53GBaud links:
sensitivities and TDECQ results versus equalizer.

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P802.3bs SMF ad hoc

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Introduction

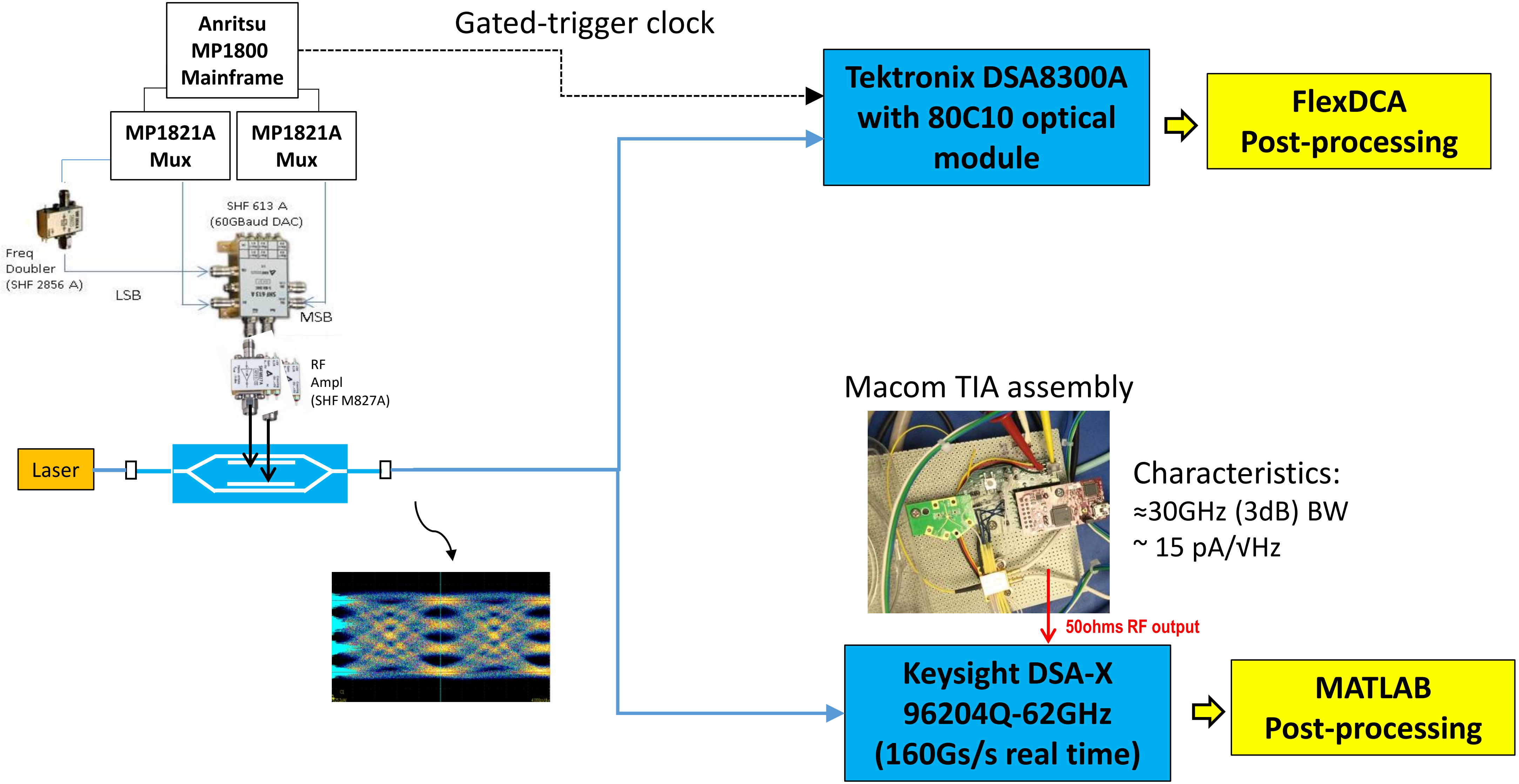
These slides present 53GBaud (measured BER) sensitivities results after Keysight DSA-X 96204Q-62GHz real-time scope acquisitions and post- processing.

- **Cisco TX:** SHF 613A DAC + LiNbO3 modulator.
- **Cisco RX**: MACOM PD+TIA assembly (current cisco reference receiver).
- Compared sensitivities trends versus FFE equalizer lenghts and taps spacing (T/2 and T).

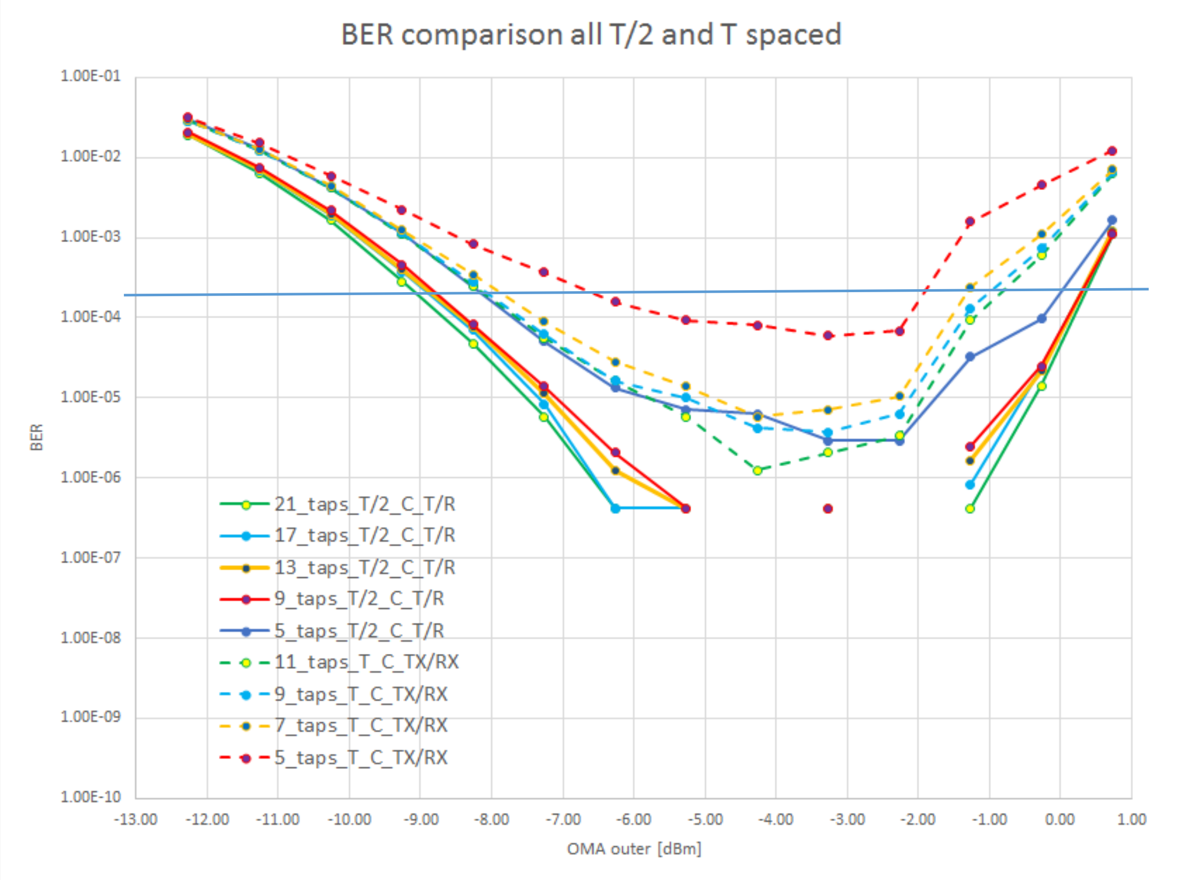
TDECQ was then calculated with Keysight FlexDCA by capturing PRBS11 waveforms on Tektronix sampling scope (80C10 optical head).

