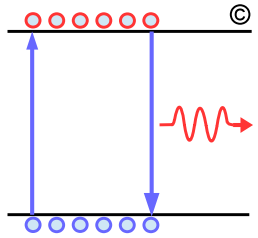

Optical Transmitters and Receivers Compliance Test Methodology

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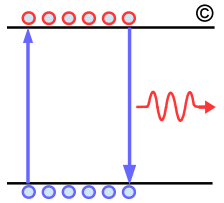
802.3bs Task Force Meeting
Waikola

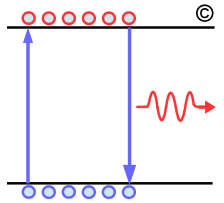
July - 2015

Contributors



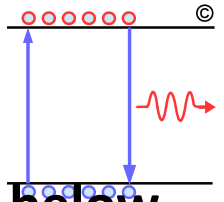
- Greg Le Cheminant – Keysight
- Pavel Zivny – Tektronix
- Marco Mazzini - Cisco

Overview of Test Method



- TDP (CL52, 87, 88)
- VECP (CL 52, 87, 88)
- TWDP (CL 68)
- TDEC (CL 95)
- CDAUI-8 (120D/E)

TDP Test Setup for 40Gbase-LR4



- **TDP is a comprehensive transmitter test method as shown below**
  - SR link uses 2 tap electrical filter
  - LR link uses 10 km fiber for the dispersion
  - In case of 400G may need to use fiber with min/max zero dispersion.
  - TDP require a reference transmitter to establish reference BER as defined by
    - **Rise/fall times of less than 25 ps at 20% to 80%.**
    - **The output optical eye is symmetric and passes the transmitter optical waveform test of 87.8.9.**
    - **In the center 20% region of the eye, the worst-case vertical eye closure penalty as defined in 52.9.9.2 is less than 0.5 dB.**
    - **Total Jitter less than 0.2 UI peak-to-peak.**
    - **RIN of less than –136 dB/Hz**
  - The drawback of the TDP has been the requirement to have a more strengthen/faster transmitter.

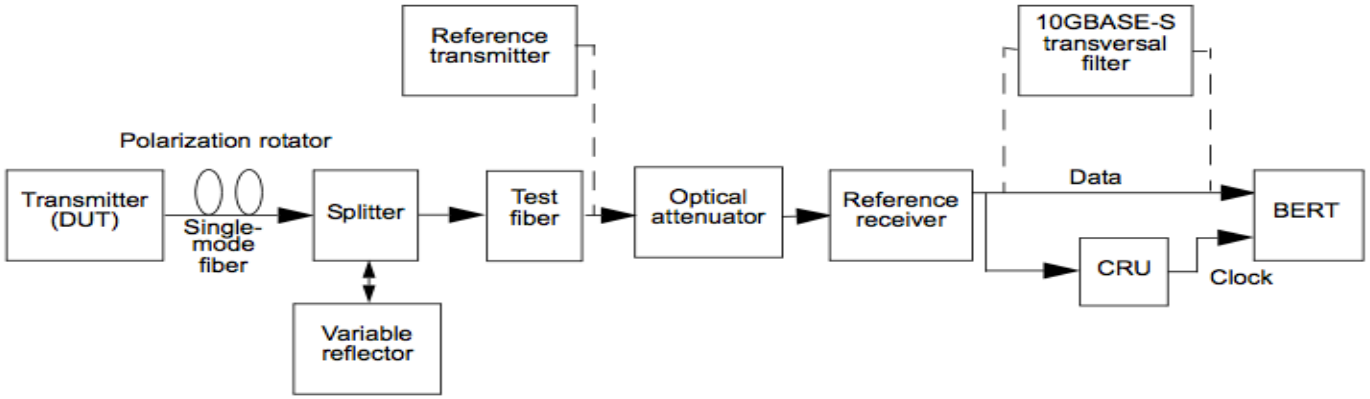


Figure 52–12—Test setup for measurement of transmitter and dispersion penalty

TDP Test Setup for 40Gbase-LR4 Cont.

