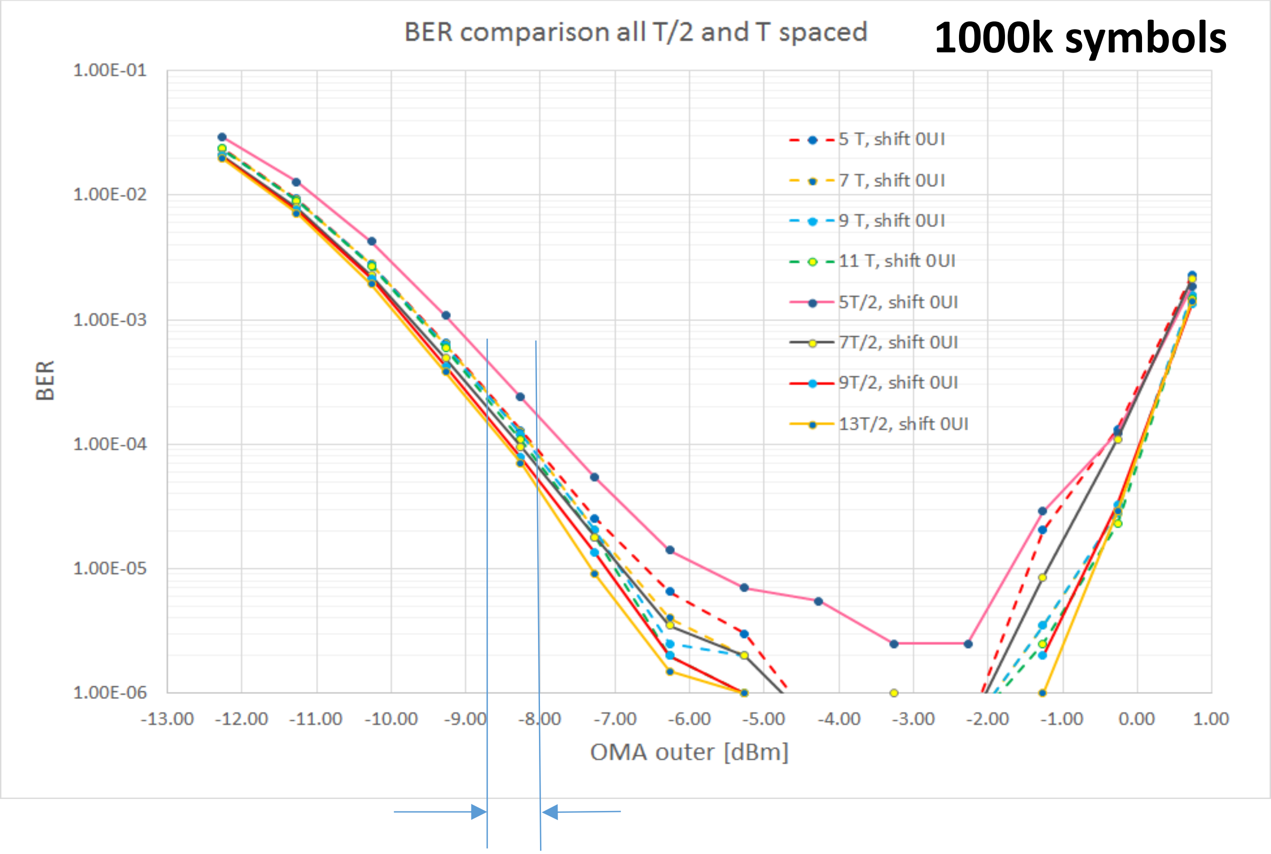
Propose change in the reference equalizer for TDECQ/SECQ methodologies of Clause 124 (David Lewis comment r01-21).

Cisco RX assembly sensitivity results with various equalizers - comparison.

