Proposed reference equalizer change in Clause 124 – updated results.

16th May 2017

P802.3bs SMF ad hoc

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Introduction

In mazzini_01_0417_smf, changing the TDECQ reference equalizer for 400GBASE-DR4, from 5T/2 to >= 5T taps equalizer was proposed.

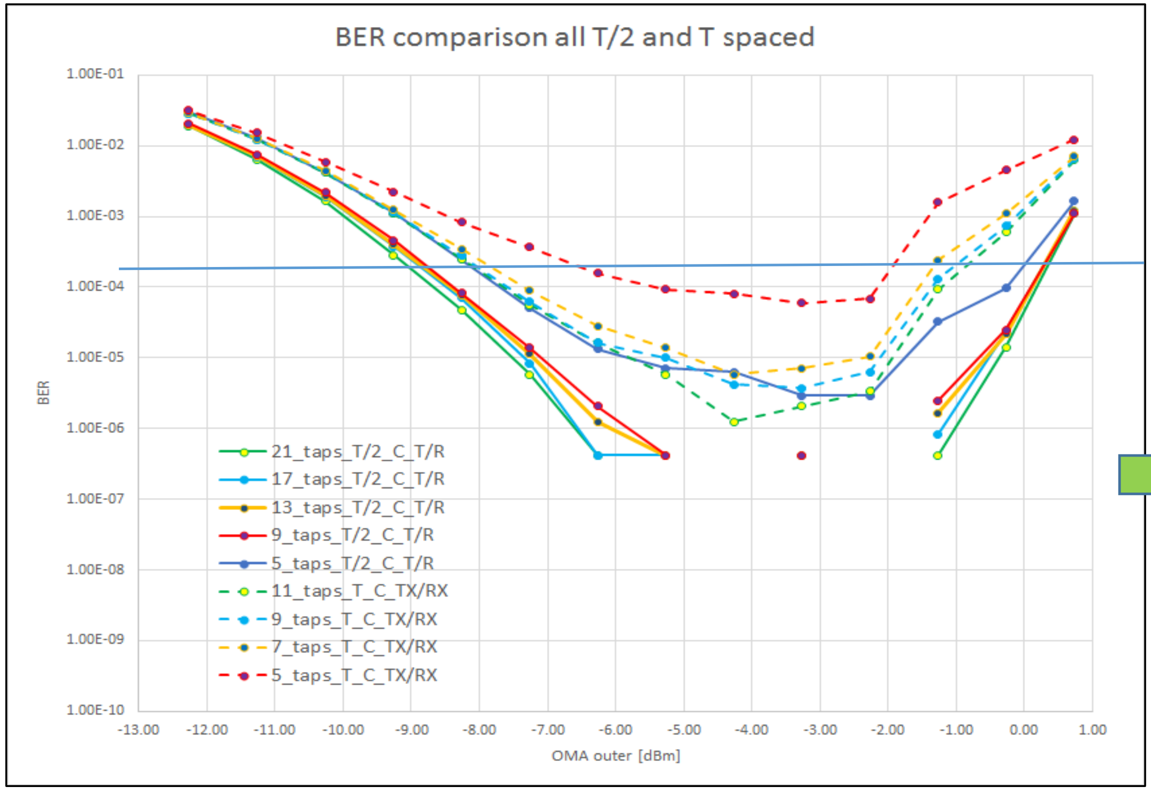
In this updated work we'll:

1. Show updated RX sensitivity results with down-sampling to T-spaced samples in the time-domain
    - Obtained better sensitivity results for T-spaced case and correct sensitivity/TDECQ trend.
    - Despite better sensitivity, the reference equalizer for TDECQ limits still needs improvement.
2. Show Cisco Lab Tx: TDECQ versus equalizer type and length.
3. Estimate TDECQ pattern dependency with similar (electrical) measurement set-up over 53GBaud DAC.
4. Show calculated and measured deltaOMA/delta SNR (Cisco_Lab_Tx/Rx) between T/2 & T spaced equalizers.
5. Calculated deltaOMA/deltaSNR over EML transmitter case between T/2 & T spaced equalizers.

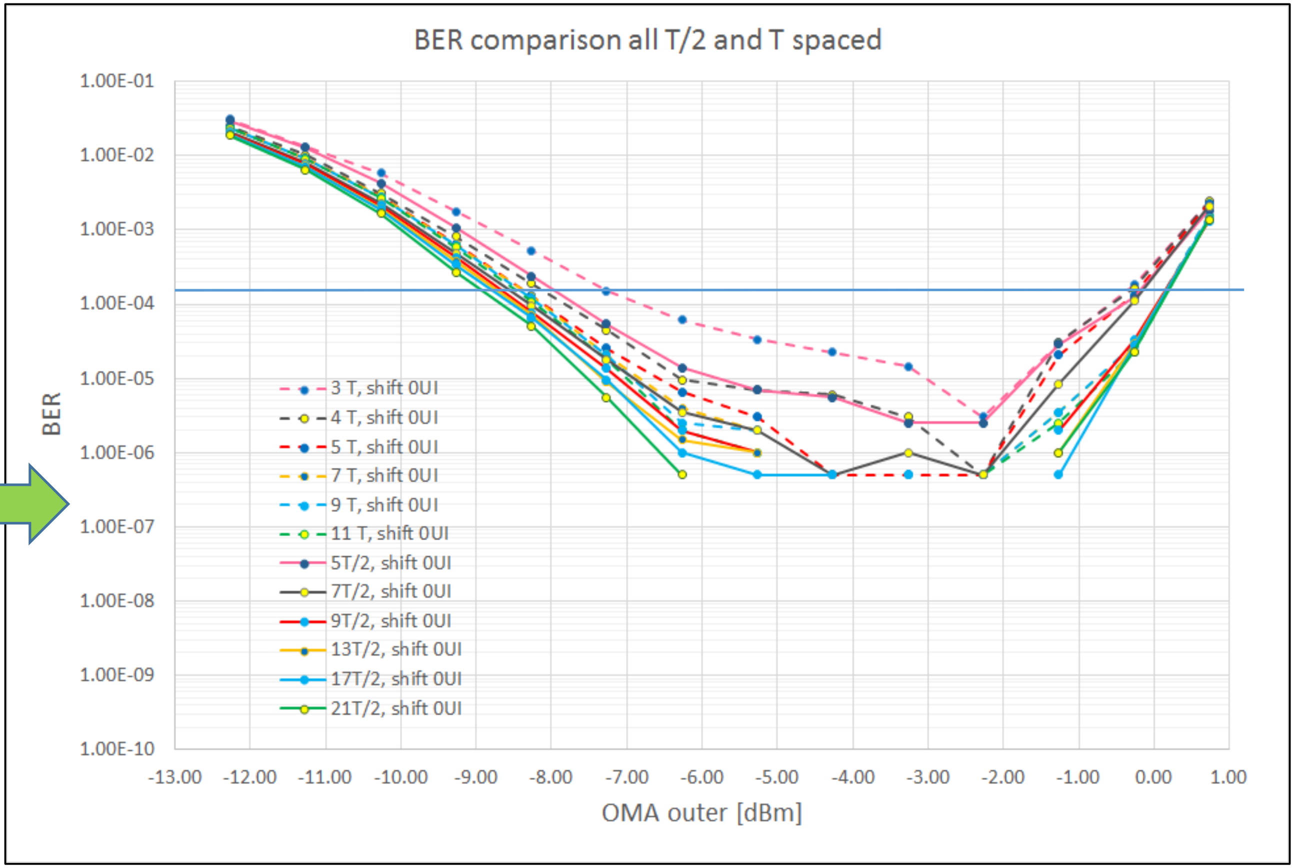
Re-inforce the proposed change in the reference equalizer for TDECQ/SECQ methodologies of Clause 124 (David Lewis comment r01-21).