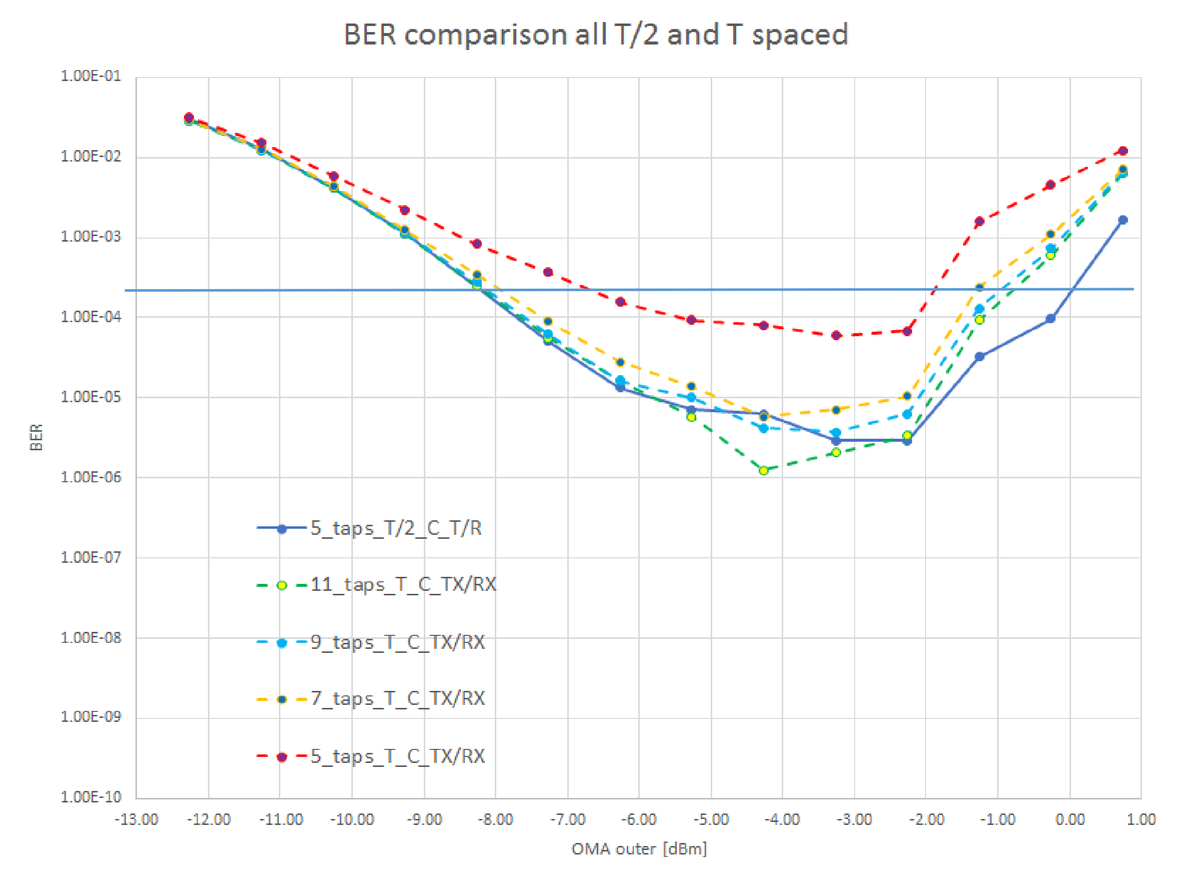
- By using different sets of reference filters and BW.
- Considering different FFE equalizer lenghts (both T/2 and T-spaced).

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



Cisco TX/RX set-up – (PRBS20) BER considerations.



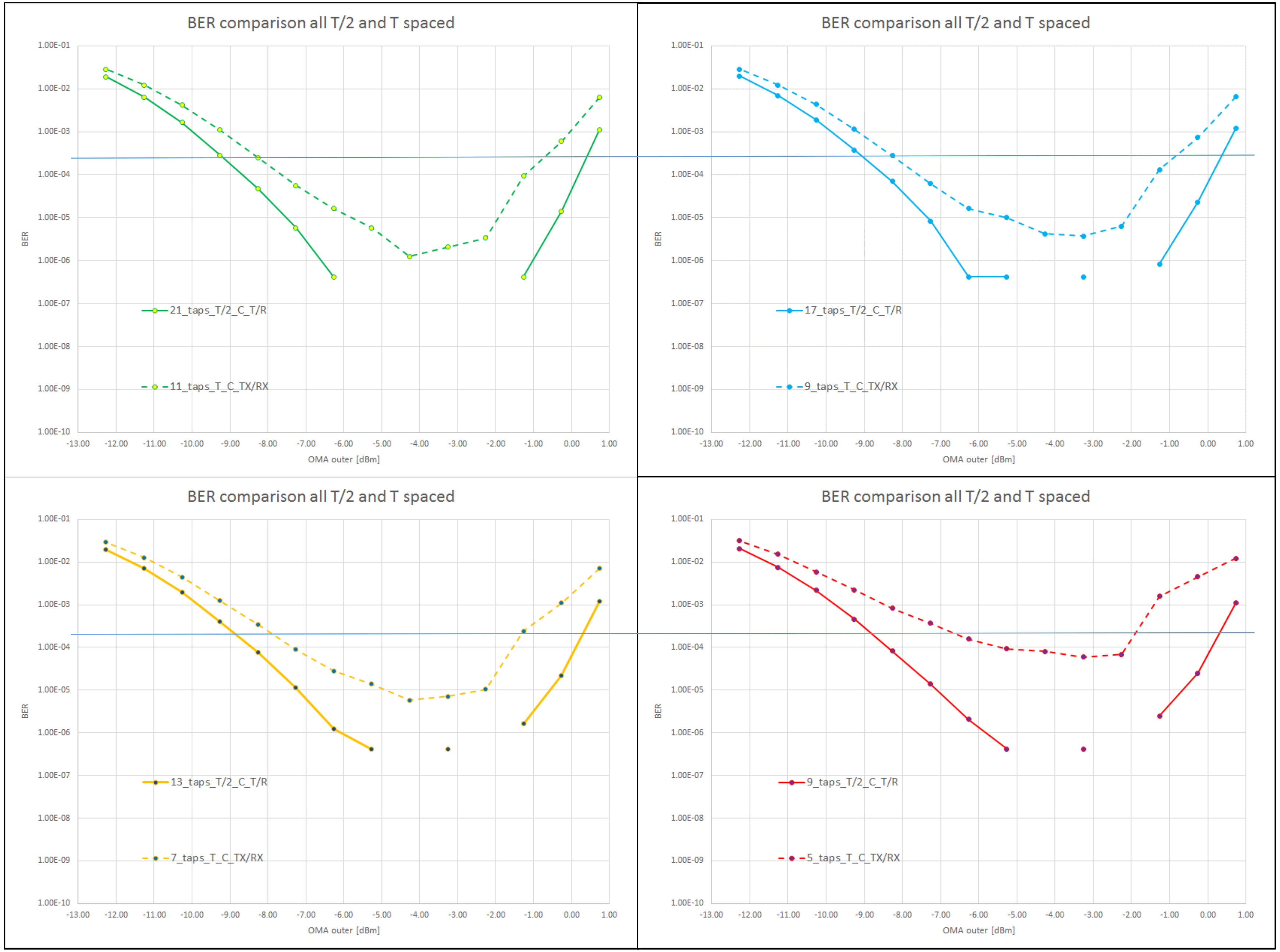


T-spaced equalizer provides close to 1dB OMAouter penalty w/respect T/2 cases.

Not significant improvement increasing the T-spaced equalizer lenght from 7 to 9 or 11 taps, 5 taps close to floor.

5 taps T/2 equalizer is almost equivalent to 9 taps T in terms of sensitivity.

Cisco TX – BER with same equalizer length.



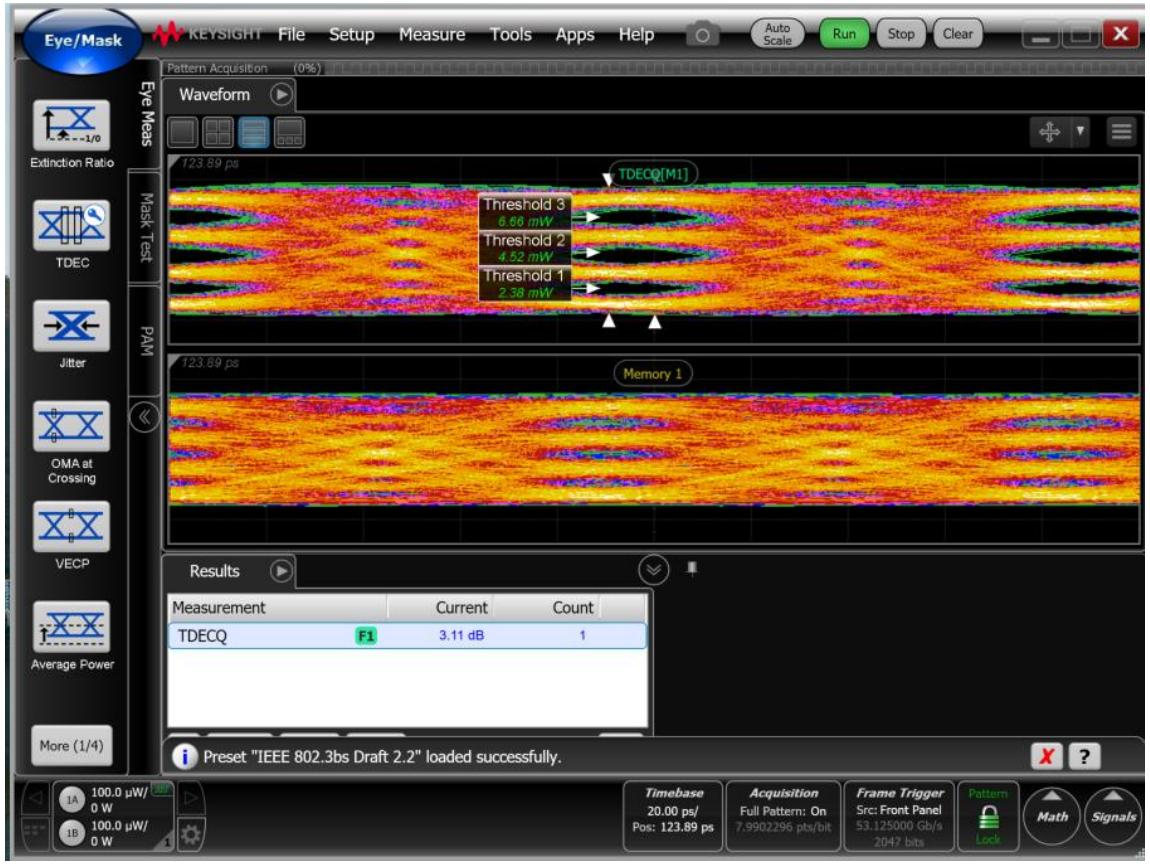
BER results compared assuming **same** equivalent equalizer lenght for T/2 and T-spaced conditions (e.g. 21 T/2 equivalent to 11 T equalizer).