FINISAR BER PLOTS

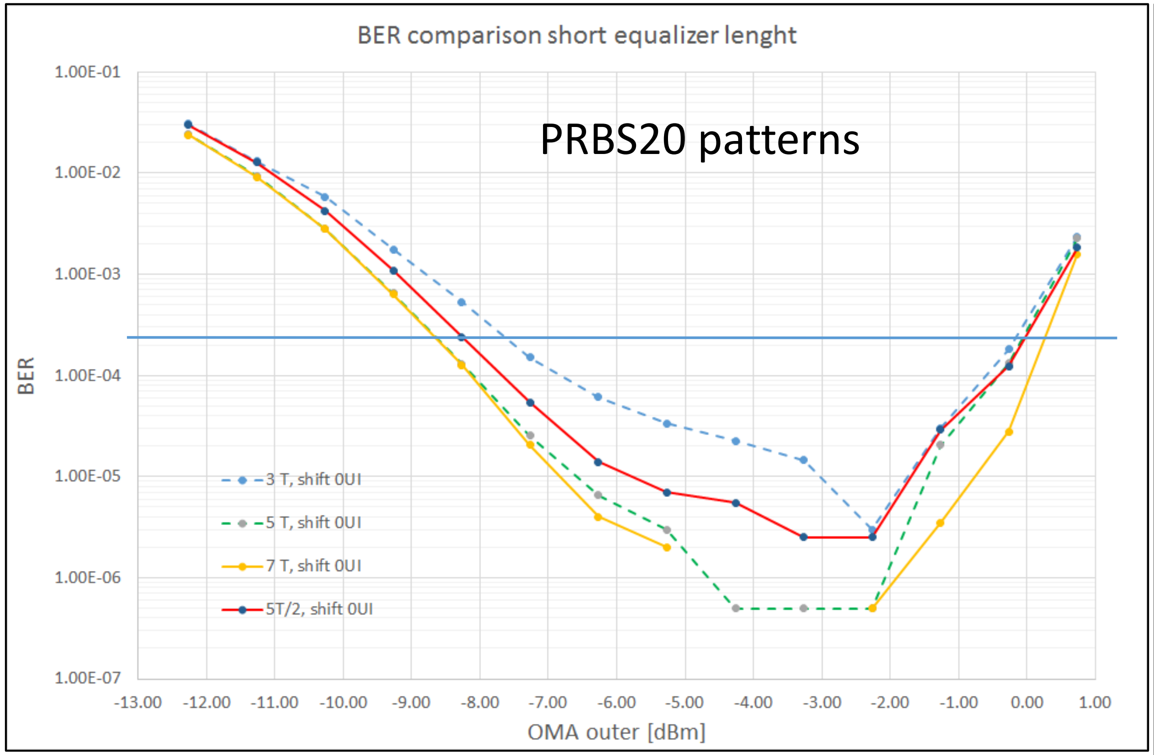


CISCO BER PLOTS

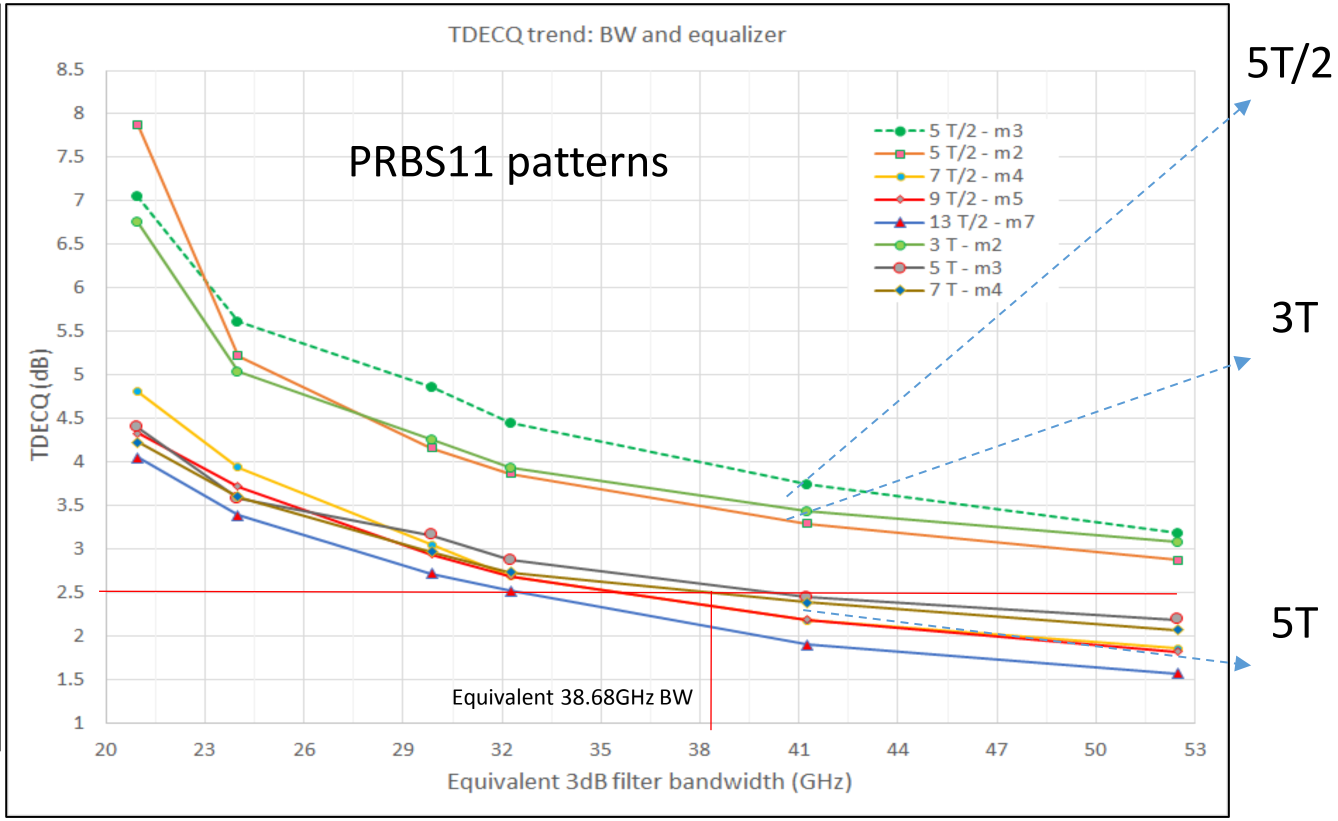


Results shown in mazzini_01a_0517_smf and king_01_0517_smf.
Same tested cases are grouped within 0.7dB for both cases.

2. Cisco Lab Tx: TDECQ versus equalizer type and length.



5T equalizer behaves better then the 5T/2 (upper chart).
There's better consistency with TDECQ results
(right chart), still the 3T and 5T/2 results are flipped.