1. Updated RX assembly sensitivity results with various equalizers.

Previous work



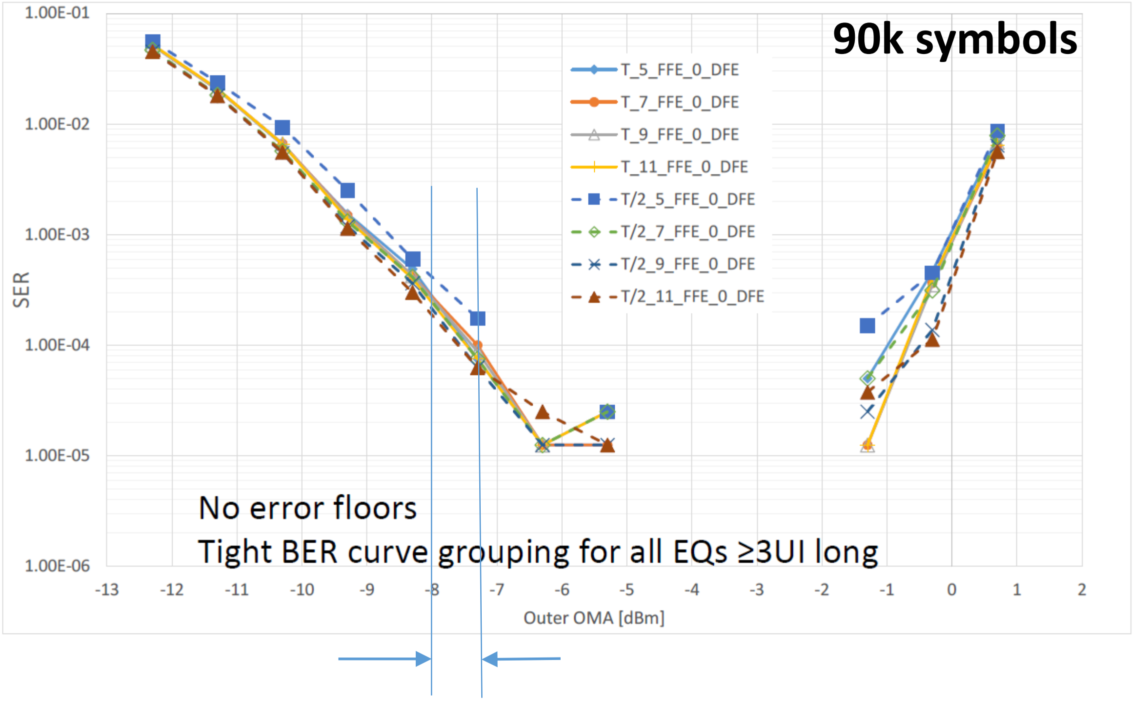
New work

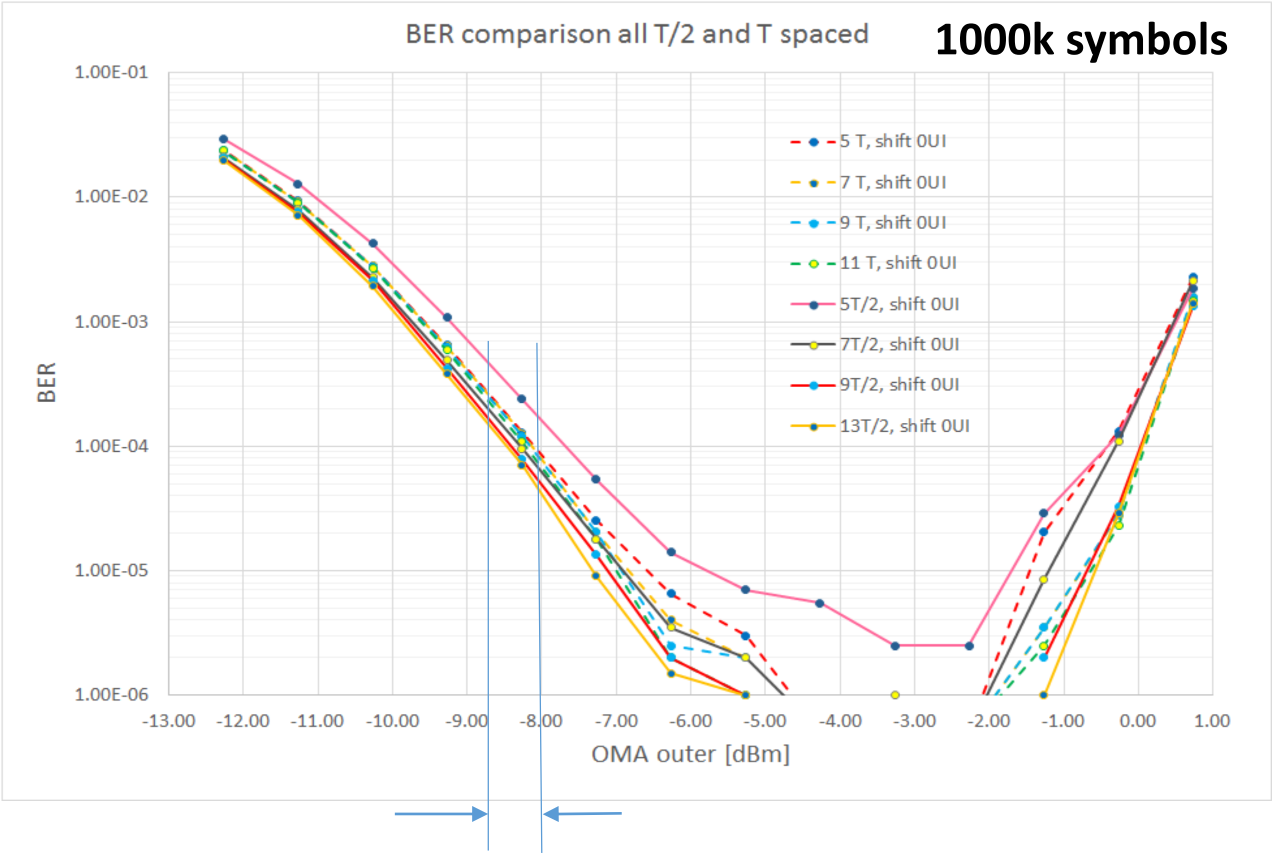


- Previous work used down sampling in frequency domain – this suffered due aliasing from wide 53G spectrum