- **To establish TDP measurement it is tested against a reference receiver with following characteristics:**
  - Nominal reference frequency of 7.5 GHz
  - Sensitivity of reference receiver limited by Gaussian noise
  - Receiver has minimum offset, DJ, hysteresis, deadlock, setup/hold, and other distortions
  - Nominal sensitivity S is measured with the reference transmitter and correct for any reference transmitter impairments
  - Sensitivity S measured at center of eye which is half way between left/right sampling point where BER is 1E-3
  - The Clock recovery unit CRU has corner frequency of 4 MHz with a slope of 20 dB/dec.
- **In case of 400 GbE it means defining a hardware CRU with build in CTLE+FFE!**

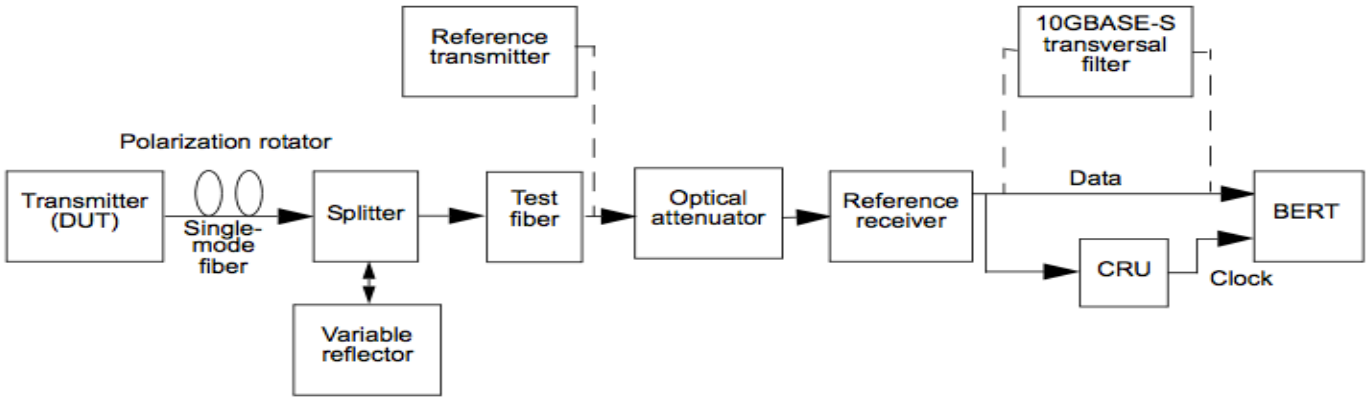


Figure 52–12—Test setup for measurement of transmitter and dispersion penalty

VECP

- **VECP (Vertical Eye Closure Penalty) is a test parameter to calibrate reference TP3 signal for DUT receiver stress sensitivity measurement**

$$VECP = 10 \times \log_{10} \frac{OMA}{A_0} \quad (dB)$$

A0 is the amplitude of the eye opening from the 99.95th% of the lower histogram to 0.05th% of the upper histogram.

OMA is the optical modulation amplitude.

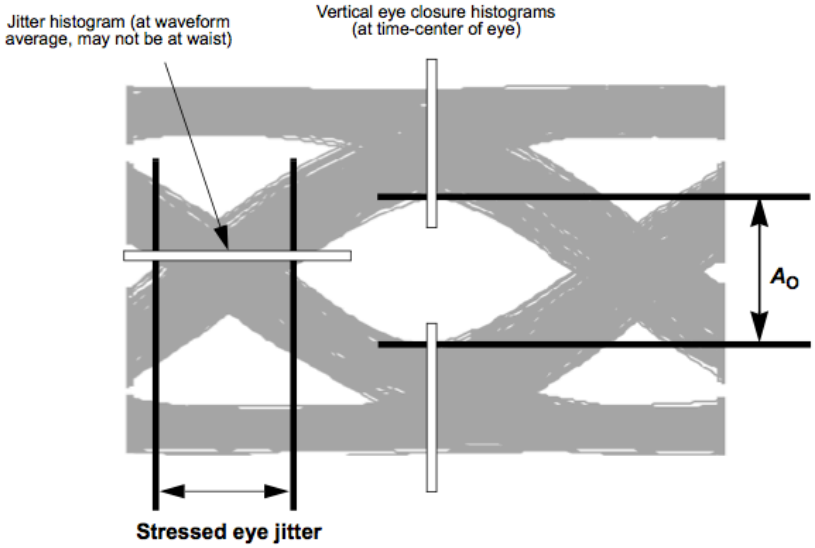
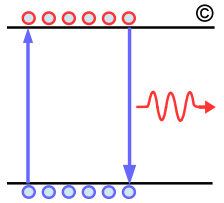