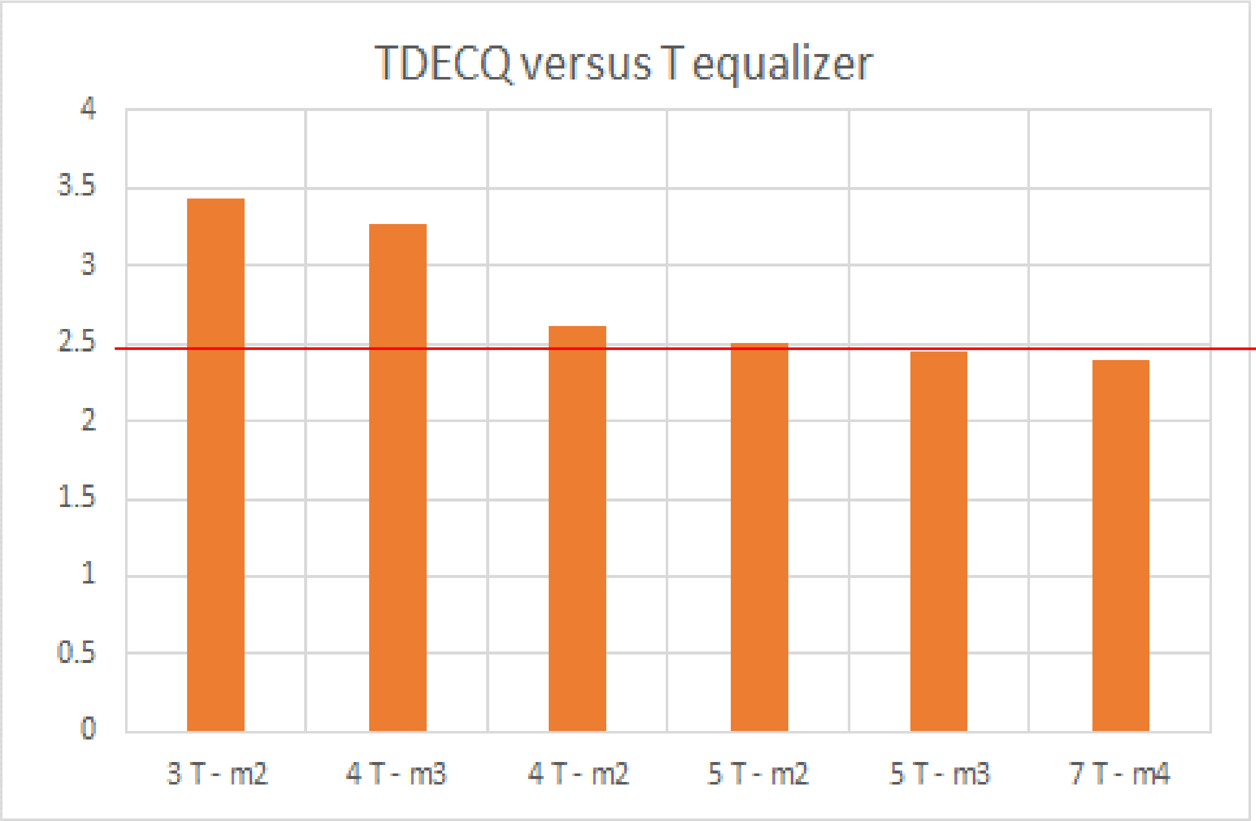


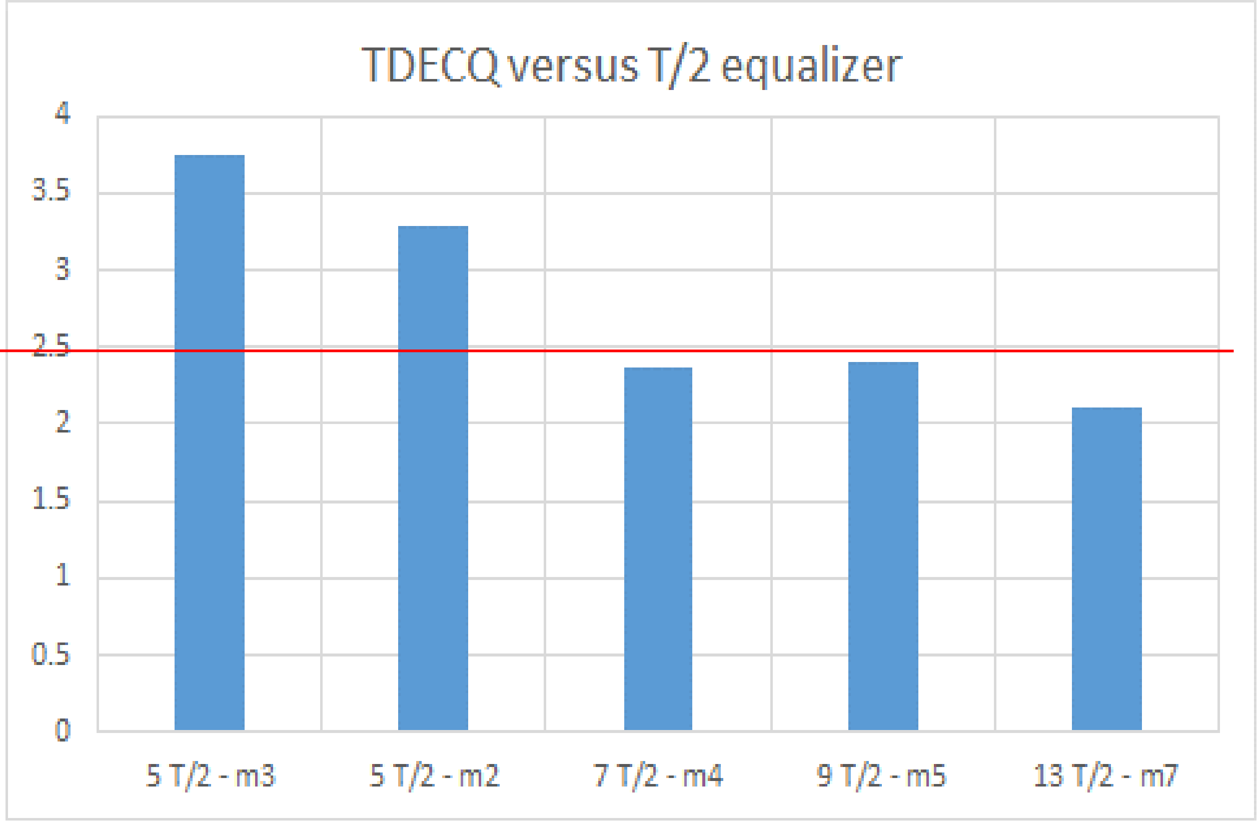
'm' is the relative main tap position (e.g. 5 T/2 – m2 is 1pre and 3post)