- New work uses down sampling in the time domain to arrive at T-spaced results
- These improved results are shown in the plot on the right – good agreement with other presentations

Finisar-Cisco sensitivity plot comparison

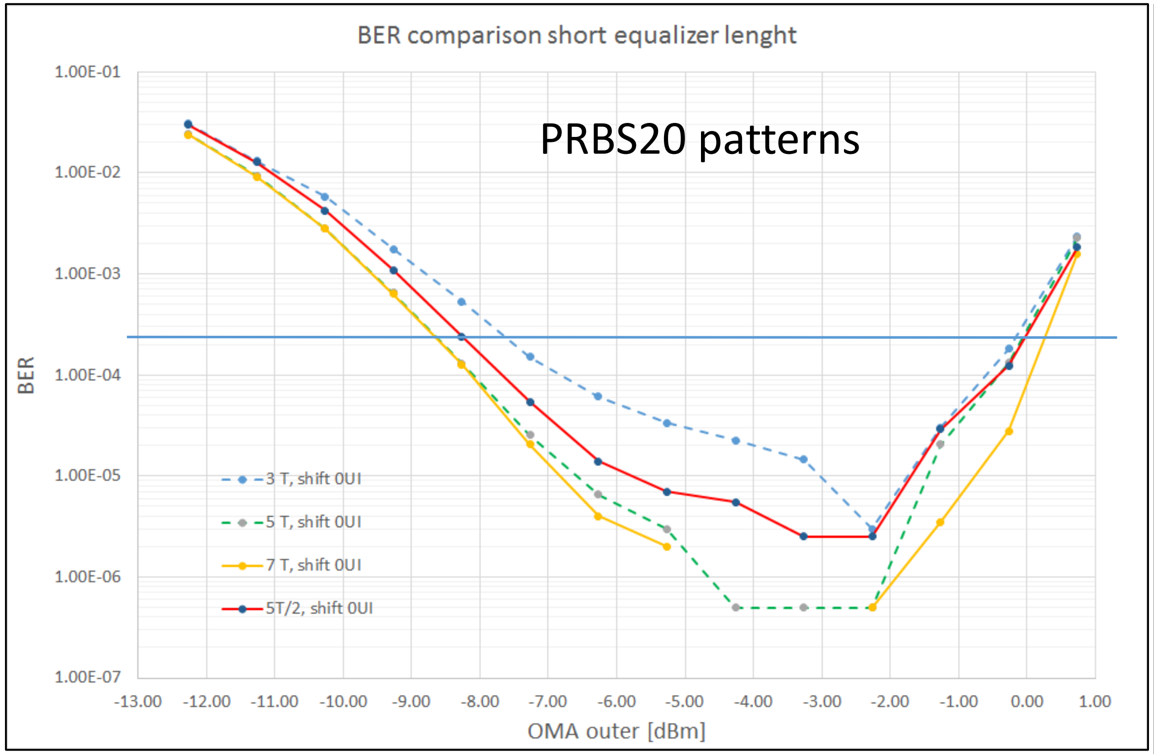
Finisar BER plots (same waveforms, different processing)