Figure 87–4—Required characteristics of the conformance test signal at TP3

Block Diagram of TWDP Model

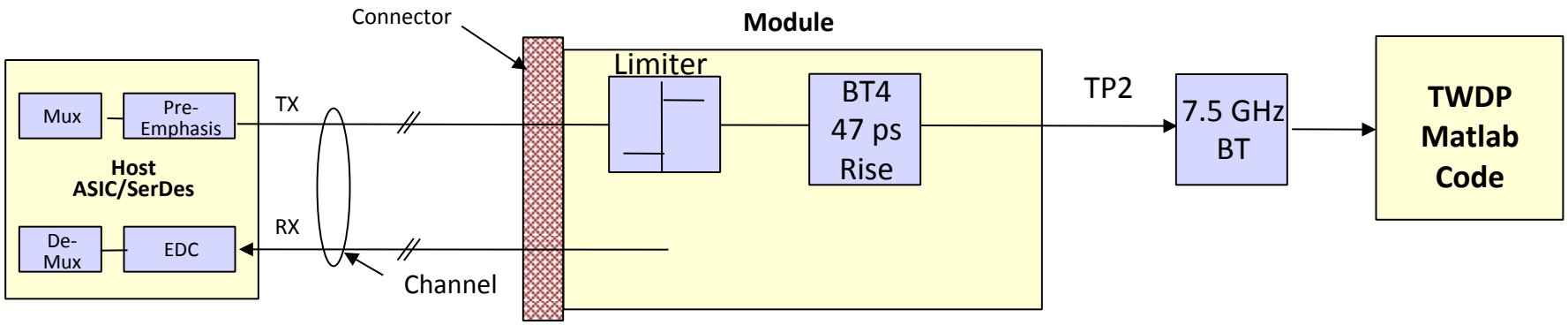


- **TWDP Matlab code emulated fibers with pre-cursor, split, and post-cursor dispersion response**
  - In case of 400G the fiber response can be implemented into the Matlab code but the challenge will be link performance dependent on chirp
  - Use of actual fiber would be more consistent
  - TWDP is defined by

$$TWDP = SNR_{REF} - SNR_{TX}(dBo)$$

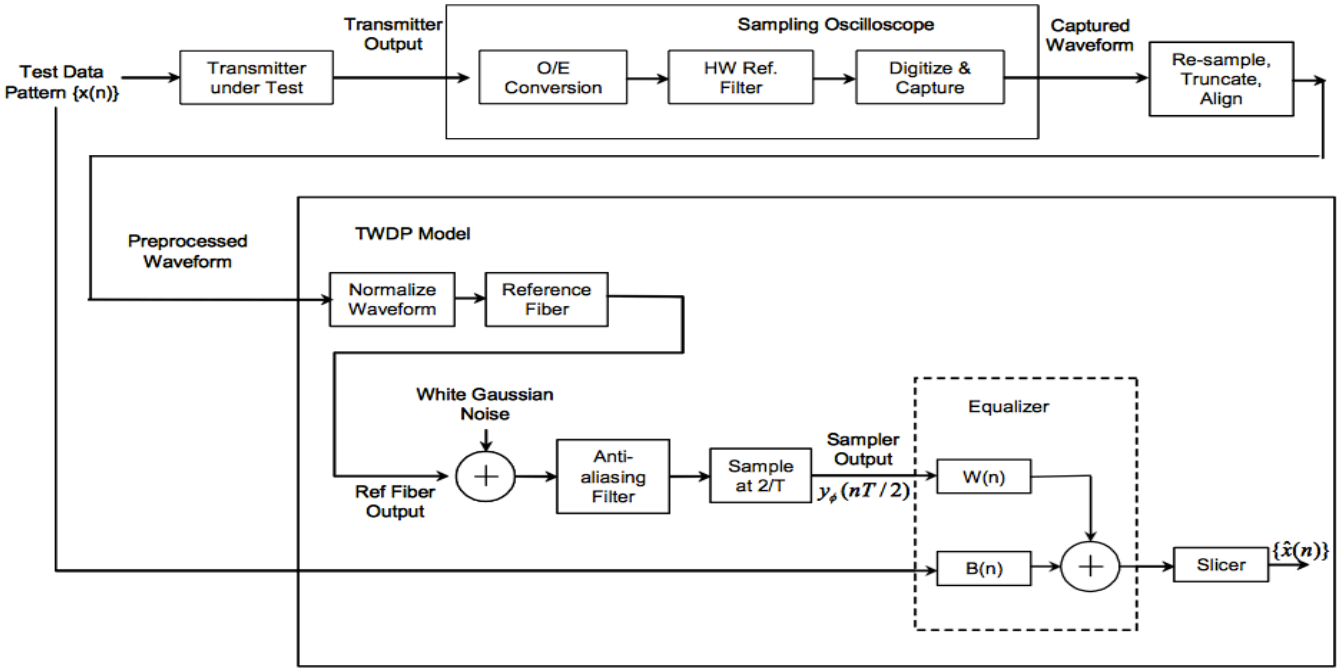
$$SNR_{REF}(dBo) = 10\log_{10}\left(OMA_{RCV}\sqrt{T/(2N_0)}\right)$$

Where OMA_{RCV} is the OMA at output of the reference channel, T is bit period, and N_0 is the AWGN.