- ***Despite good sensitivity results, the TDECQ results appear too high comparing to current 2.5dB limit***
- In this example, the Cisco Lab Tx does not meet the TDECQ limit with the 5xT/2 equalizer
- However, if 5xT (<u>same complexity</u>) equalizer is used, the same TX is compliant

2. Cisco Lab Tx: TDECQ versus equalizer type and length.

The Cisco Lab Tx is not compliant to TDECQ considering 5xT/2 equalizer, but is compliant for a 5xT equalizer, which is same complexity for DSP developers.
Longer equalizers than 5xT give smaller improvements (<0.5dB) on TDECQ.





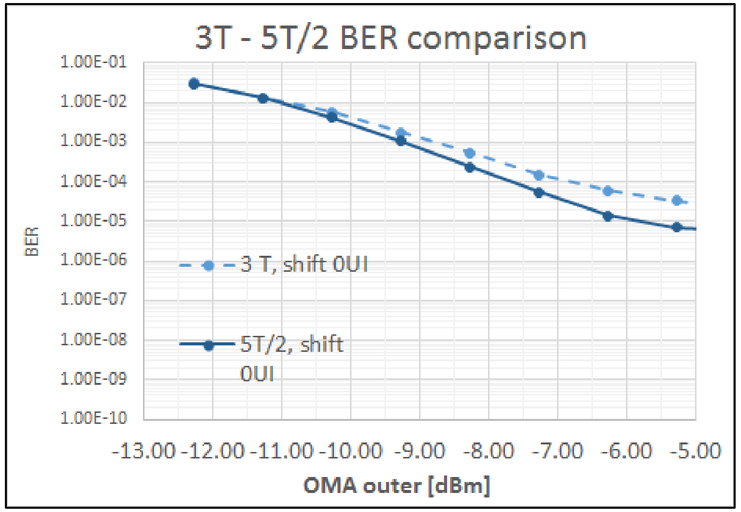
‘m’ is the relative main tap position (e.g. 5 T/2 – m2 is 1pre and 3post)

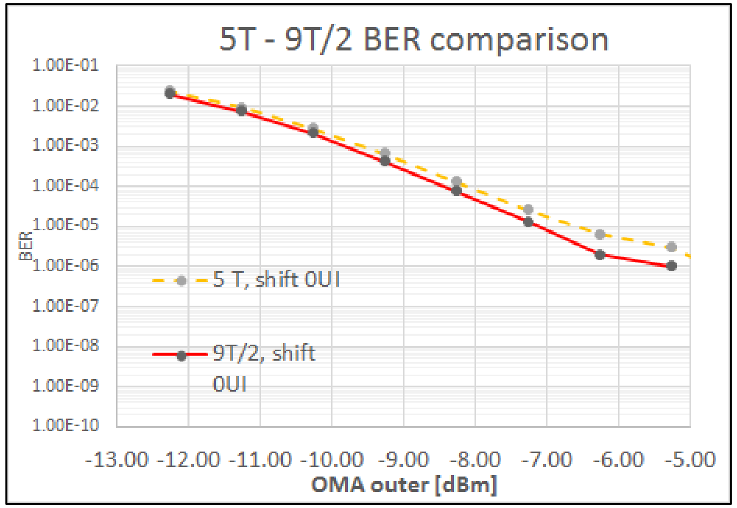
(41.25GHz BW = 55GHz*0.75 case results)

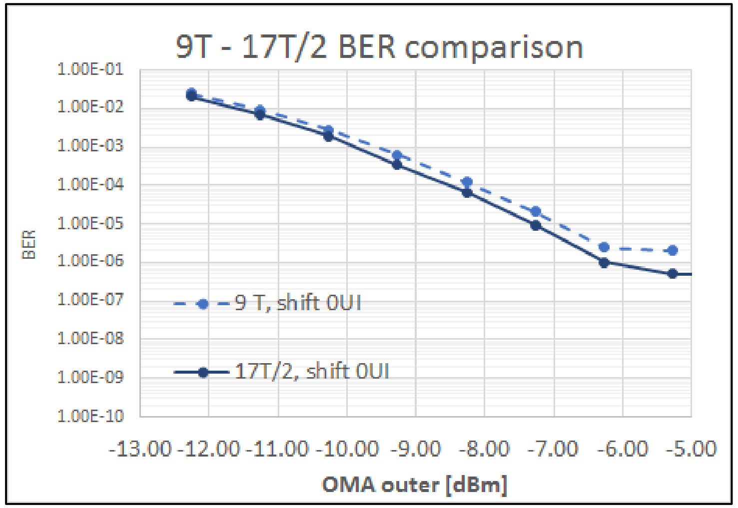
3. Examining the change in OMA sensitivity across T/2 - T spaced equalizers and equalizer UI length.

- TDECQ penalties are reduced as equalizer length increases
  - Currently specified 5T/2 just covers 2UI length.
  - Lab grade TX requires > 4UI for a stable TDECQ.
- Additionally, we should understand the performance penalty of a T-space equalizer relative to a T/2 spaced equalizer of same equivalent length.
  - Ideally, there should be a fixed offset between TDECQ (deltaTDECQ) and OMA (deltaOMA) sensitivity comparing T and T/2 equalizers.
  - In other words, we should tend to a linear deltaTDECQ/deltaOMA trend.
- With this target, we tried to compare deltaTDECQ and deltaOMA sensivitity between T/2 and T-spaced equalizers at different equivalent lengths.