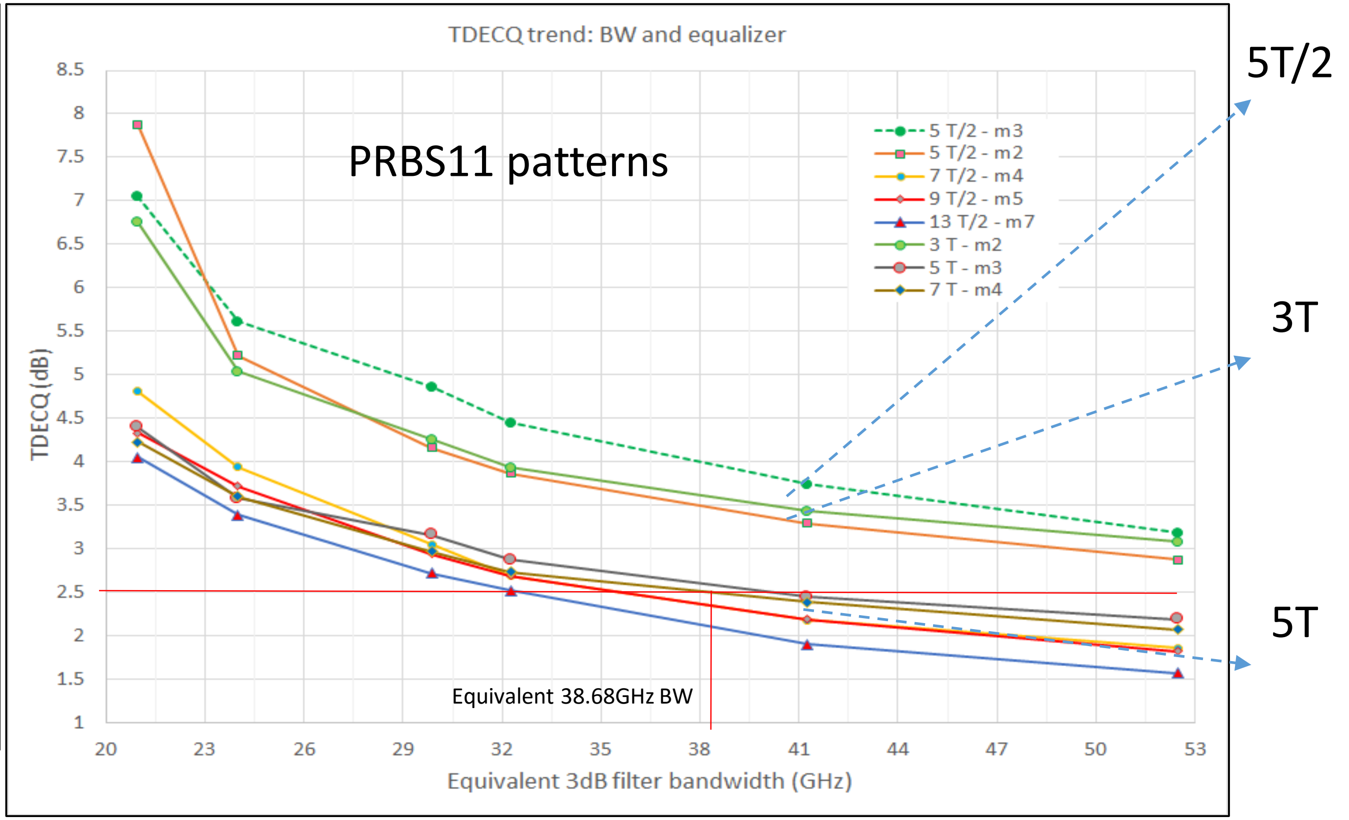


New results are in line with Finisar's presented previously king_01_0517_smf.
Same tested cases are grouped within 0.7dB for both cases.

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.