Block Diagram Implementation of TWDP

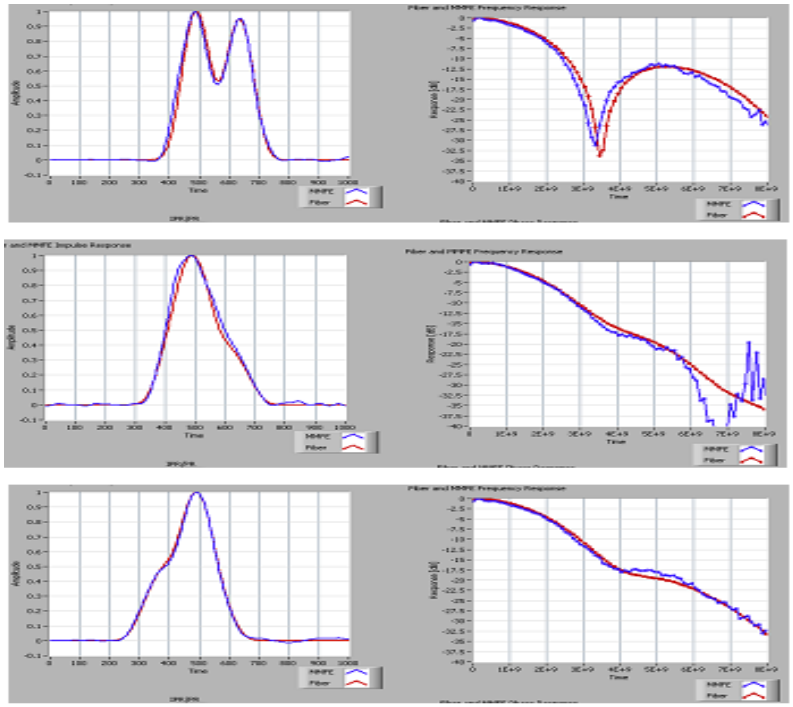
- **TP2 signal is captured then TWDP code applies the stressor "channel" to determine compliance effectively at TP3**
  - With stressor bypassed the WDP code is used to calibrate TP3 stressor
- **Limitation of TWDP test method**
  - On modern scope PRBS15 or SSPR could be used instead of PRBS9
  - Averaging of the data result in loss of noise distribution
  - Unless an SMF stressor which needs to be chirp depended can be defined then TWDP looses its greatest benifit measuring TP2 but guaranteeing TP3 compliance!

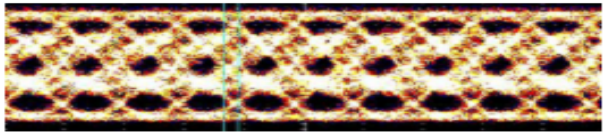


Swenson Norm, et al. Standards Compliance Testing of Optical Transmitters Using a Software-Based Equalizing Reference Receiver, OFC/NFOEC 2007.

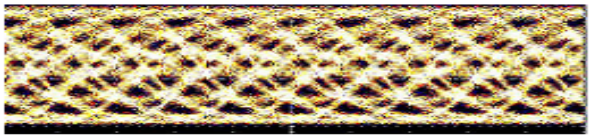
TWDP Stressors

- **Receiver DUT is tested with Pre, split, and post stressor pulse response as shown below**
  - PIE-D for each stressor is also shown (theoretical value in bracket)

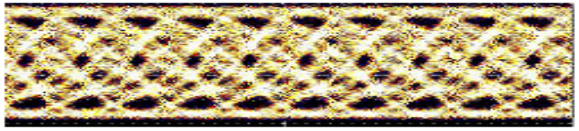




Symmetric 3.87dB (3.83dB)



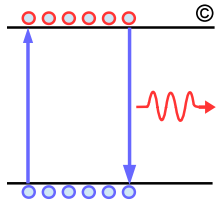
Post-cursor 4.24dB (4.20dB)



Pre-cursor 4.09dB (4.0dB)

Bohja S., et al. Next-generation 10 GBaud module based on emerging SFP+ with host-based EDC, COMSOC, Vol 45, Issue 3, 2007.

