

53.125 Gb/s, DML, PAM-4 10 km Transmission: FFE Tap Number Perspective

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Problem Statement

- **IEEE 802.3cd D2.2 clause 139.7 defines the 50 Gb/s FR-4 and LR-4 Transmitter Optical Measurement and Measurement Methods**
 - Subclause 139.7.5.4 defines the reference equalizer for 50GBASE-FR/LR TDECQ measurement as “a 5 tap, T spaced, feed-forward equalizer (FFE), where T is the symbol period. The sum of the equalizer tap coefficients is equal to 1”
 - Most TDECQ tests currently published use LN, MZM or EML for 10 km SMF transmission
 - Directly Modulated Laser (DML) results have recently been reported by Applied Optoelectronics Inc. at OFC/ECOC/IPC
- **The reference equalizer defined in subclause 139.7.5.4 is much simpler than practical industry standard implementations**

Problem Statement-2

- **High Speed Directly Modulated Laser Based Transmitter Implementations have “eye skew” due to direct modulation dynamics which is absent from LN MZM and EML implementations**
 - A 5-Tap reference equalizer cannot mitigate this “eye skew” efficiently leading to elevated TDECQ values.
 - This will negatively impact DML based transmitter implementations even though they can close up to 10 km links (shown later in the presentation)
 - Most PAM-4 DSP ASICS implement more than 7 T-spaced Taps
- **TDECQ does not show one to one correspondence with RX sensitivity at KP-4 FEC limit.**

Impact of Number of Taps on Eye Skew Penalty

DML Testing Condition:

25 °C, $I_{op}=40\text{mA}$, ER=4.5dB

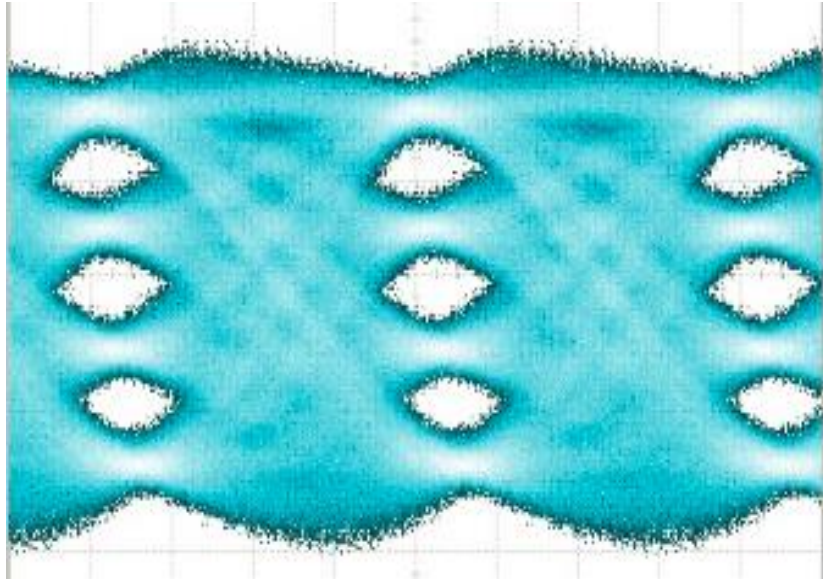
70 °C, $I_{op}=55\text{mA}$, ER=4.5dB

- Ten devices were selected from a production grade 28 Gbaud PAM-4 1310 nm DML wafer.
- TDECQ values were measured at 25 °C and 70 °C TOSA case temperatures.
- TDECQ optimizer was turned off for all measurements.
- Bias condition is a typical DML bias condition.
- Number of FFE taps were increased and their impact on TDECQ was investigated. Results at 70 °C TOSA case temperature are presented.