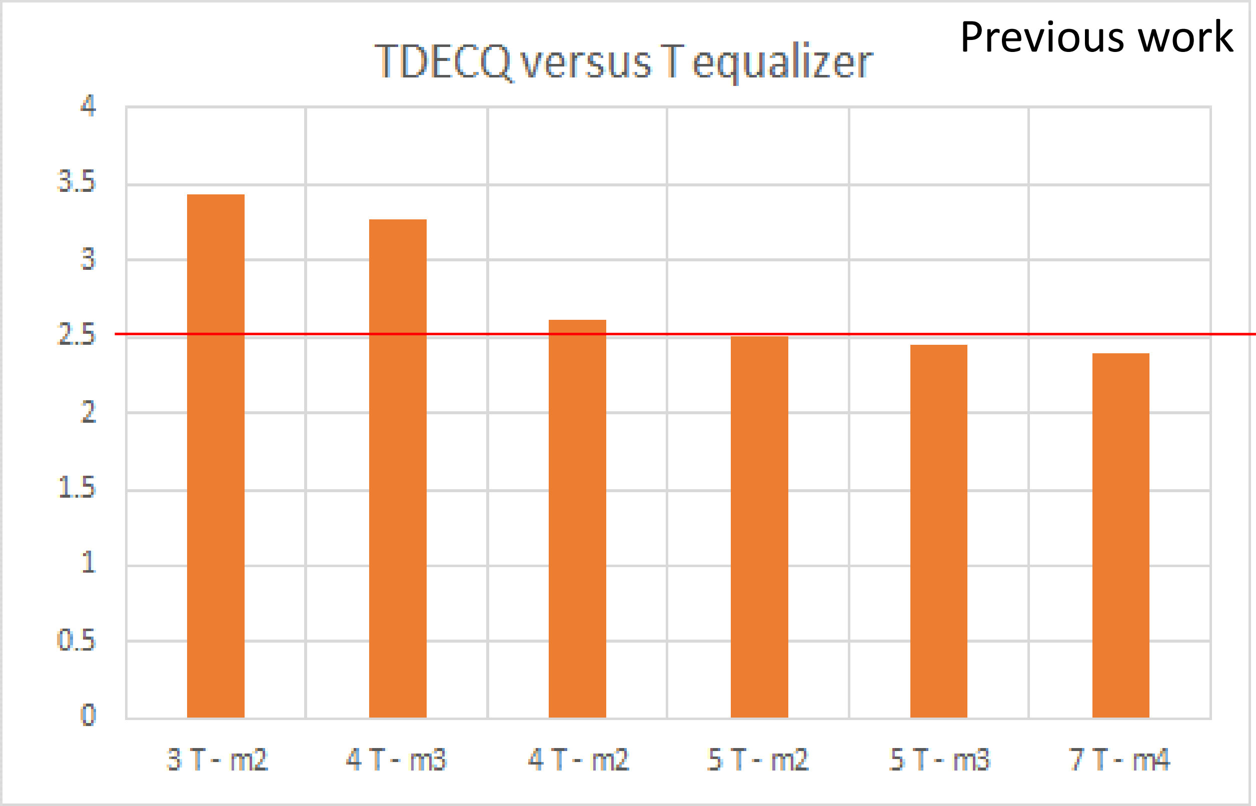


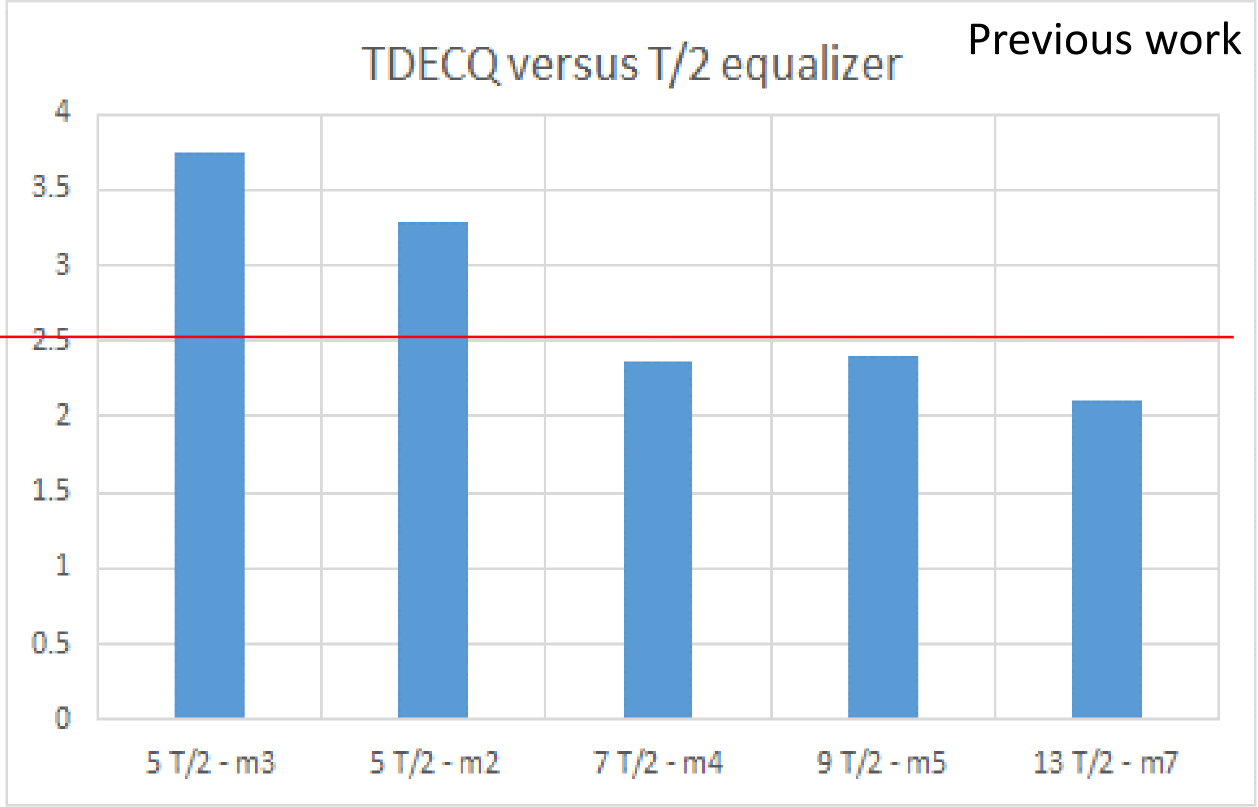
'm' is the relative main tap position (e.g. 5 T/2 – m2 is 1pre and 3post)

- ***Despite good sensitivity results, the TDECQ results appeared high relative 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.

As shown, 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)

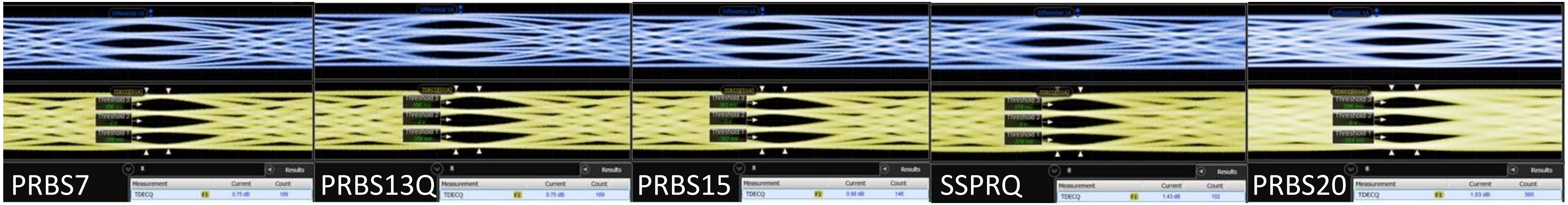
3. Estimating TDECQ pattern dependency.

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.

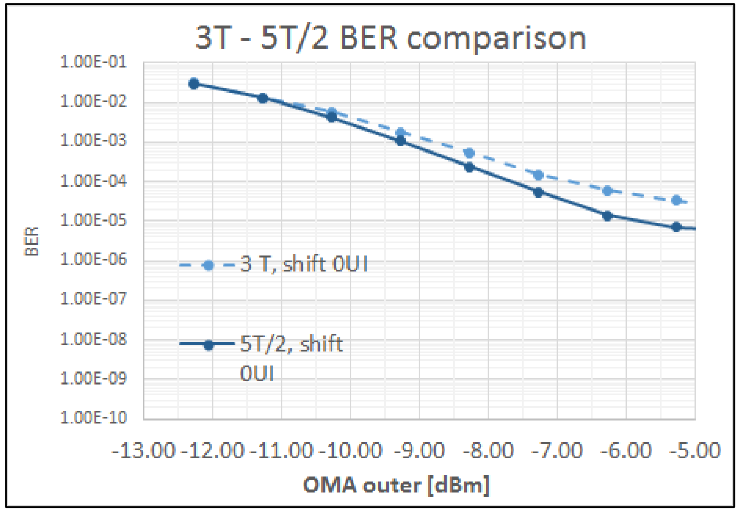
SSPRQ is expected to give higher TDECQ values compared to other patterns.
Seems representative of PRBS31Q (planned for SRS calibration).
Aside from PRBS20 case, TDECQ standard deviation is similar.