Transmitter and Dispersion Eye Closure (TDEC) CL-95



- **TDEC is a measure of transmitter VEC based on vertical histogram through O/E and worst case optical channel**
  - Extend the VECP test method to include the dispersion and noise penalty
  - TDEC test method is defined in 95.8.5.2
  - In case of 400G the challenge will be fiber response interaction with transmitter chirp and guaranteeing there is no error floor for an HOM link which are more prone to error floors!

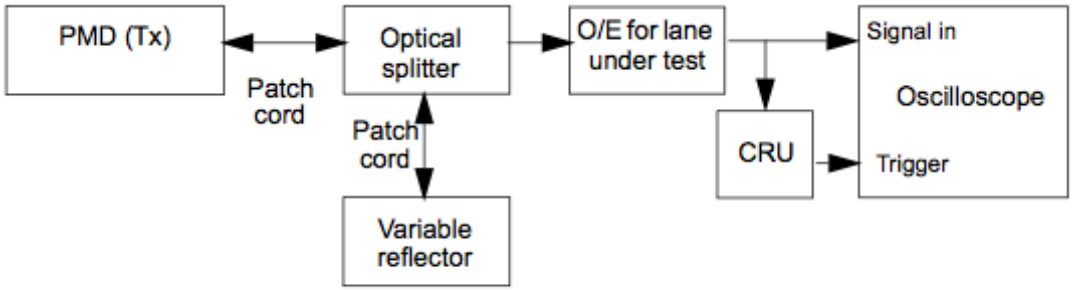


Figure 95–3—TDEC conformance test block diagram

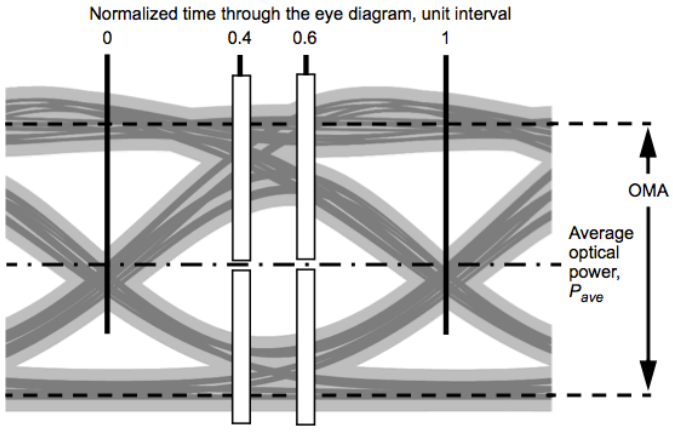


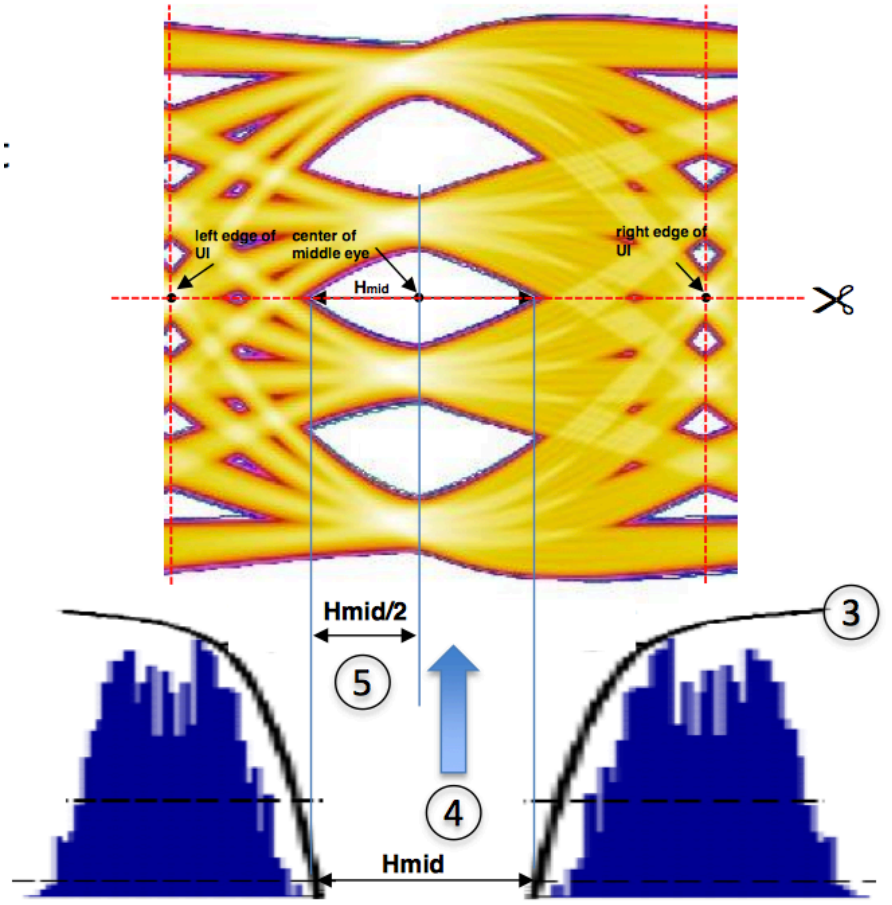
Figure 95–4—Illustration of the TDEC measurement