Eye Skew Comparison: DML vs. EML

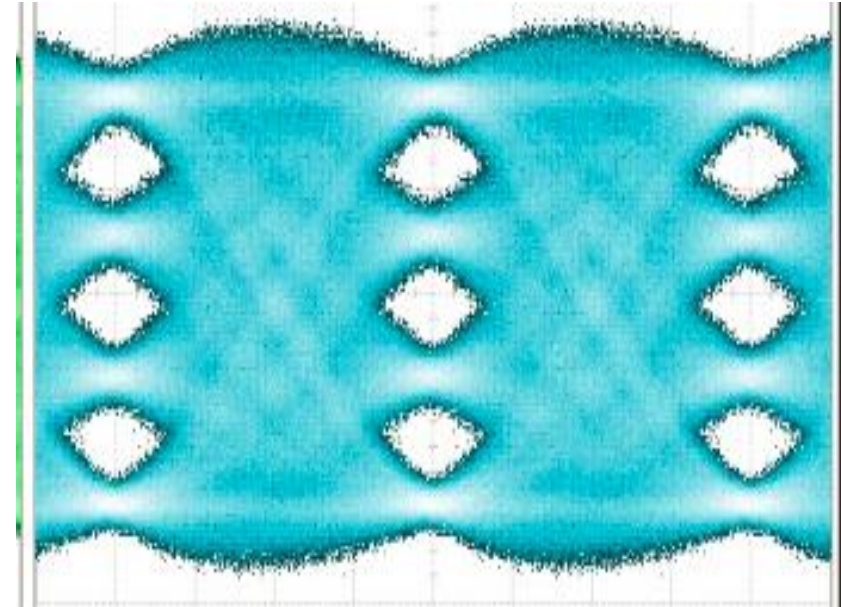
AOI DML

70°C/55mA, ER = 4.5dB;
TDECQ = 3.93 dB



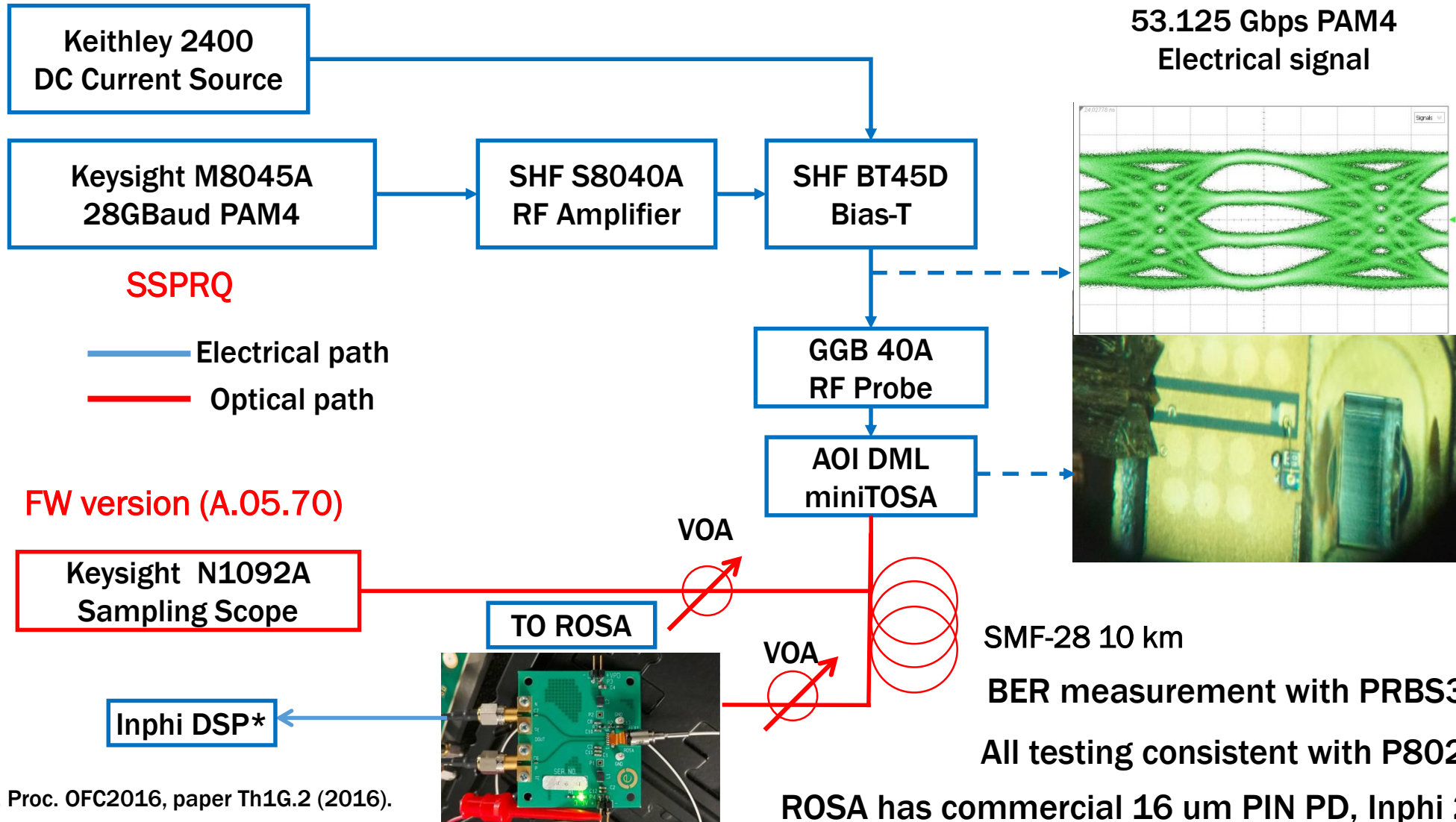
AOI EML

50°C/60mA, V1 = -0.8V, V0 = -2.2V;
ER = 4.5dB; TDECQ = 1.5 dB



- Eye Skew is enhancing the TDECQ value for DML compared to EML.
- Both devices have comparable bandwidth on packaged AOI mini-TOSA