There's ~1dB delta OMAouter between T/2 and equivalent T-spaced (no link margins with 5 taps T equalizer).

Cisco TX: TDECQ

TDECQ of Cisco TX measured by:

1. PRBS11 waveforms acquisitions with Tektronix sampling scope and 80C10 optical head.
   - Acquistion done using different reference filters (43, 39 and 28Gb/s) and head's optical bandwidth (70, 55 and 32GHz).
2. Acquired waveforms were post- processed using Keysight FlexDCA software and PAM4 analysis tool.

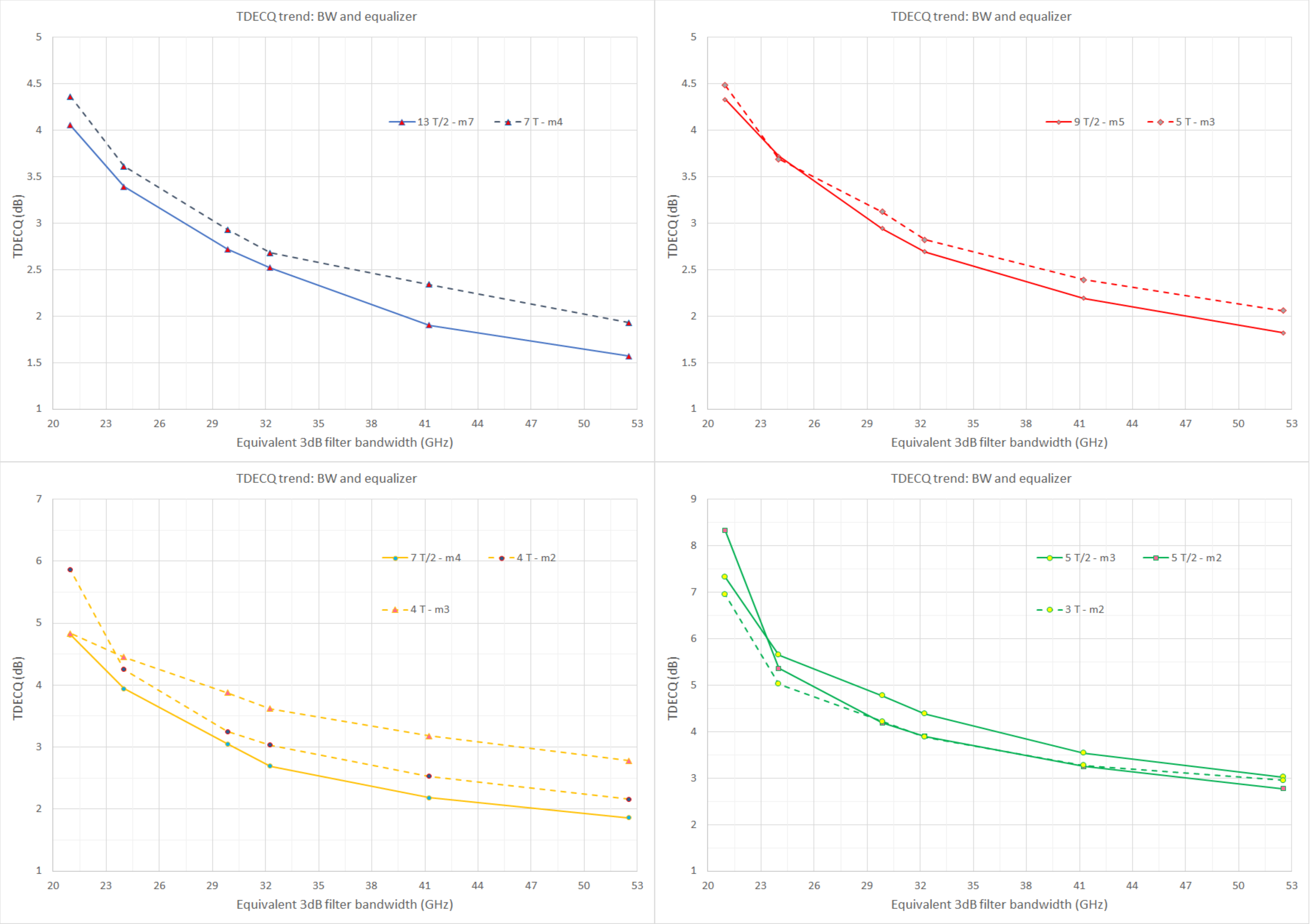


Left case showing FlexDCA TDECQ analysis with current IEEE reference equalizer and 70GHz BW on optical head (note: standard requires 38.68GHz, not yet available on scope).

Cisco TX: TDECQ versus equalizer and bandwidth.

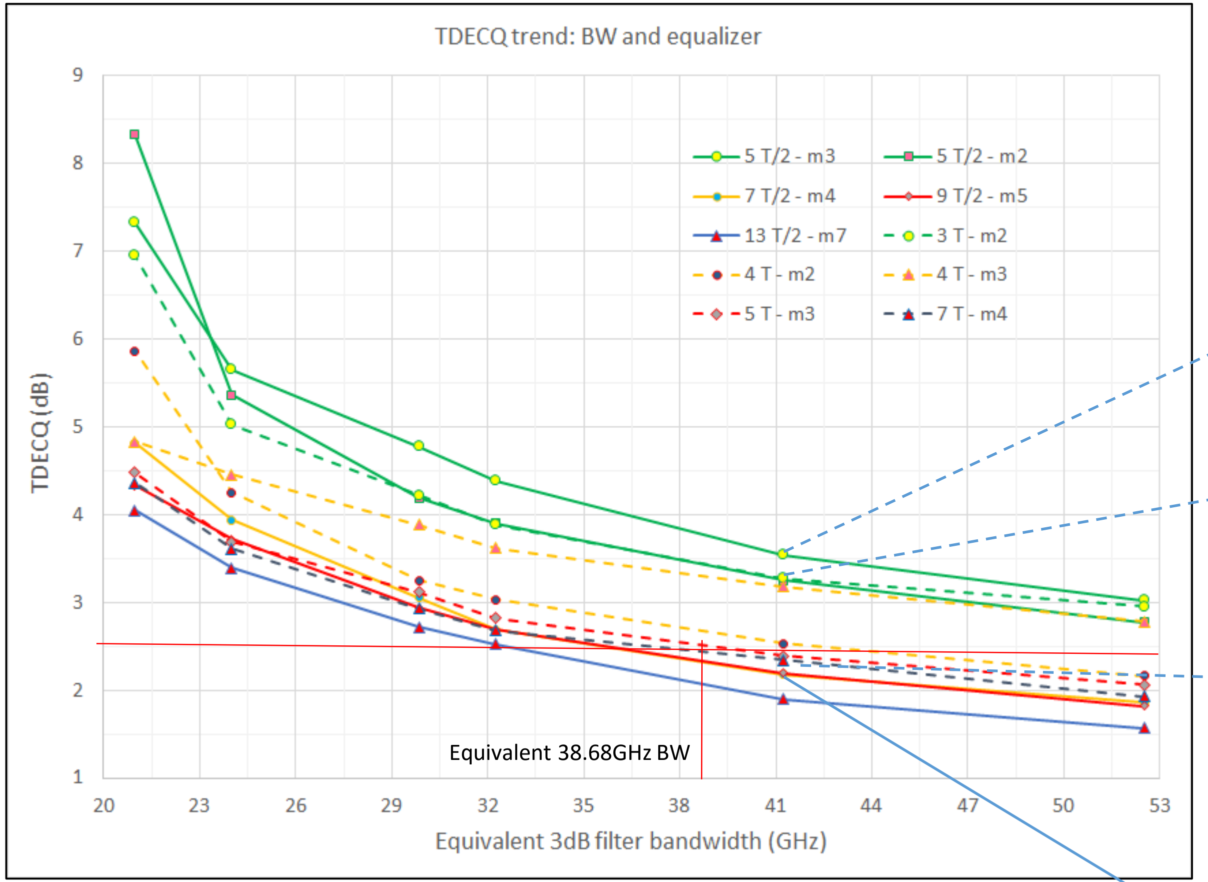
Calculated TDECQ worse for equivalent lenght T-spaced equalizers w/respect T/2 ones.