Re-use CDAUI-8 Test Method

- **Reuse Annex 83E.4.2 method to:**
  - As proposed by

http://www.ieee802.org/3/bs/public/15_03/brown_3bs_01a_0315.pdf

  - Capture QPRBS13 pattern (> 4 million symbols)
  - Apply reference CTLE for optical links instead apply CTLE+nxFFE or nxDFE
  - Construct CDFs of eye edges at zero crossing
  - Hmid = $1e^{-6}$ inner eye width
  - Locate center of middle eye at Hmid/2
  - For optical link Hmid probability can be changed to $2e^{-4}$
  - This approach with addition of fiber potentially could measure TDP directly without the need for reference receiver.

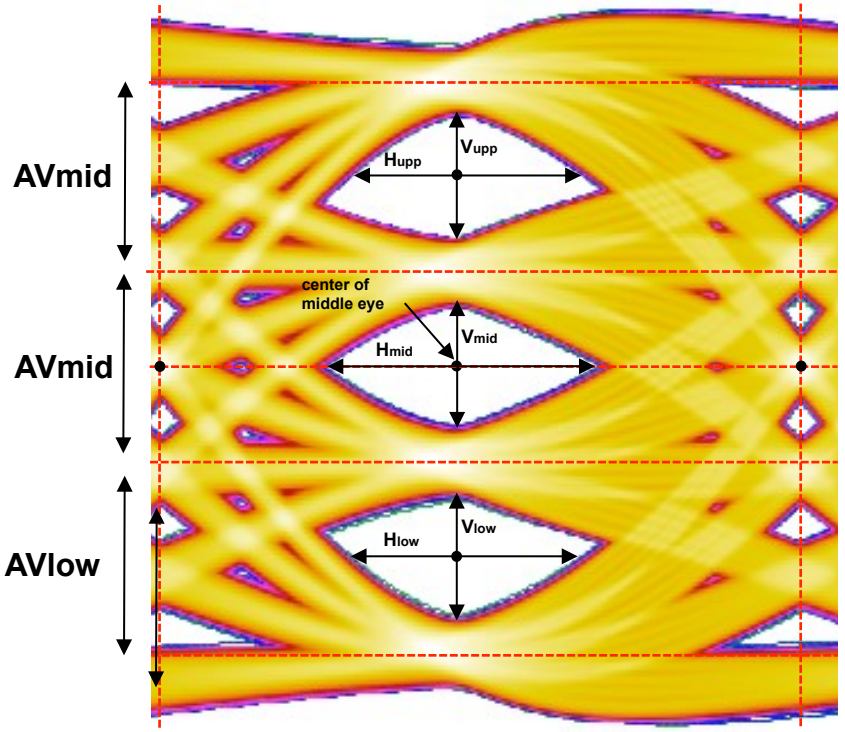


Re-Use CDAUI-8 Test Method Cont.