3. Calculated and measured deltaOMA/deltaSNR vs. T/2 - T spaced equalizers.

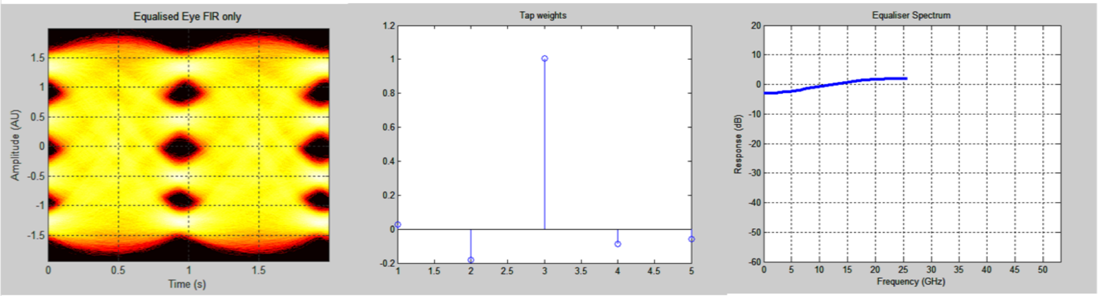






At same equivalent length, T/2 equalizer is obviously always better than the T one, because T/2 equalizer can equalize distortion beyond Nyquist.

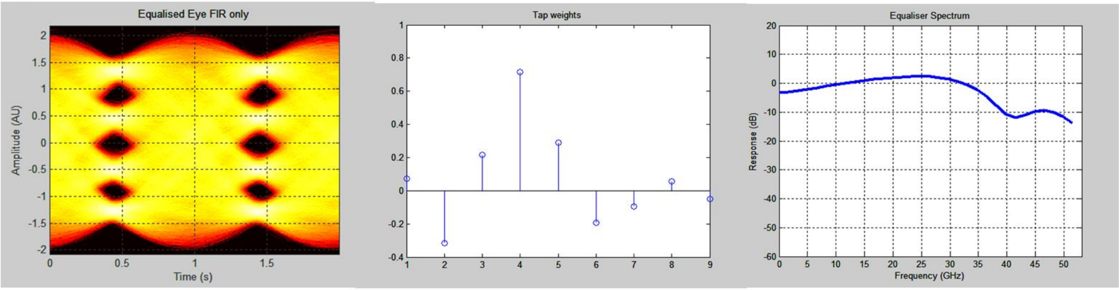
5T FIR equalizer (2+1)



FIR only : Total BER (error counting) 0

FIR only : SNR (dB) 20.827

9T/2 FIR equalizer (2+1)



FIR only : Total BER (error counting) 0

FIR only : SNR (dB) 21.2844

Comparison with T and T/2 equalizers of same length is then done also by computing SNR at -5dBm OMAouter.

4. deltaOMA/deltaSNR vs. T/2 - T spaced equalizers (cont.).

Terms

DeltaSNR
DeltaTDECQ
DeltaOMAm
DeltaOMAc

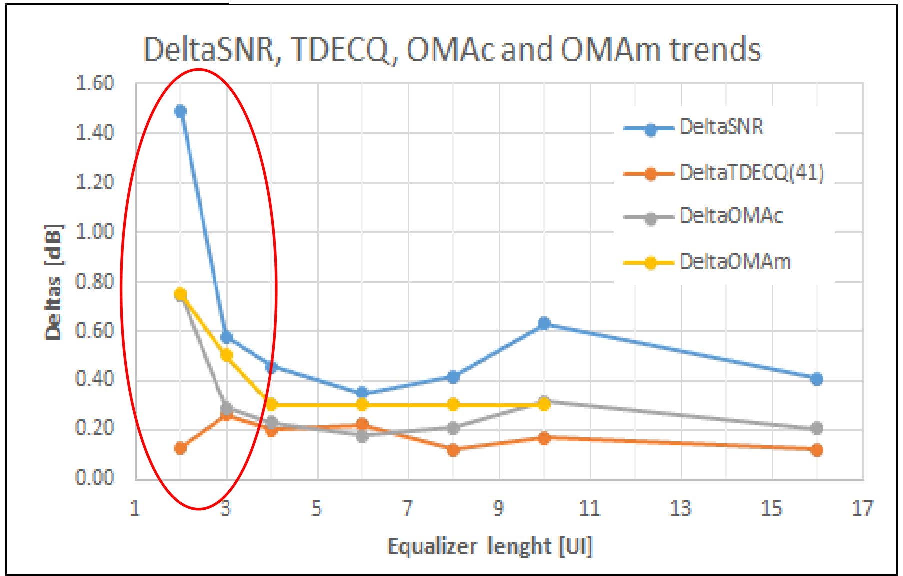
Parameter delta between T/2 and T same length equalizers

DeltaOMAc = (Delta SNR)/2

DeltaOMAc almost equal to the measured DeltaOMAm

UI Lenght	T/2	SNR	TDECQ(41)	T	SNR	TDECQ(41)	DeltaSNR	DeltaTDECQ(41)	DeltaOMAc	DeltaOMAm
2	5	20.44	*3.3*	3	18.95	*3.43*	1.49	0.13	0.75	0.75
3	7	20.93	*2.36*	4	20.30	*2.62*	0.63	0.26	0.31	0.5
4	9	21.28	*2.25*	5	20.83	*2.45*	0.46	0.2	0.23	0.3
6	13	21.31	*2.07*	7	20.96	*2.29*	0.35	0.22	0.17	0.3
8	17	21.38	*2.04*	9	20.97	*2.16*	0.42	0.12	0.21	0.3
10	21	21.78	*1.88*	11	21.16	*2.05*	0.63	0.17	0.31	0.3
16	33	21.89	*1.84*	17	21.48	*1.96*	0.41	0.12	0.21	not done

Note: green cells for TDECQ41 < 2.5dB and DeltaOMAc < 0.3dB. TDECQ41 done with PRBS11 pattern, SNR and OMA with PRBS20.