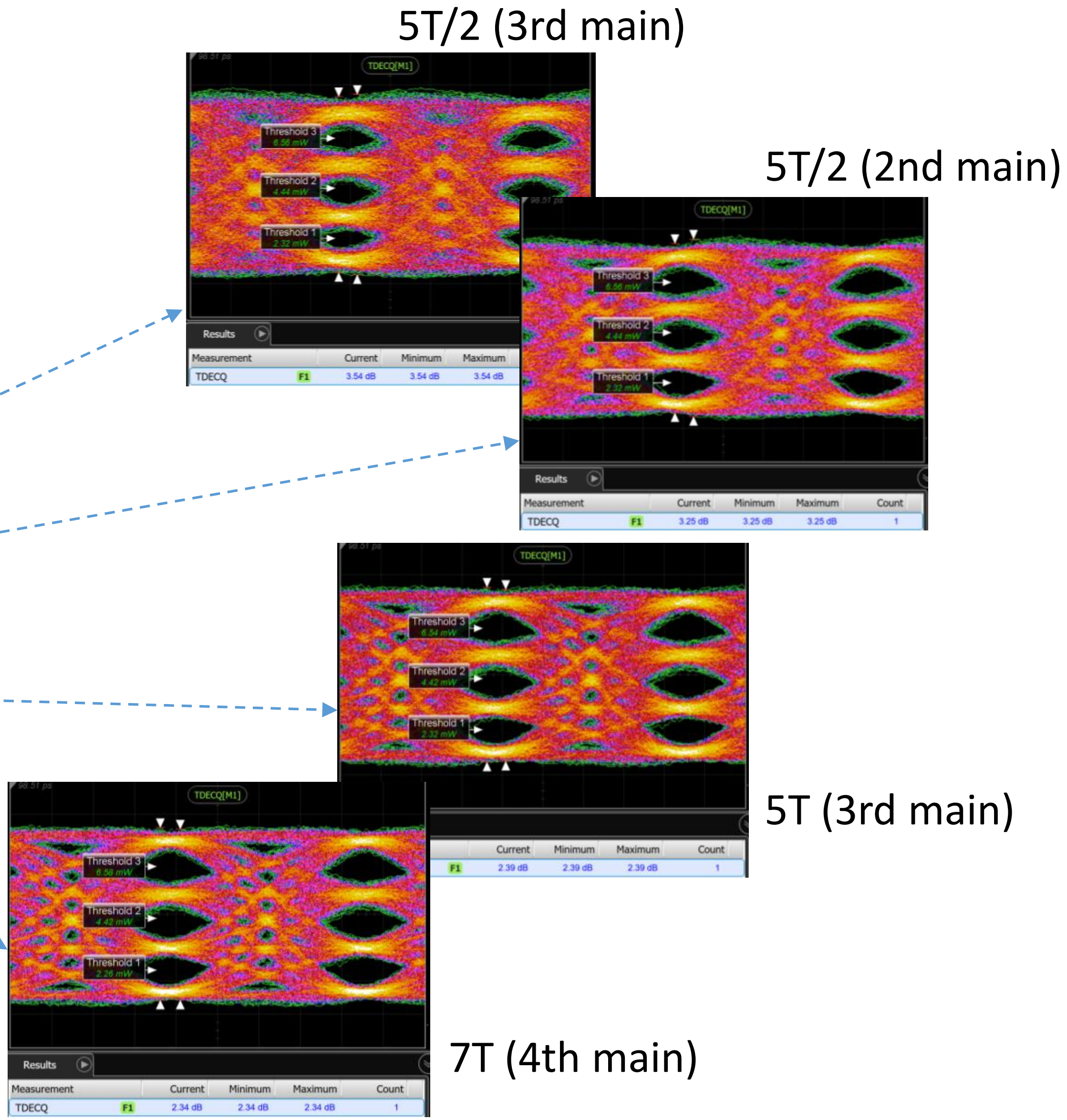
TDECQ is better over T spaced, when 5 T/2 or lower taps are considered.



Cisco TX: TDECQ versus equalizer and bandwidth.

All TDECQ plots show similar trends by varying RX BW.
Longer equalizers than reference (> 5 T- spaced, > 7 T/2) have < 0.5dB delta TDECQ.

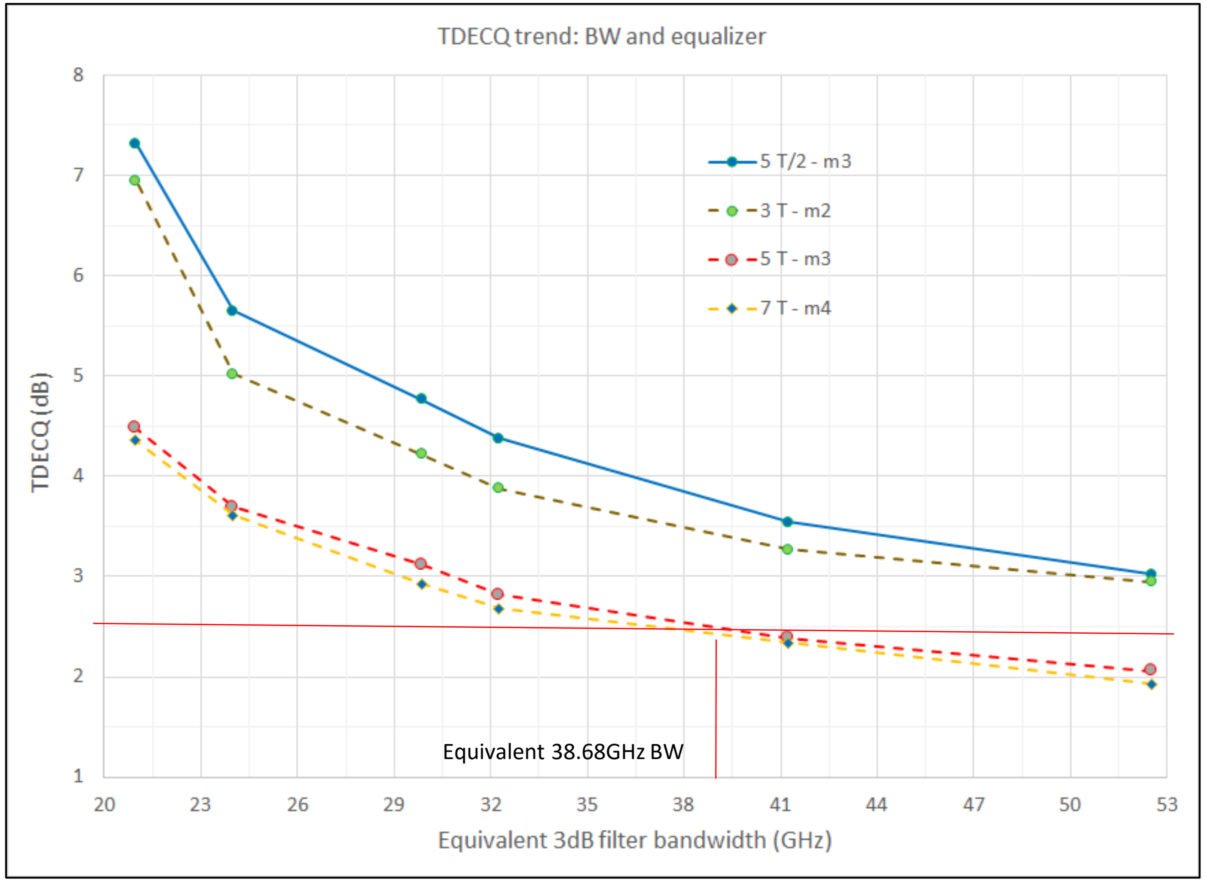


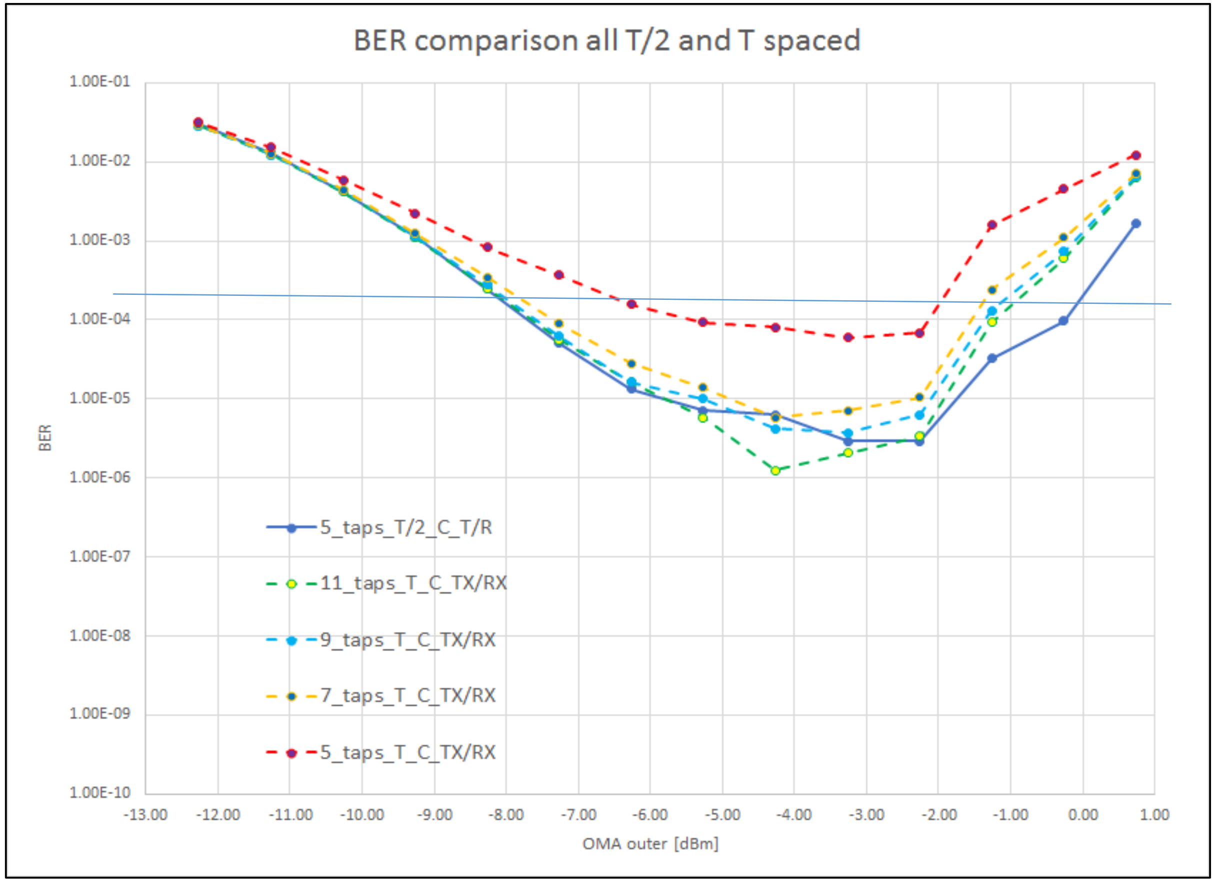


Cisco TX not compliant to TDECQ considering 5 T/2 equalizer.
Compliance is achieved with 7 T/2 spaced or 5 T spaced equalizer.