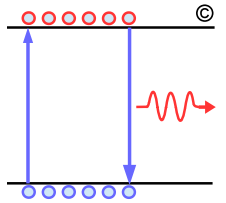
- **TDP could be calculated from the scope measurement at TP3 by measuring:**
  - Vup, Vmid, and Vlow on the scope through a software CTLE+nFFE or nDFE

$$TDP = \max\left(10\times\log_{10}\left(\frac{AVlow}{Vlow}\right), 10\times\log_{10}\left(\frac{AVmid}{Vmid}\right), 10\times\log_{10}\left(\frac{AVhigh}{Vhigh}\right)\right)$$

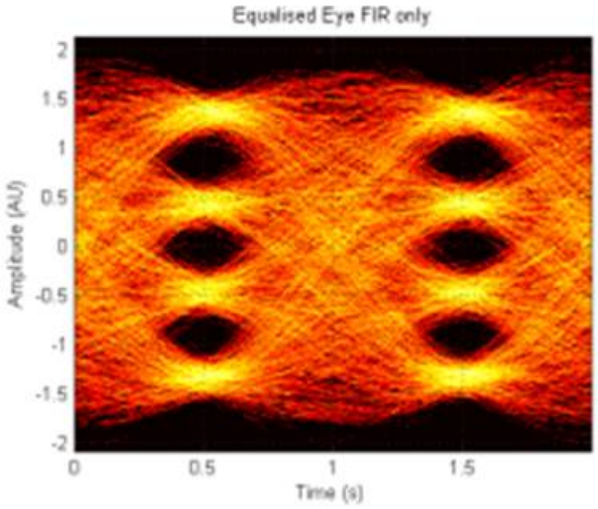
  - Hup, Hmid, and Hlow are equivalent to the (1-stress eye jitter)
  - This method similar to TDEC has potential concern with error floor.



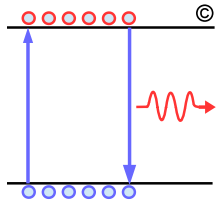
Reviewing Previous Work for Potential Reference Equalizer



- **Typically a receiver with 4-8 taps T/2 FFE with 1-2 taps of DFE is sufficient to equalize band limited OE and the electrical driver impairments**
  - Uses 21 tap FFE, AWG with 23 GHz limiting the overall BW for 100G PAM
    - http://www.ieee802.org/3/bs/public/14_09/way_3bs_01a_0914.pdf
  - Uses 22 taps T/2 with 35 GHz LiNO3 MZM and 32 GHz receiver
    - http://www.ieee802.org/3/bs/public/14_09/mazzini_3bs_01_0914.pdf
  - Updated result Way/Mazzini showed 14 T/2 FFE having identical performance to 22 T/2 FFE
    - http://www.ieee802.org/3/bs/public/15_01/way_3bs_01a_0115.pdf
  - Even more updated results (below) contributed by Mazzini indicate 7 T/2 FFE is adequate with ~0.4 dBo penalty compare to 22 tap FFE

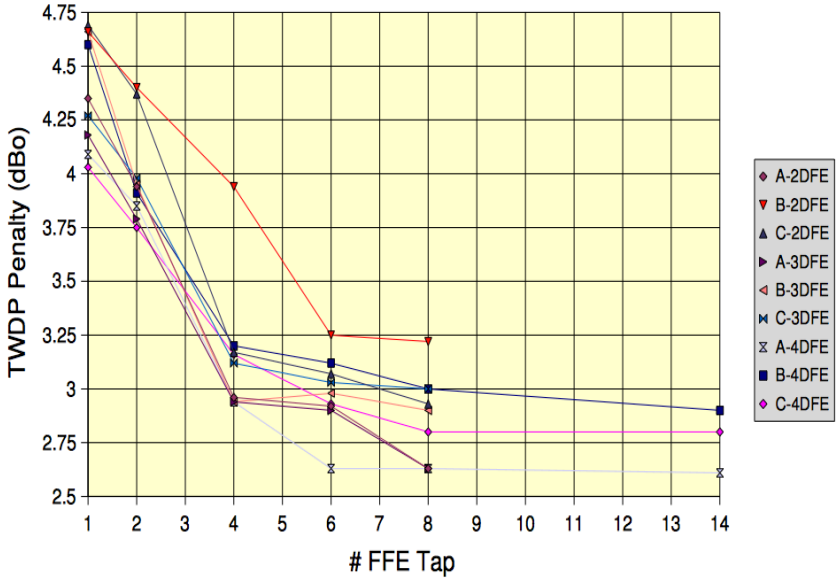


Reviewing Previous Work for Potential Reference Equalizer Cont.