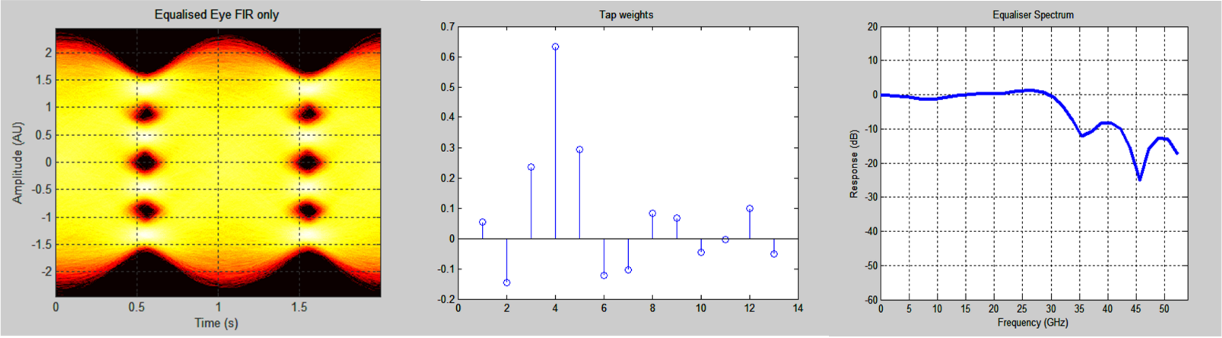
DeltaTDECQ is shown to be almost flat.
Short equalizer lengths are not appropriate to forecast a linear deltaOMA/deltaTDECQ ratio, because deltaOMA tends to diverge.
For the Cisco_Lab_Tx/Rx, at least 4UI length (5T, 9T/2) are needed.

5. Calculated deltaOMA/deltaSNR over EML transmitter case.

We had permission from a company developing EML TXs to post-process and publish results on one of their waveforms (PRBS15, 54GBaud) acquired with real-time scope.
Note: this waveform is here used for relative equalizer taps comparison. The absolute performances of this link is not representative of manufacturer's development or production.

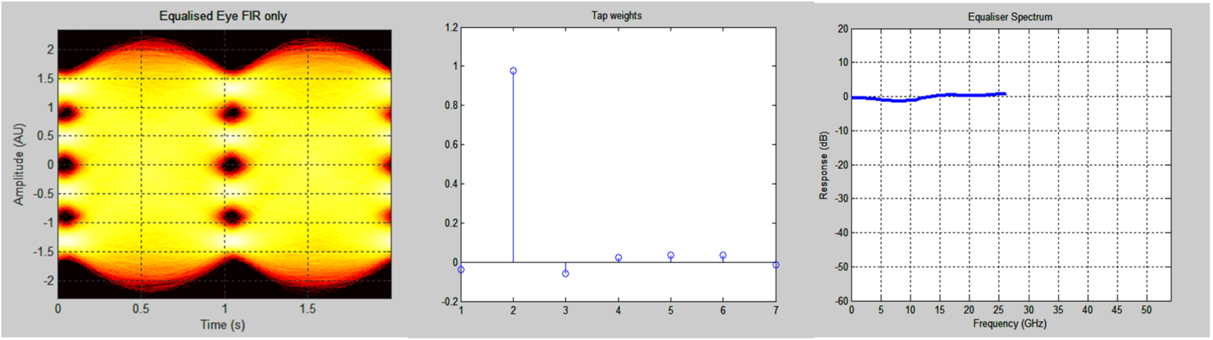
The spectral content beyond Nyquist, as well the optimal main tap position are different from the Cisco Lab Tx case. We cannot compute DeltaTDECQ because the signal was acquired after O/E conversion to real time (so too distorted), but we calculated DeltaSNR and DeltaOMAc.

13T/2, 2+1



FIR only : Total BER (error counting) 1.00257e-05
FIR only : SNR (dB) 20.11

7T, 1+1



FIR only : Total BER (error counting) 1.00257e-05
FIR only : SNR (dB) 19.4773

DeltaOMAc = (Delta SNR)/2 trends versus equalizer length is then done on this case too.