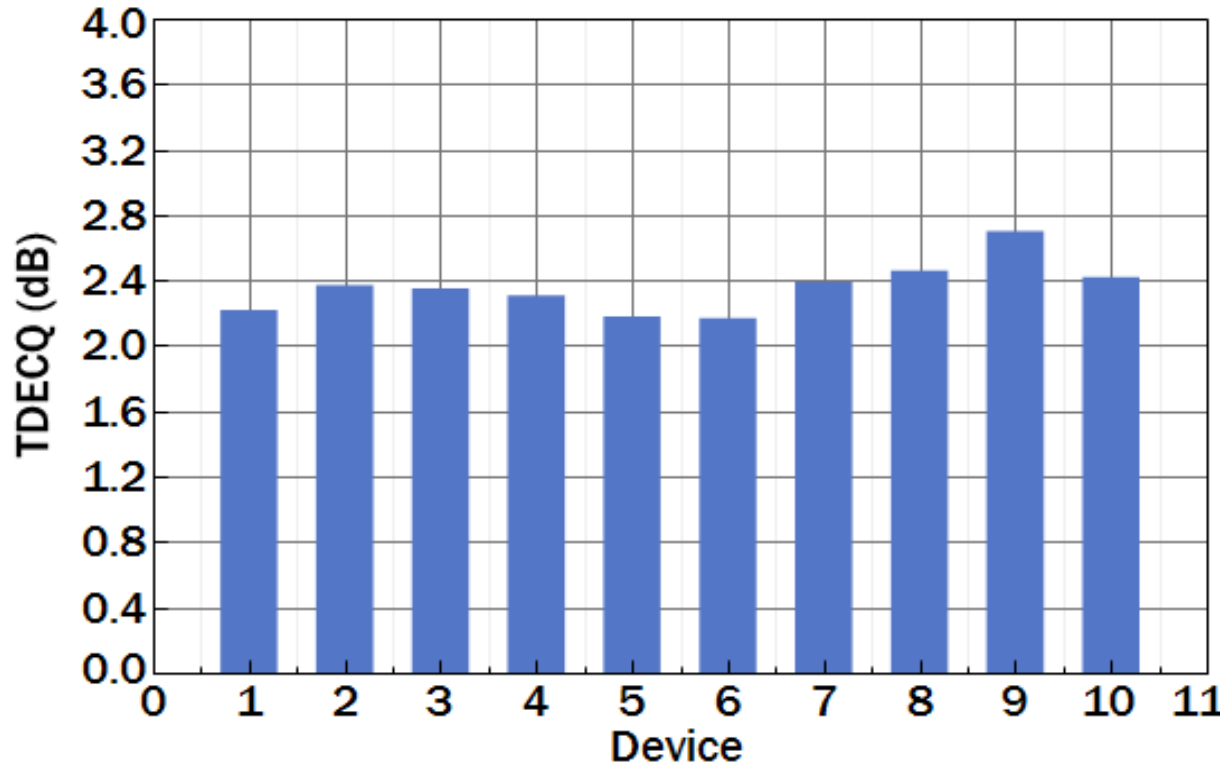
Experimental Setup



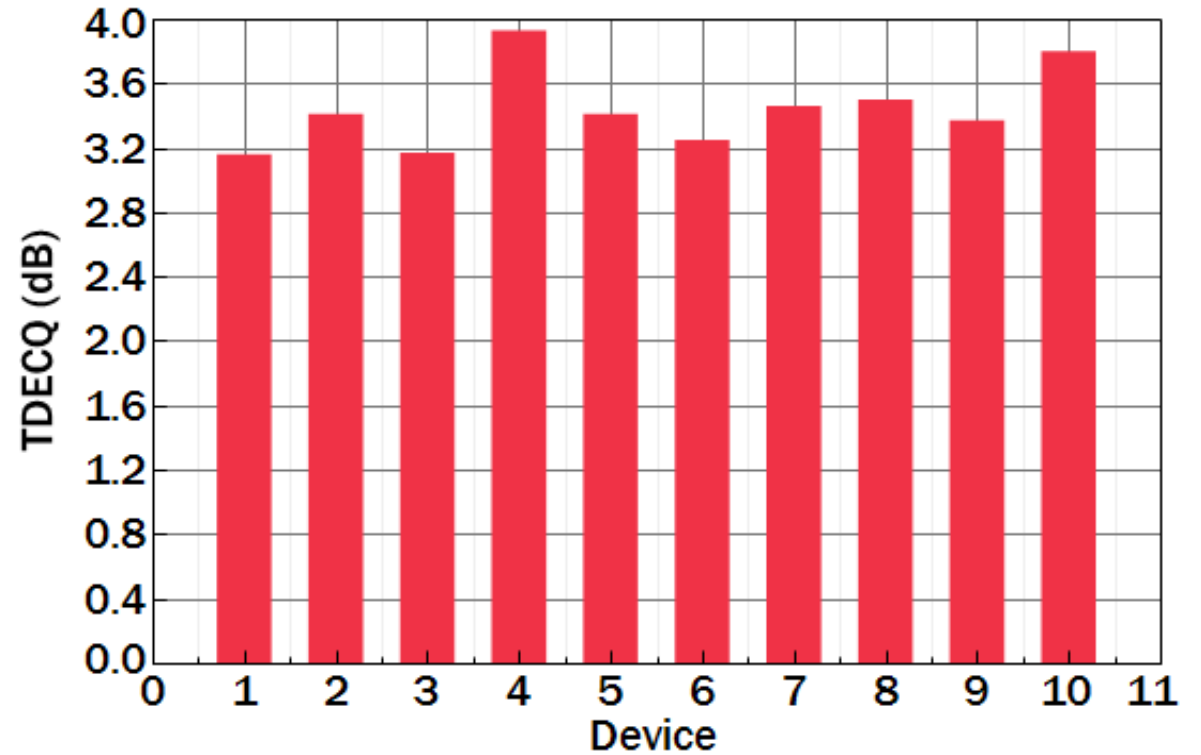
*F. Chang et. al., Proc. OFC2016, paper Th1G.2 (2016).