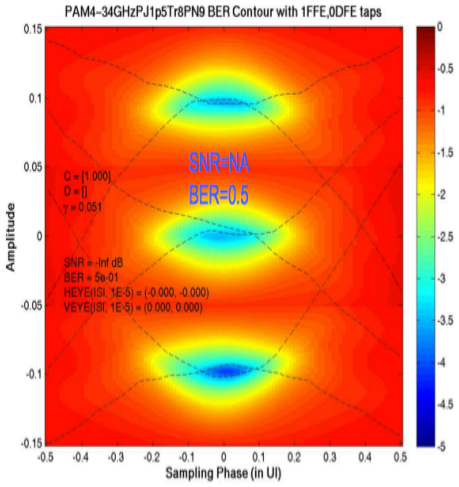


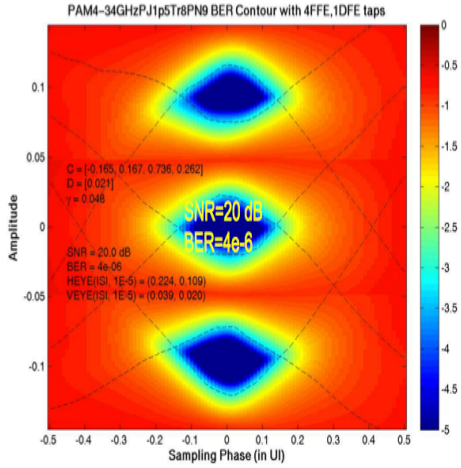
- Luxtera MZM with ~32 GHz BW coupled to 28 GHz PIN/TIA operating at 100 Gb/s PAM4, 11 tap FFE was adequate (possibly FFE could be shorten to 7 tap with small penalty)
  - P. V. Mena, E. Ghillino, Synopsys, Inc., A. Ghiasi, Ghiasi Quantum LLC, B. Welch, Luxtera, Inc., M. S. Khaliq, DET - Politecnico di Torino, and D. Richards, College of Staten Island, 100-Gb/s PAM4 Link Modeling Incorporating MPI, IEEE Optical Interconnect 2015
- Considering result presented in IEEE BS project (previous page), IO conference (above), 4G DML operating at 10G (below), and Optsim simulation of 34 GHz MZM with added jitter (below) indicates 6-10 tap T/2 FFE with 1 tap DFE is should cover broad range of MZM and DML transmitters.

4G DML operating at 10G, 6 T/2 + 2 T DFE sufficient
http://www.ieee802.org/3/hssg/public/nov07/ghiasi_01_1107.pdf

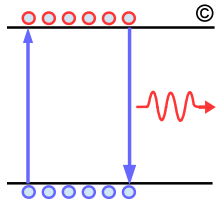


8 ps TX with 34 GHz RX operating at 100G 4 T/2 + 1 T DFE sufficient
http://www.ieee802.org/3/bm/public/nov12/ghiasi_01a_1112_optx.pdf



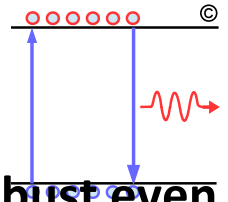


Feedback from Scope Suppliers



- **Supplier I feedback regarding sampling scope**
  - Supports pattern length up to 2^17 bits
  - Supports CTLE, FFE, and DFE
    - CTLE is not adaptive
    - FFE will average non-synchronous noises
    - FFE can be T or T/2 spaced
- **Supplier II feedback regarding sampling scope**
  - Supports pattern length up to 2^16 bits
  - Supports CTLE, FFE, and DFE
    - CTLE, FFE, and DFE could be made adaptive
    - Technically can be measure prior to EQ then based on the FFE noise can be shaped prior to display
    - FFE can be T or T/2 spaced
- **Both scope supplier could support PRBS15 or SSPR pattern at expense of test time**
  - The biggest challenge is how to capture non-synchronous noises then accurately included it in the measurement.

Summary



- **With limited experience the initial HOM test method must be robust even at potential expense of test time**
  - Any test method should not hide potential error floors
  - Modern scope can support PRBS15 or SSPR at expense of 1-2 min test time
  - Test method such as TWDP could also be extended to support longer data pattern
    - Without suitable SMF stressor TWDP does not provide added benefit over extending the TDEC/CDAUI-8 test method
- **The TDP and stress sensitivity methods of CL52, 87, 88 are excellent in identifying potential error floor but the challenge has been lack of available or inconsistent hardware reference receiver**
  - It is not clear that hardware reference receiver which will need to incorporate CTLE+nFFE or even DFE will be available
- **A more viable method is extending TDEC/CDAUI-8 test method using PRBS15 or SSPR measured with a reference software receiver on the scope**
  - The challenge here is how to measure non-synchronous noises
- **Any of the above methods require agreement on the transmitter and receiver BW and only then the reference receiver/Equalizer can be defined**
  - It is the balancing act of using higher BW components vs using more equalization!