5. Calculated deltaOMA/deltaSNR over EML transmitter case (cont.).

Terms

DeltaSNR
DeltaOMAc

Parameter delta between T/2 and T <u>same</u> length equalizers

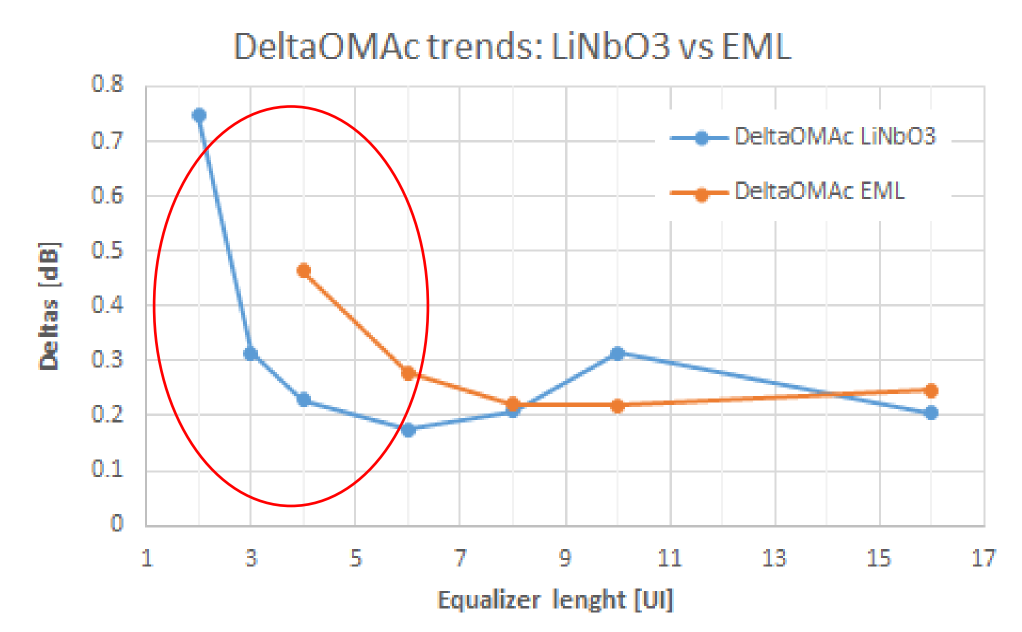
DeltaOMAc = (Delta SNR)/2

Omitted the short equalizer case due to very low SNR

For the EML case a longer, 6UI equalizer (7T spaced) is needed to forecast an offset between T and T/2 equalizers performance, where 4UI (5T) were enough for **Cisco Lab Tx (**LiNbO3).

UI Lenght	T/2	SNR	T	SNR	DeltaSNR	DeltaOMAc
4	9	19.87	5	18.94	0.93	0.46
6	13	20.11	7	19.55	0.56	0.28
8	17	20.17	9	19.72	0.44	0.22
10	21	20.19	11	19.75	0.44	0.22
16	33	20.30	17	19.81	0.49	0.25

Note: green cells for DeltaOMAc < 0.3dB. TDECQ41 done with PRBS11 pattern, SNR and OMA with PRBS20.



- Most surveyed DSP companies plan to implement baud rate sampling (T-spaced) for 53GBaud signaling
- These T-spaced equalizers thus are expected to avoid this observed sensitivity mismatch which seems technology-dependent.
- However, if a long T/2 equalizer is used, a DeltaOMA issue may arise as different transmit and receiver technologies are considered.

Summary of results and considerations.

1. Presented sensitivity results on Cisco Lab TX/RX set-up. There results were independently verified by other companies.

2. Cisco Lab Tx: TDECQ versus equalizer type and length.
   Sensitivity and TDECQ post-processing results are now more in line, still there's an inversion between 3T and 5T/2 cases.
   Looks challenging to achieve 2.5dB TDECQ, despite good margin on sensitivity.

3-4. Calculated and measured deltaOMA/deltaSNR vs. T/2 - T spaced equalizers.
   Short equalizer lengths are not appropriate to forecast a fixed offset between T and T/2 equalizers.
   For the Cisco_Lab_Tx/Rx, at least 4UI length (5T, 9T/2) seems needed, while for for EML transmitters we need 6UI length to observe a flat delta between T and T/2 equalizers.

Comments.

1. **At 53Gbaud, TDECQ < 2.5dB is hard to achieve with < 5xT equalizer**.
   - Received same feedback from different sources during and after OFC.
     (Note: on Cisco's Lab TX, 7x does not provide strong TDECQ improvement).
   - Yet links can work with margin by using 5xT equalizers.

2. **Results using short equalizers (3xT, 5xT/2) are not a stable metric to correlate Rx BER with TDECQ: some convergence issues were exposed**.
   - In line with other companies findings and with lecheminant_01_1016_smf (slides 4, 5).
   - As per mazzini_01a_0317_smf, this can cause issues for SECQ calibration.

3. ***'Formally, TDECQ/SECQ signal processing should mimic what's expected for a real receiver'*** (king_04_0217_smf, 2), thus:
   - Multiple DSP-suppliers developing 53GBaud solutions were surveyed.
   - All of them confirmed that:
     a) That their ADC will sample at 1 sample per bit.
     b) That their RX equalizer will be equivalent to a 7xT (or more) T-spaced equalizer, not a T/2-spaced equalizer.

Proposed Strawman

- After some offline discussions, propose to modify the TDECQ equalizer to be a moderate length 5 tap T-spaced
- Strongly request interested parties share waveforms
  - No publicly available EML based waveforms
  - No publicly available DML based waveforms
- The strawman 5 tap T-spaced equalizer may need to be changed based on additional waveform analysis

Comment r01-21 against IEEE P802.3bs D3.1.

Change from: The TDECQ of each lane shall be within the limits given in Table 124-6 if measured using the methods specified in 121.8.5.1, 121.8.5.2, and 121.8.5.3 using a reference equalizer as described in 121.8.5.4, with the following exceptions:
- The signaling rate of the test pattern generator is as given in Table 124-6.
- The combination of the O/E converter and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 38.68 GHz.