TDECQ (dB) with 5-Tap FFE

25 °C

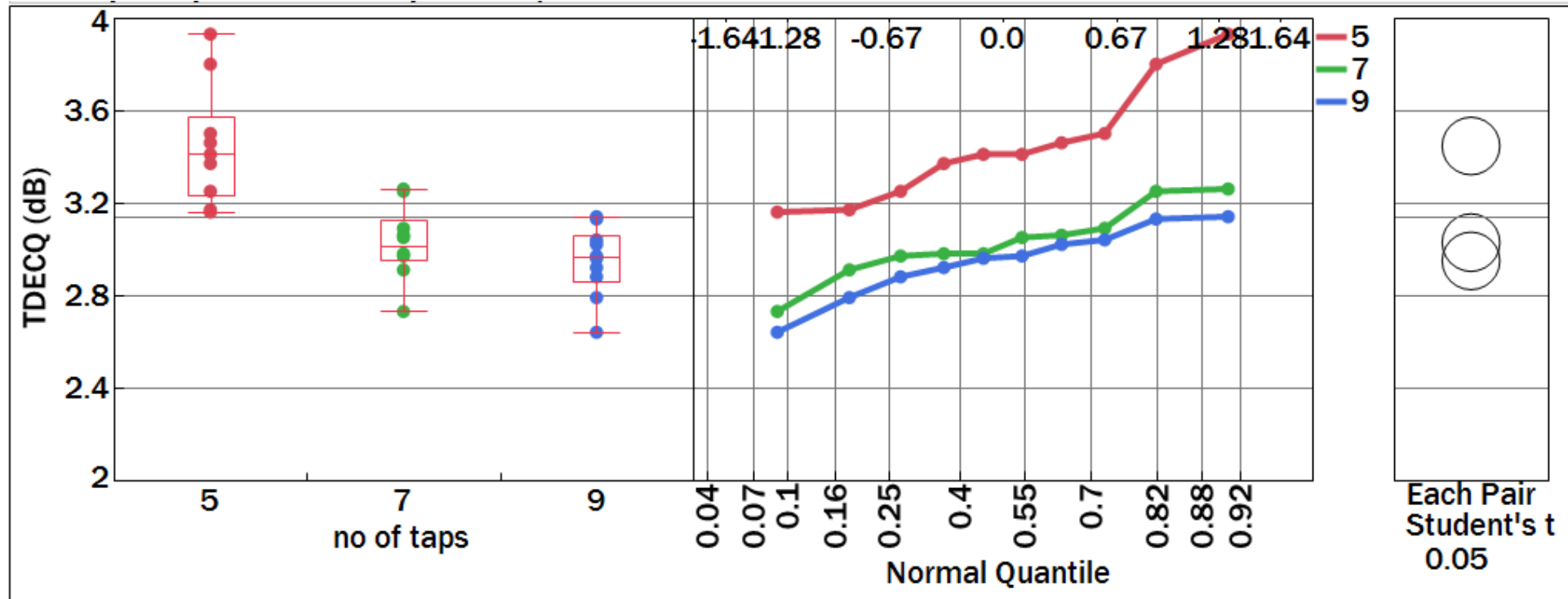


70 °C



➤ Significant population shows elevated TDECQ at 70 °C with 5 Tap FFE

TDECQ (dB) @70 °C Case vs. Number of FFE Taps



Quantiles							
Level	Minimum	10%	25%	Median	75%	90%	Maximum
5	3.16	3.161	3.23	3.41	3.575	3.917	3.93
7	2.73	2.748	2.955	3.015	3.13	3.259	3.26
9	2.64	2.655	2.8575	2.965	3.0625	3.139	3.14

- Difference between 7 and 9 taps is statistically insignificant
- 7 taps allow for enhanced yield for DML based implementations