Cisco TX: TDECQ versus equalizer and bandwidth.

All TDECQ plots show similar trends by varying RX BW.
Longer equalizers tan reference (> 5 T- spaced, > 7 T/2) have < 0.5dB delta TDECQ.





- Considering qualitative information from these results –

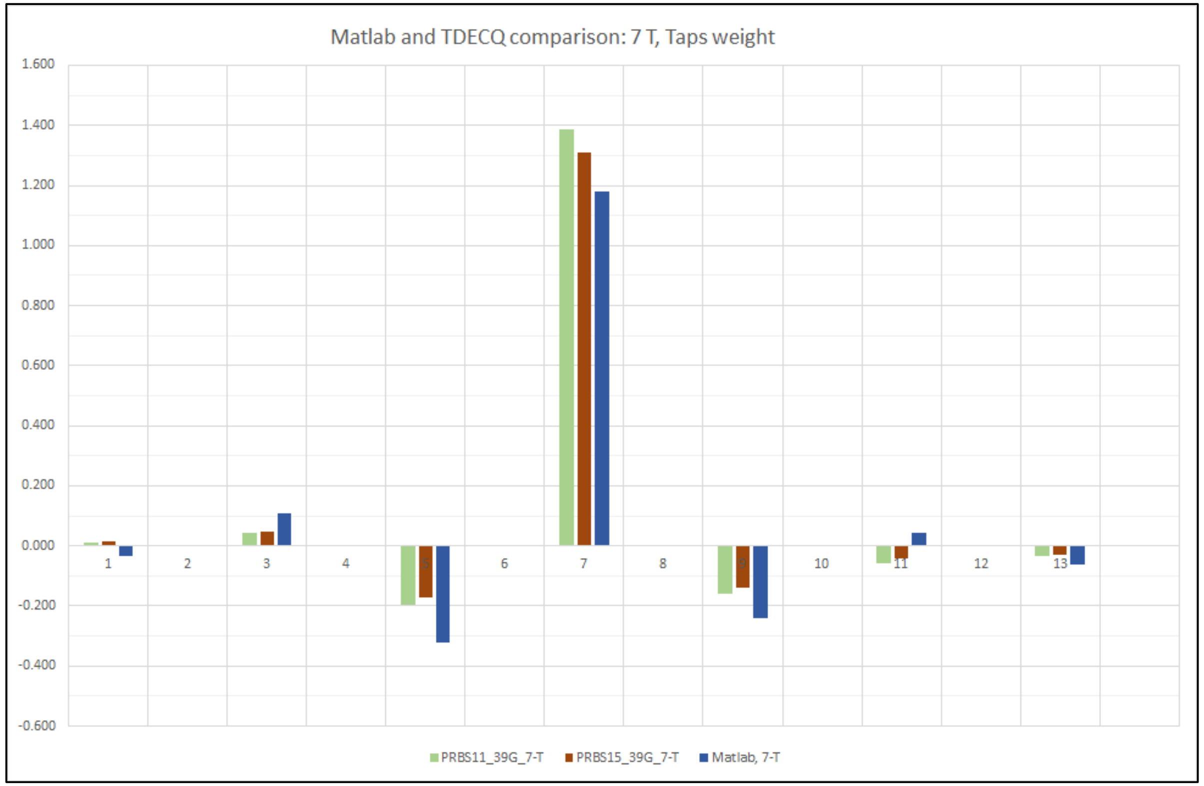
The Cisco TX is completely not compliant to TDECQ considering 5 T/2 equalizer, the link works fine with it.
The Cisco TX is close to compliance to TDECQ considering 5 or 7 T equalizer, but the same link has less margins with it.
(3 T will floor dramatically, but its TDECQ is better than the 5 T/2 reference equalizer)

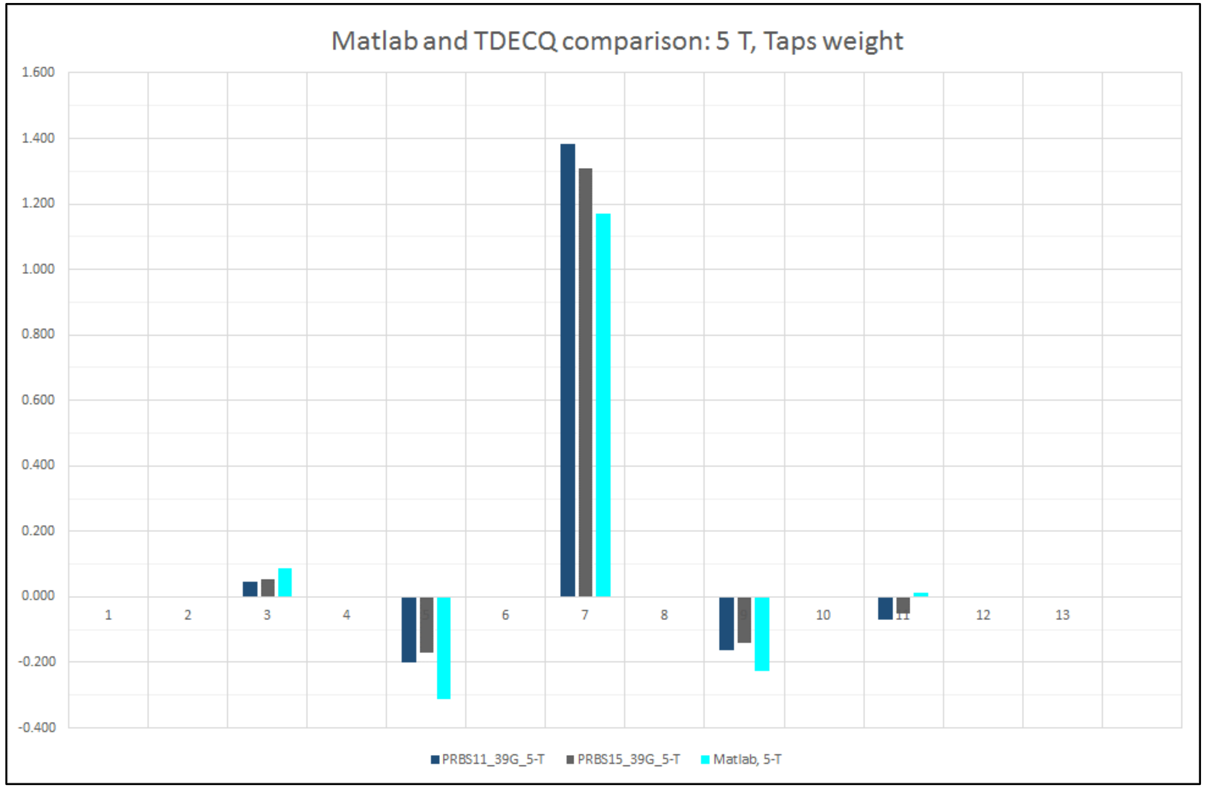
Cisco TX: TDECQ investigation.

Inverse trend between TDECQ/sensitivity due to actual RX: PD+TIA (assuming negligible impact of RT front end) added distortion.

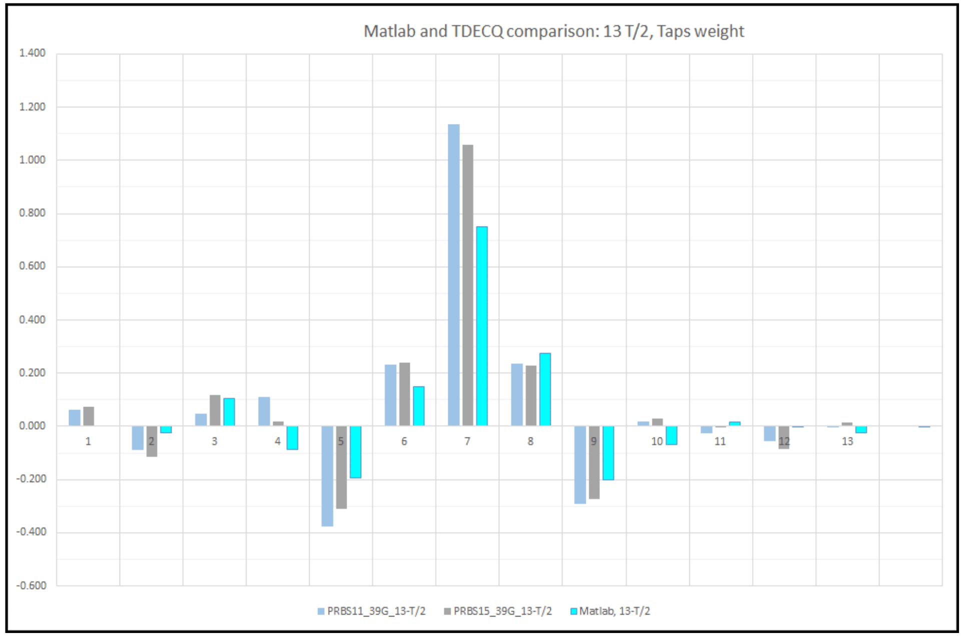
- Below is shown comparison of FlexDCA equalizer and Cisco-Matlab equalizer lenghts/taps for similar BW cases
  - TDECQ experiment: 39.813Gb/s reference filter (29.85GHz BW effective BW)
  - Sensitivity (post processing) experiment: assumed to be close to 30GHz BW.