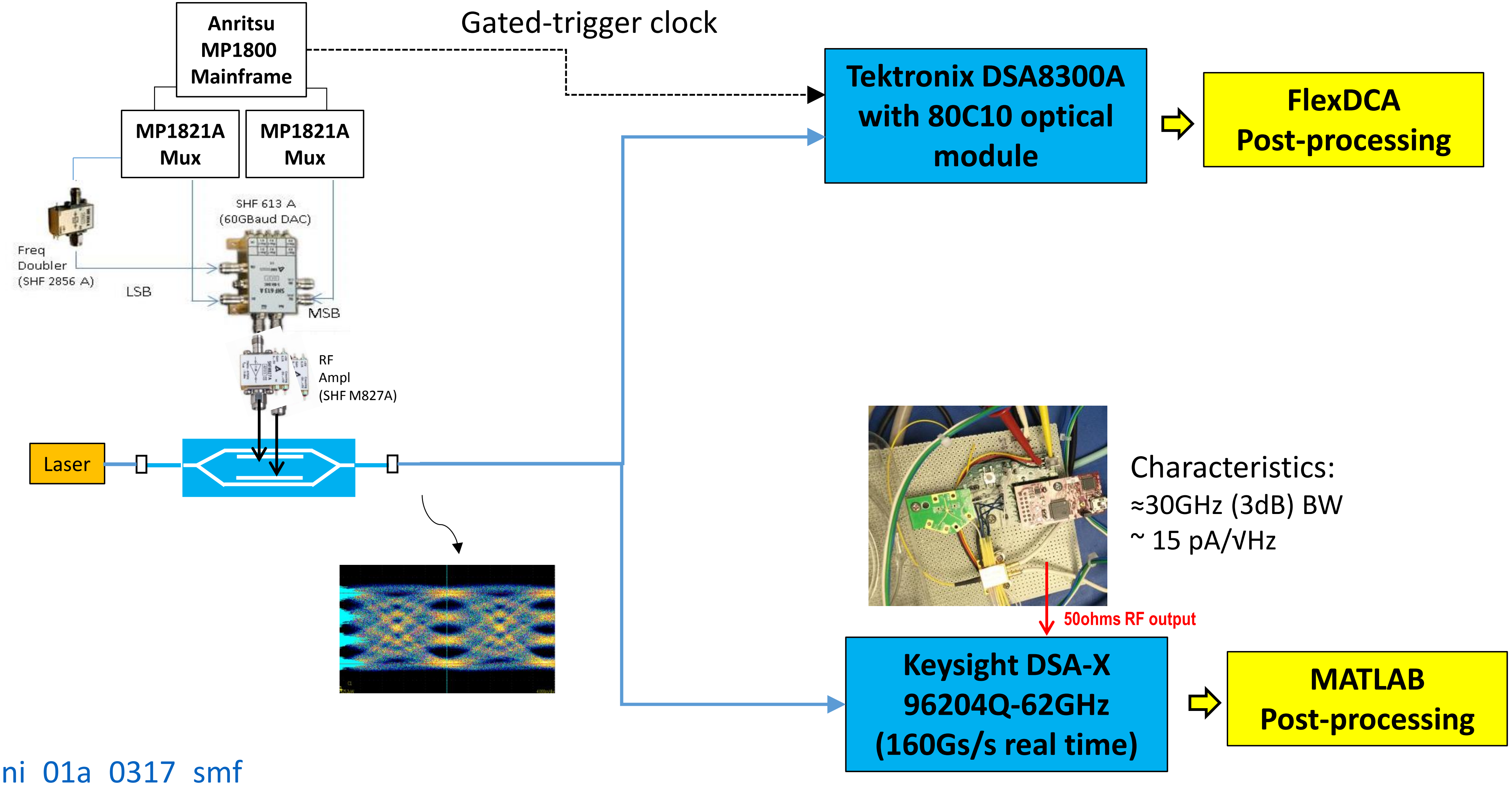
Change to: The TDECQ of each lane shall be within the limits given in Table 124-6 if measured using the methods specified in 121.8.5.1, 121.8.5.2, and 121.8.5.3 with the following exceptions:
- The signaling rate of the test pattern generator is as given in Table 124-6.
- The combination of the O/E converter and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 38.68 GHz.
- The reference equalizer is a 5 tap, T spaced, feed-forward equalizer (FFE), where T is the symbol period.

NOTE-This reference equalizer is part of the TDECQ test and does not imply any particular receiver equalizer implementation

THANK YOU

Back-up

53GBaud PAM 4 TX/RX : sensitivity and TDECQ set-up.



mazzini_01a_0317_smf

About sampling scope reference RX filter and optical BW relationship.

- When applying a “Reference Receiver Filter" the electrical –3dB bandwidth is set to 0.75x of the bit rate.
- When selecting an unfiltered “Bandwidth” setting, the optical –3dB bandwidth is set to the listed number (acquisition done 32GHz, 55GHz, 70GHz).
- Since optical –3dB bandwidth is equal to the –6dB electrical bandwidth (due to 10*log versus 20*log calculations), and for a Gaussian or 4th-order Bessel-Thompson frequency response roll-off the –3dB frequency point is approximately ~0.75 of the –6dB frequency, this means that effectively an optical (e.g. “55GHz”) bandwidth selection has a –3dB optical (and –6dB electrical) bandwidth of 55GHz and a –3dB electrical bandwidth of roughly 0.75of the optical bandwidth (e.g. ~41.25GHz).
- In other words the “55GHz” bandwidth setting is essentially the same as a 55Gb/s reference receiver filter.

Estimating TDECQ pattern dependency.

Meas#/ Pattern	PRBS7	PRBS13Q	PRBS15	SSPRQ	PRBS20
#1	0.73	0.75	0.88	1.4	1.16
#2	0.75	0.77	0.86	1.43	1.08
#3	0.76	0.78	0.84	1.41	1.12
#4	0.77	0.76	0.87	1.39	1.1
#5	0.76	0.78	0.86	1.39	1.03
Average	0.75	0.77	0.86	1.40	1.10
StDev	0.015	0.013	0.015	0.017	0.048

5T/2 equalizer, optimized main tap

TDECQ pattern dependence was estimated by applying the algorithm in the electrical domain (different set-up than standard).
The 53GBaud signal was generated by Anritsu DAC, acquired and post-processed by using Keysight sampling scope (no clock recovery, 50GHz head, precision time base at 6.64GHz, at least 100 count for stable results).
To verify measurement repeatability, 5 acquisitions were done for each pattern.

SSPRQ is expected to give higher TDECQ values compared to other patterns.
Seems representative of PRBS31Q (planned for SRS calibration).
Aside from PRBS20 case, TDECQ standard deviation is similar.