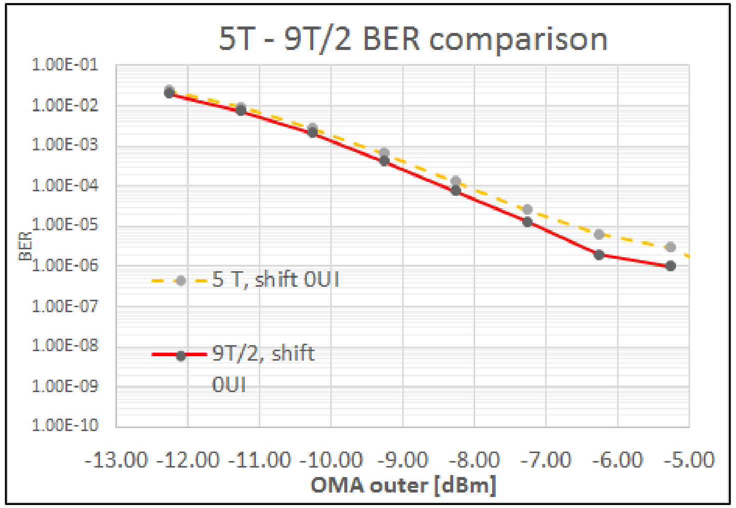


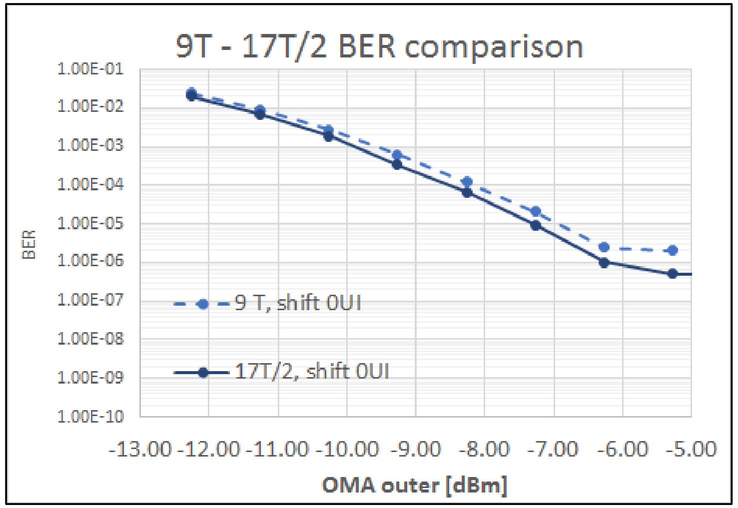
4. Examining the change in OMA sensitivity across T/2 - T spaced equalizers and equalizer UI length.

- 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.
- If the task force consensus is to prefer T/2 over T spaced reference equalizer then we should consider a longer equalizers.
- 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.

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

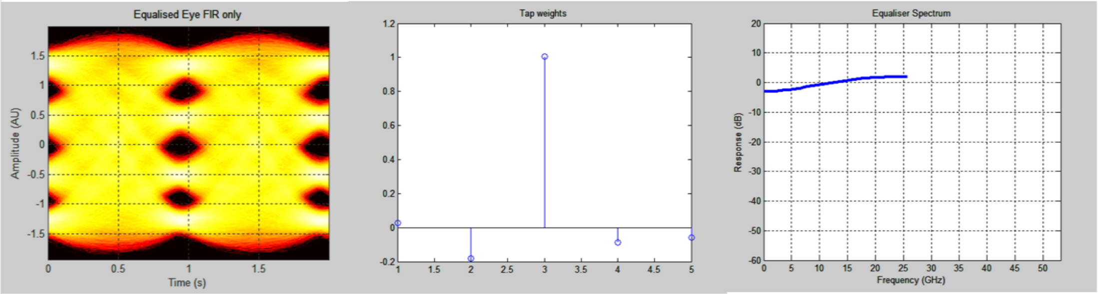






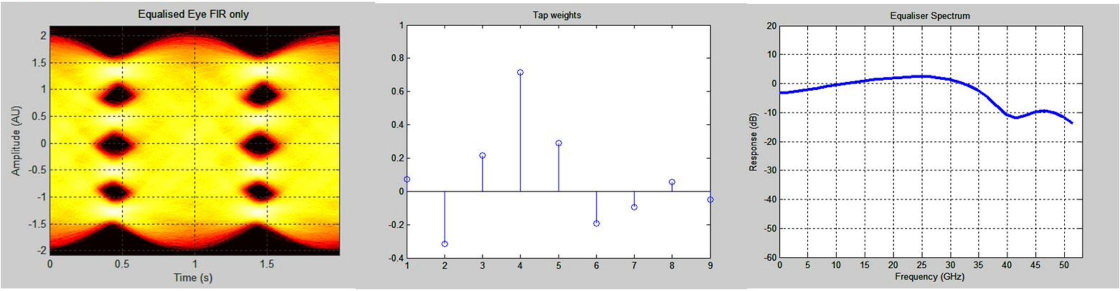
At same equivalent length, T/2 equalizer is obviously always better than the T one, because T/2 equalizer can equalize distortion beyond Nyquist.