5 vs. 7 Taps: TDECQ Eye @70 °C Case

5 Taps : TDECQ= 3.93 dB

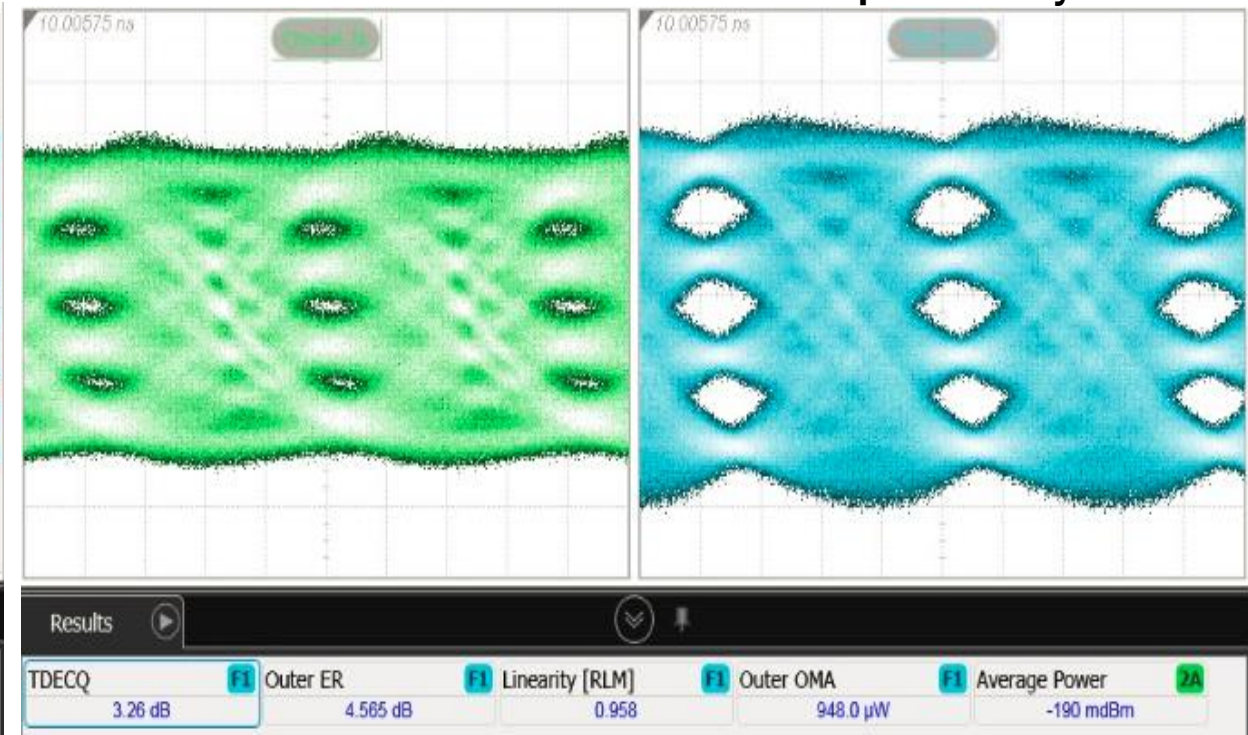