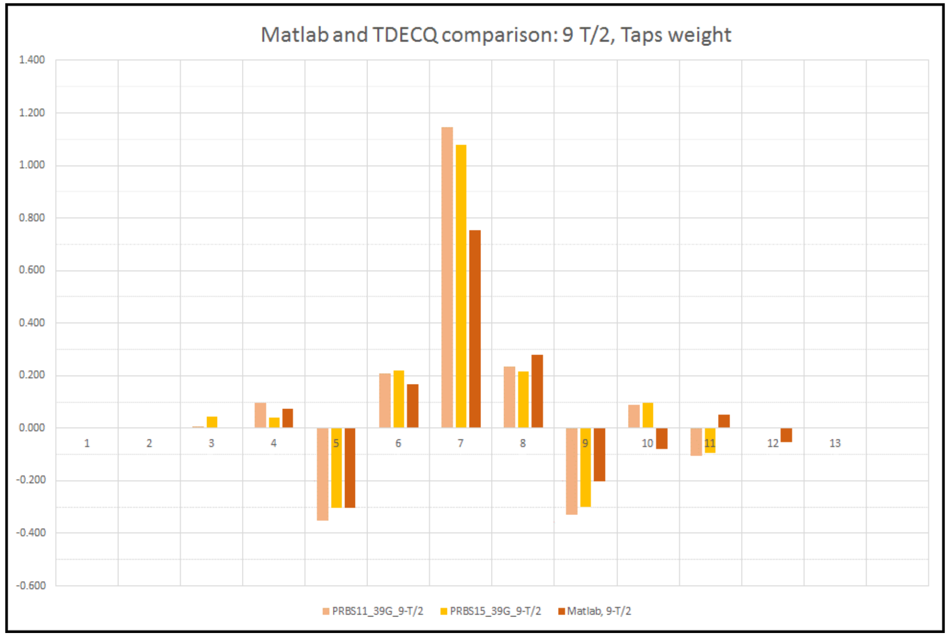
The T-spaced behavior is very similar (accounting difference in RX stage).
Pre-post taps have same energy (~0.1) for both cases.

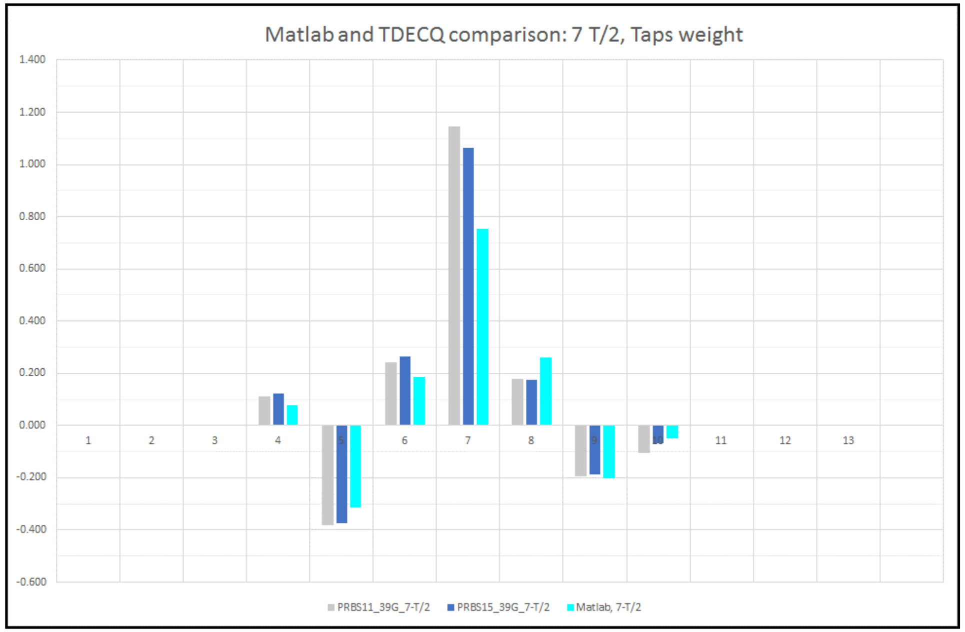


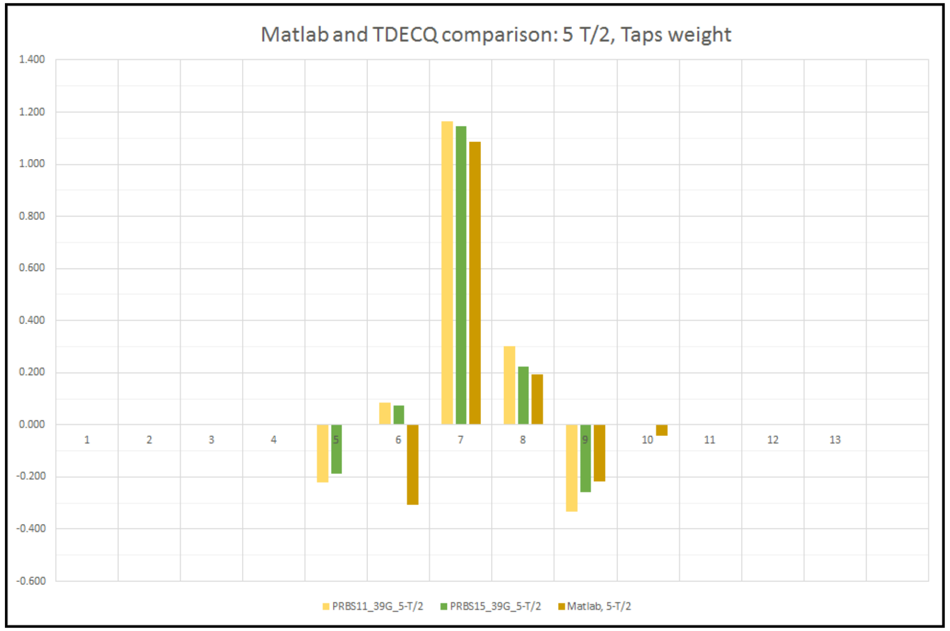


Cisco TX: TDECQ investigation (T/2).





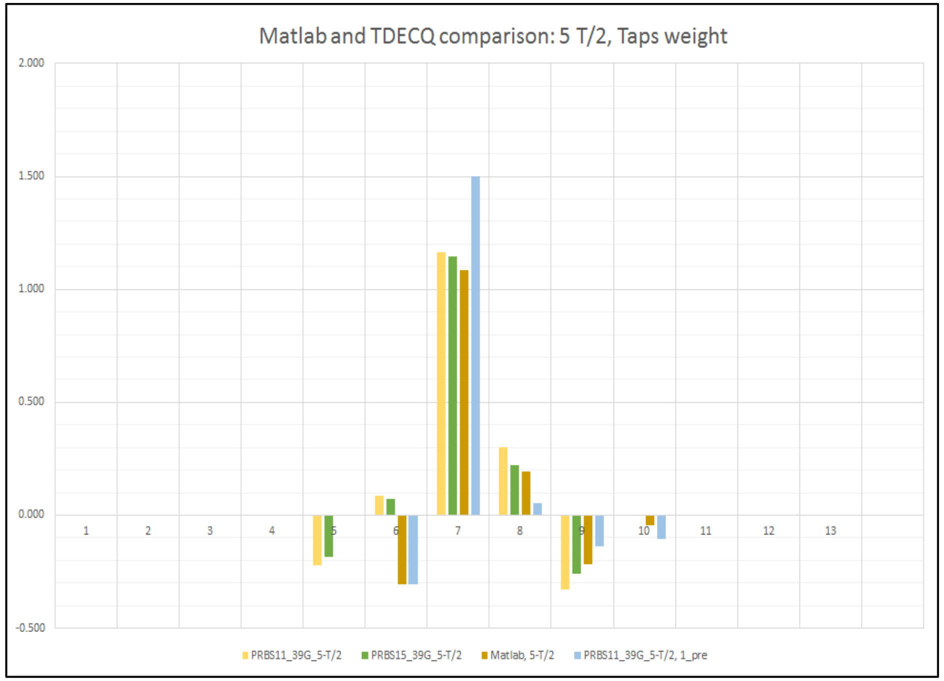




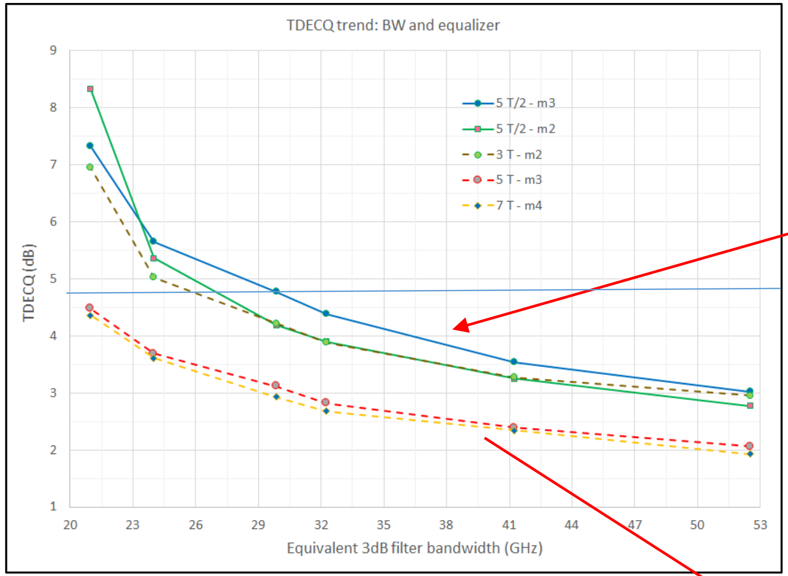
The reference IEEE equalizer (5 T/2 taps) for TDECQ has less pre-cursor energy then the equivalent Matlab one used to compute sensitivity.