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

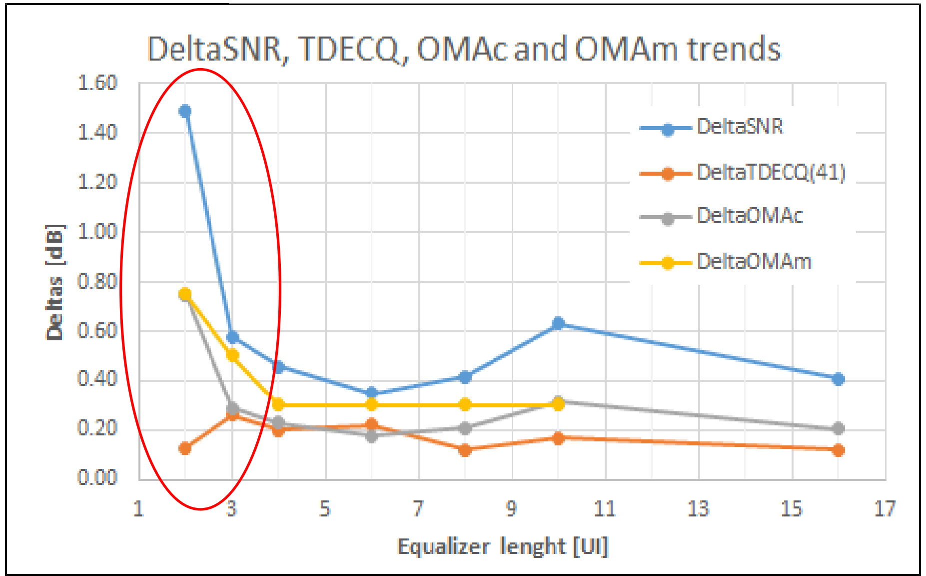
Parameter delta between T/2 and T same length equalizers

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.



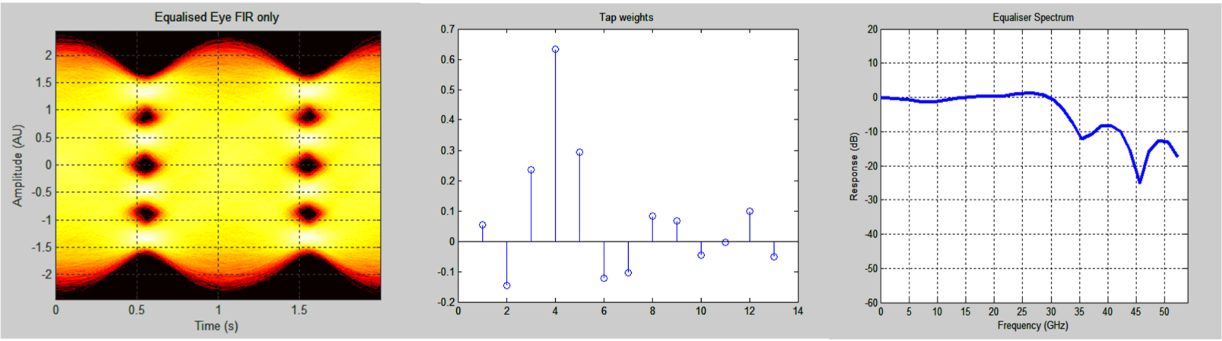
DeltaTDECQ is shown to be almost flat.
Short equalizer lengths are not appropriate to forecast a <u>linear</u> deltaOMA/deltaTDECQ ratio, because deltaOMA tends to diverge.
For the Cisco_Lab_Tx/Rx, at least 4UI length (5T, 9T/2) are needed.

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.

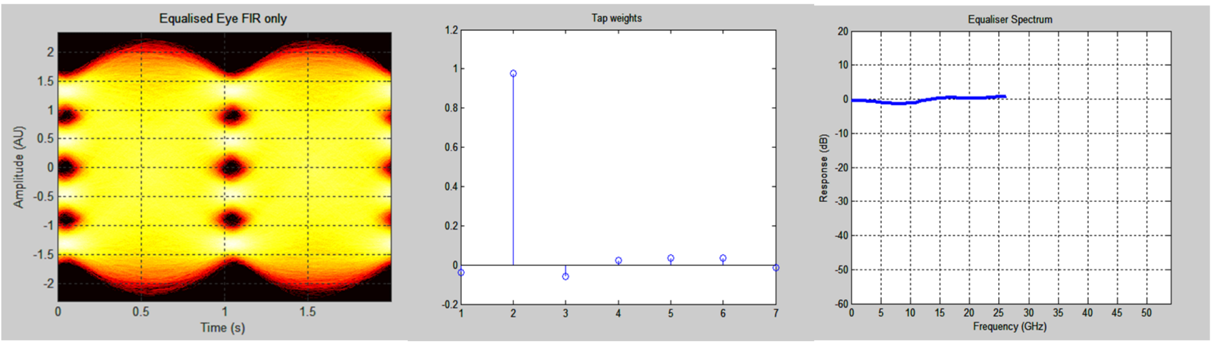
The spectral content beyond Nyquist, as well the optimal main tap position are different from the Cisco Lab Tx case. We cannot compute DeltaTDECQ because the signal was acquired after O/E conversion to real time, but .