13, 9 and 7 T/2 spaced taps equalizer behaves similarly.

Cisco TX: TDECQ investigation (T/2).



Pre-cursor energy comparable to Matlab post processing now.



Main tap position from 1 to 3 for both T/2 and T case.

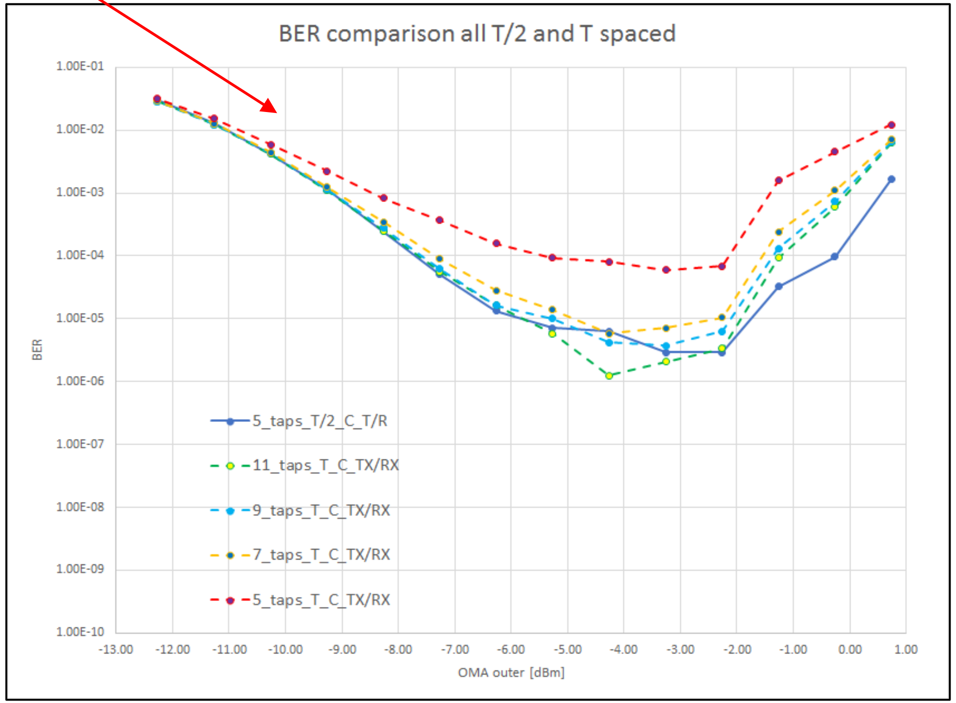
TDECQ 5 T/2 taps

1	2	3	BW (GHz)
2.77	3.02	3.59	52.50
3.25	3.54	4.08	41.25
3.9	4.38	5.04	32.26
4.19	4.77	5.71	29.86
5.36	5.65	6.51	24.00
8.32	7.32	10.1	20.97

TDECQ 5 T taps

1	2	3	BW (GHz)
2.36	2.06	2.82	52.50
2.42	2.39	3.17	41.25
2.97	2.82	3.7	32.26
3.21	3.12	3.85	29.86
4.19	3.69	4.57	24.00
5.81	4.48	4.83	20.97

TDECQ and Sensitivity results are still not in line considering our experimental case.

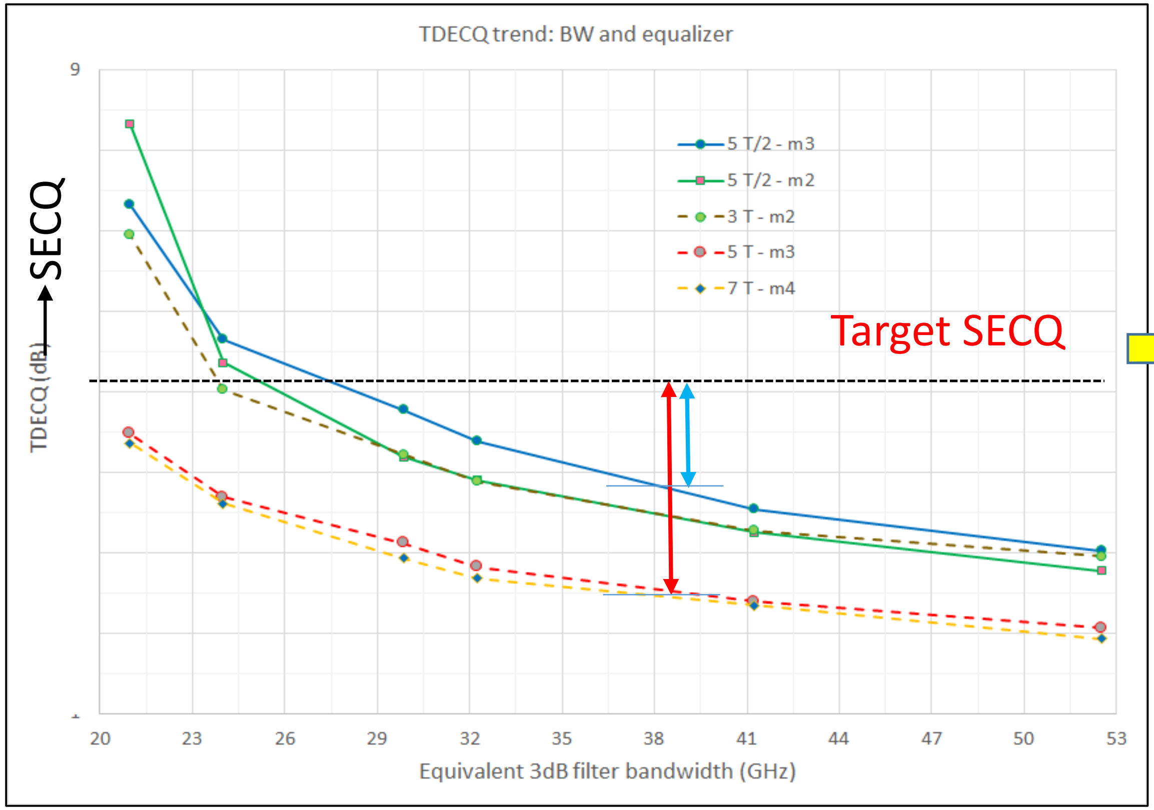


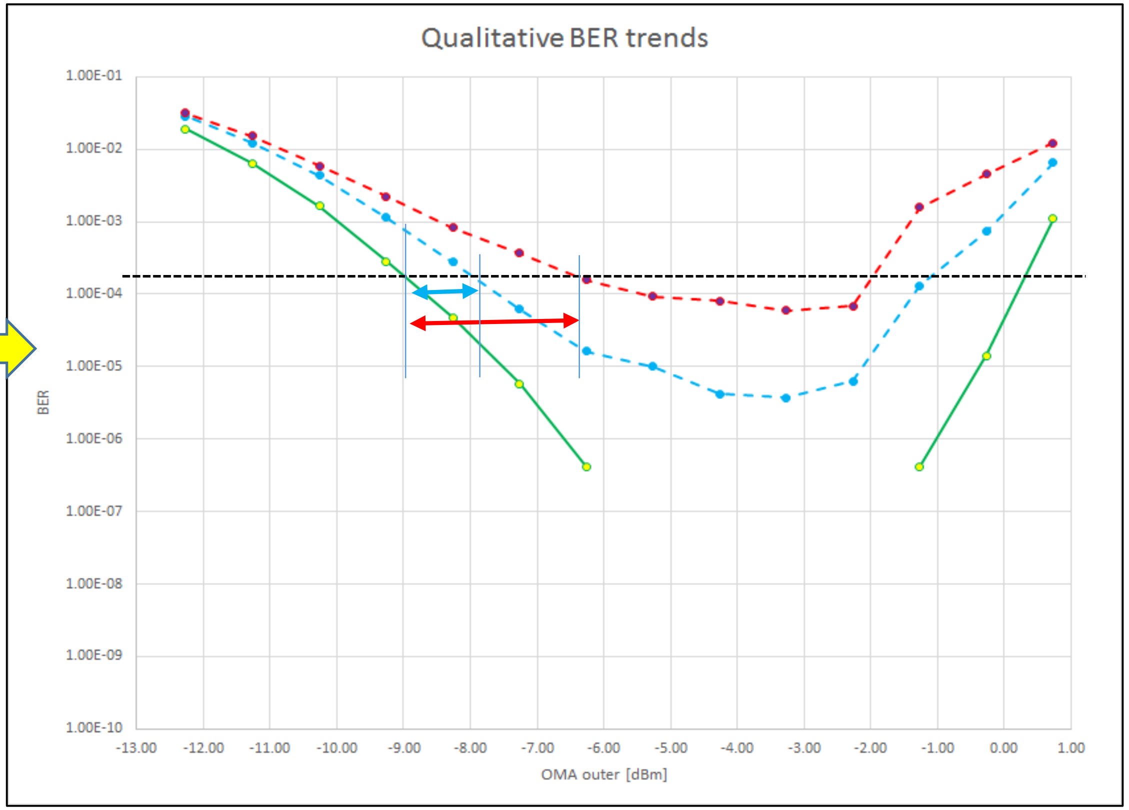
TDECQ/SECQ considerations.