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

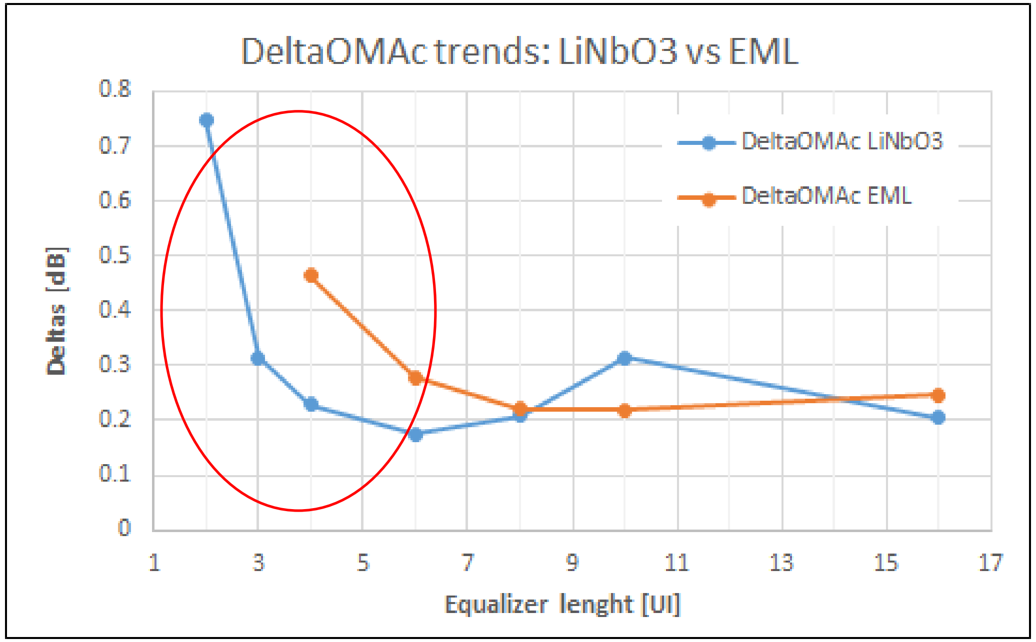
DeltaOMAc = (Delta SNR)/2

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. Updated RX assembly sensitivity results with various equalizers. Presented updated sensitivity results where T-spaced equalizer sensitivity is improved.

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. Estimated TDECQ pattern dependency. SSPRQ is expected to give higher TDECQ values with respect other patterns. It can be representative of PRBS31Q as planned, but need some more work/contribution to complete this analysis.

4-5. 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.

Same identical comments as in mazzini_01_0417_smf , with changes are in red.

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 **5**xT equalizers (**as per this updated work**).

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.

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:

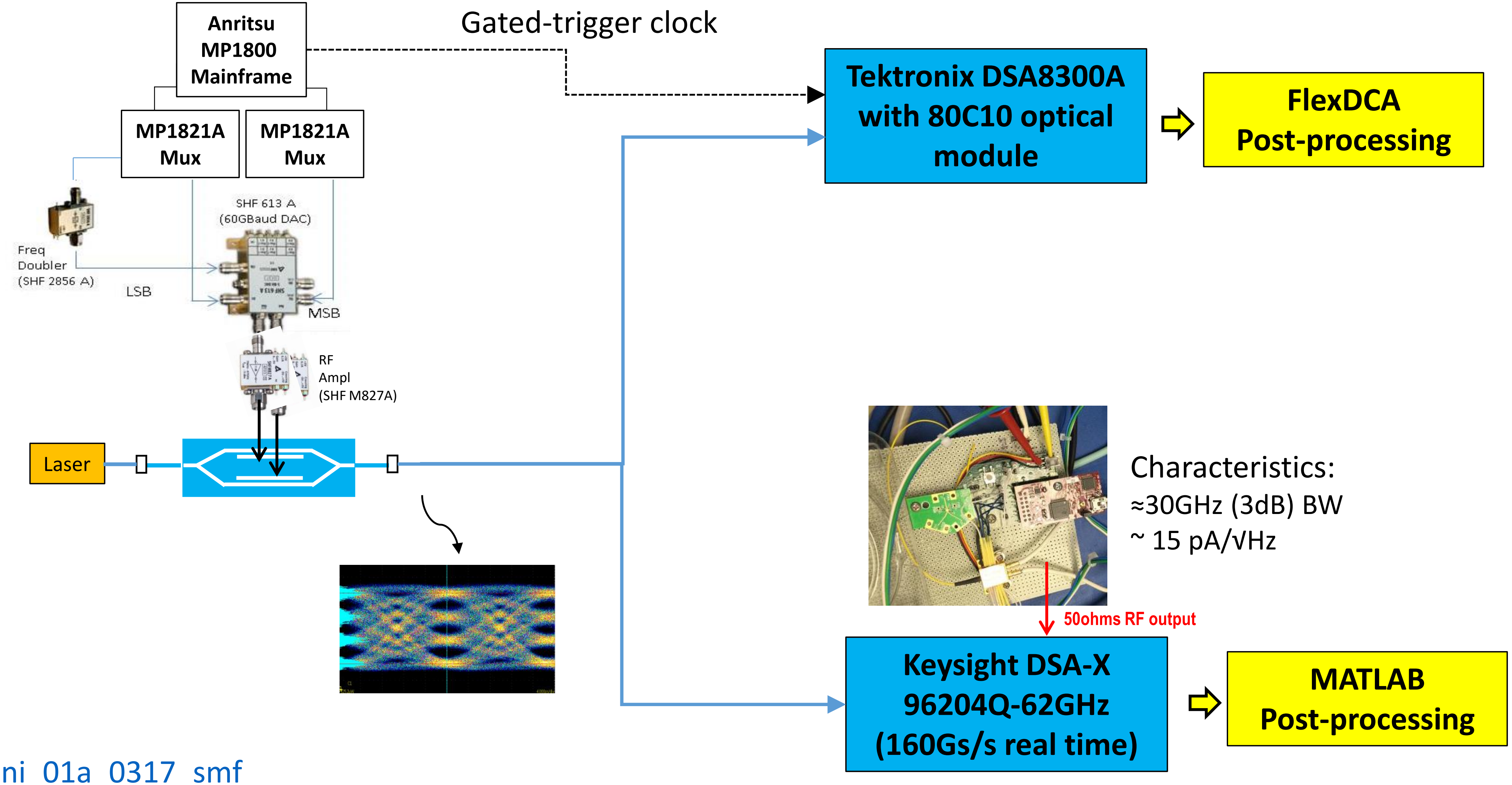
- The signaling rate of the test pattern generator is as given in Table 124-6.
- The combination of the O/E converter and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 38.68 GHz.
- The reference equalizer is a 5 tap, T spaced, feed-forward equalizer (FFE), where 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.