TDECQ is a transmitter metric, but same method (and reference equalizer) is used to calibrate SECQ for SRS testing. We observed there's <u>no trend correlation</u> between measured BER/TDECQ into our experiment.

So from previous results, consider below (qualitative) case:

1. Calibrating SRS with 5 T/2 spaced taps reference equalizer, can produce higher SECQ values than T-spaced ones **->**
   2. The SECQ target value will be reached by adding <u>less</u> Gaussian noise and sinusoidal interference (blue arrow) **->**
      3. SRS will be less stressful w/respect the calibration with 5T-spaced taps reference equalizer (blue arrow) **->**
         4. There can be a margin erosion (or link failure) for the same DUT RX (blue versus red BER).





Questions.

Did anyone run a similar investigation/found same results ?
If yes, how we ensure against potential margin erosion behavior into IEEE 802.3bs ?

A possible workaround would be run TDECQ and SECQ calibration with different reference equalizers (e.g. 5 T/2 and 5T).

Formally TDECQ/SECQ signal processing should mimic what's expected for a real receiver.
Our experiment shows a good correlation between worst case BER/TDECQ using a 5T-spaced equalizer, as well understanding is that most of the 53GBaud ADCs will sample at 1 sample per bit.
Should we think to adopt (5 taps?) T equalizer for 53GBaud interfaces then, if these findings will be confirmed ?

(note: we plan to share the PRBS11 waveforms used to calculate TDECQ to everyone, as well as PRBS20 sensitivities captures can be made available too).

THANK YOU

Back-up

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.

IEEE TDECQ and SECQ descriptions and block diagrams (draft 3.0).

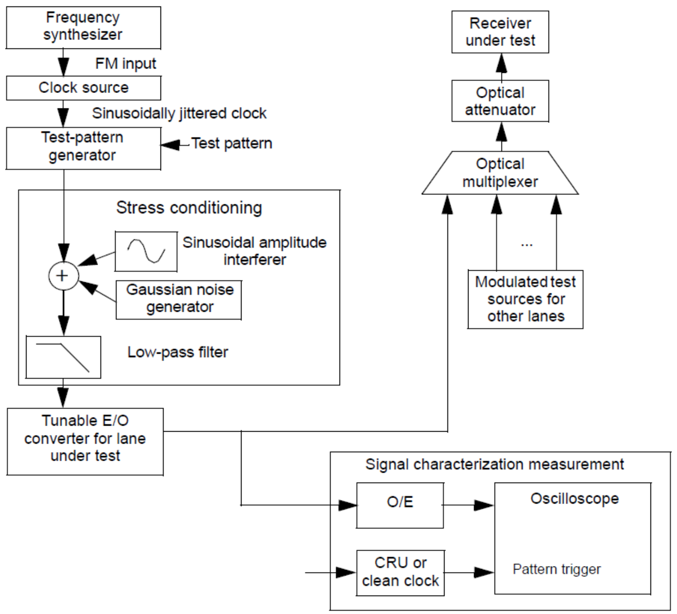


Figure 122–5—Stressed receiver conformance test block diagram

124.8.9 Stressed receiver sensitivity

Stressed receiver sensitivity shall be within the limits given in Table 124–7 if measured using the method defined in 121.8.9 with the following exceptions:

— The SECQ of the stressed receiver conformance test signal is measured according to 124.8.5, except that the test fiber is not used.

— The signaling rate of the test pattern generator and the extinction ratio of the E/O converter are as given in Table 124–6.

— The required values of the “Stressed receiver sensitivity (OMA_{outer}), each lane (max)”, “Stressed eye closure for PAM4 (SECQ), lane under test”, and “OMAouter of each aggressor lane” are as given in Table 124–7.

124.8.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)

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.

121.8.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)

The TDECQ of each lane shall be within the limits given in Table 121–6 if measured using the methods specified in 121.8.5.1, 121.8.5.2, and 121.8.5.3.

TDECQ is a measure of each optical transmitter's vertical eye closure when transmitted through a worst case optical channel (specified in 121.8.5.2), as measured through an optical to electrical converter (O/E) and oscilloscope with the combined frequency response given in 121.8.5.1, and equalized with the reference equalizer (as described in 121.8.5.4). The reference receiver and equalizer may be implemented in software or may be part of an oscilloscope.

Table 121–10 specifies the test patterns to be used for measurement of TDECQ.

121.8.5.1 TDECQ conformance test setup

A block diagram for the TDECQ conformance test is shown in Figure 121–4. Other equivalent measurement implementations may be used with suitable calibration.

Each optical lane is tested individually with all other lanes in operation and all lanes using the same test pattern. There shall be at least 31 UI delay between the test pattern on one lane and the pattern on any other lane. The optical splitter and variable reflector are adjusted so that each transmitter is tested with the optical return loss specified in Table 121–11. The state of polarization of the back reflection is adjusted to create the greatest RIN. Each optical lane is tested with the optical channel described in 121.8.5.2. The combination of the O/E and the oscilloscope has a fourth-order Bessel-Thomson filter response with a bandwidth of 19.34 GHz. Compensation may be made for any deviation from an ideal fourth-order Bessel-Thomson response.

The test pattern (specified in Table 121–10) is transmitted repetitively by the optical lane under test and the oscilloscope is set up to capture the complete pattern for TDECQ analysis as described in 121.8.5.3. The clock recovery unit (CRU) has a corner frequency of 4 MHz and a slope of 20 dB/decade. The CRU can be implemented in hardware or software depending on oscilloscope technology.

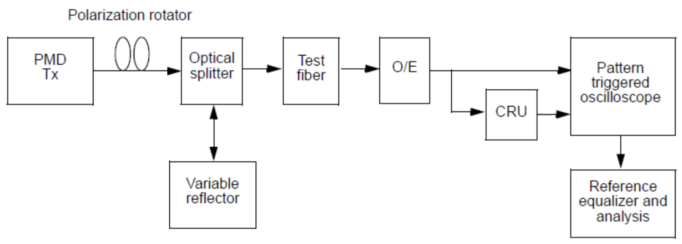


Figure 121–4—TDECQ conformance test block diagram

121.8.5.3 TDECQ measurement method

The standard deviation of the noise of the O/E and oscilloscope combination, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

OMA_{outer} is measured according to 121.8.4 on the equalized signal.

The test pattern specified for TDECQ (see Table 121–10) is transmitted repetitively by the optical lane under test and the oscilloscope is set up to capture samples from all symbols in the complete pattern.

The reference equalizer (specified in 121.8.5.4) is applied to the waveform. The equalizer taps are optimized for the minimum mean square error about the symbol levels ($P_{ave} - OMA/2$), ($P_{ave} - OMA/6$), ($P_{ave} + OMA/6$), and ($P_{ave} + OMA/2$), where the mean square error is calculated over the central 0.1 UI of the eye diagram. An eye diagram is formed from the optimally equalized captured waveform.

If an equivalent-time sampling oscilloscope is used, the impact of the sampling process and the reference equalizer on transmitter noise must be compensated for, so that the correct magnitude of noise is present at the output of the equalizer.

If a real-time sampling oscilloscope is used, and the reference equalizer is implemented in the oscilloscope, then the equalized eye diagram can be generated in the oscilloscope.

The average optical power (P_{ave}) of the equalized eye diagram is determined, and the 0 UI and 1 UI crossing points are determined by the average of the eye diagram crossing times, as measured at P_{ave}, as illustrated in Figure 121–5.

Two vertical histograms are measured through the eye diagram, centered at 0.45 UI and 0.55 UI. Each of the histogram windows spans all of the modulation levels of the eye diagram, as illustrated in Figure 121–5.

Each histogram window has a width of 0.04 UI. Each histogram window has outer height boundaries which are set beyond the extremes of the eye diagram (so that no further samples would be captured by increasing the vertical separation of the height boundaries).

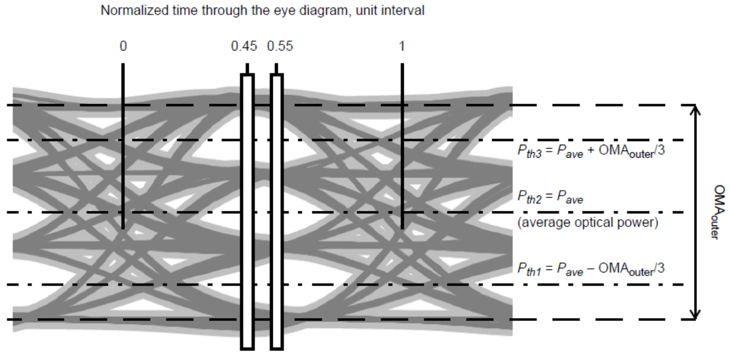


Figure 121–5—Illustration of the TDECQ measurement

121.8.5.4 TDECQ reference equalizer

The reference equalizer for 200GBASE-DR4 is a 5 tap, T/2 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.