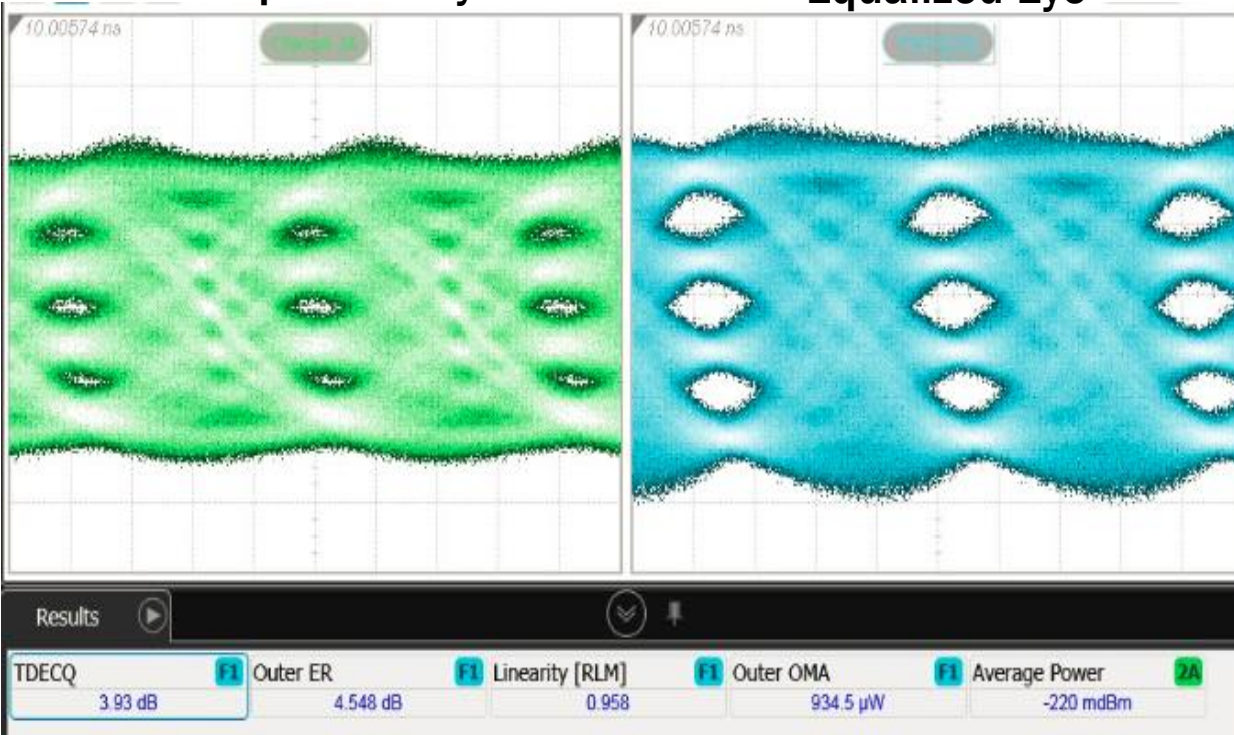
7 Taps: TDECQ= 3.26 dB

Un-equalized Eye

Equalized Eye

Un-equalized Eye

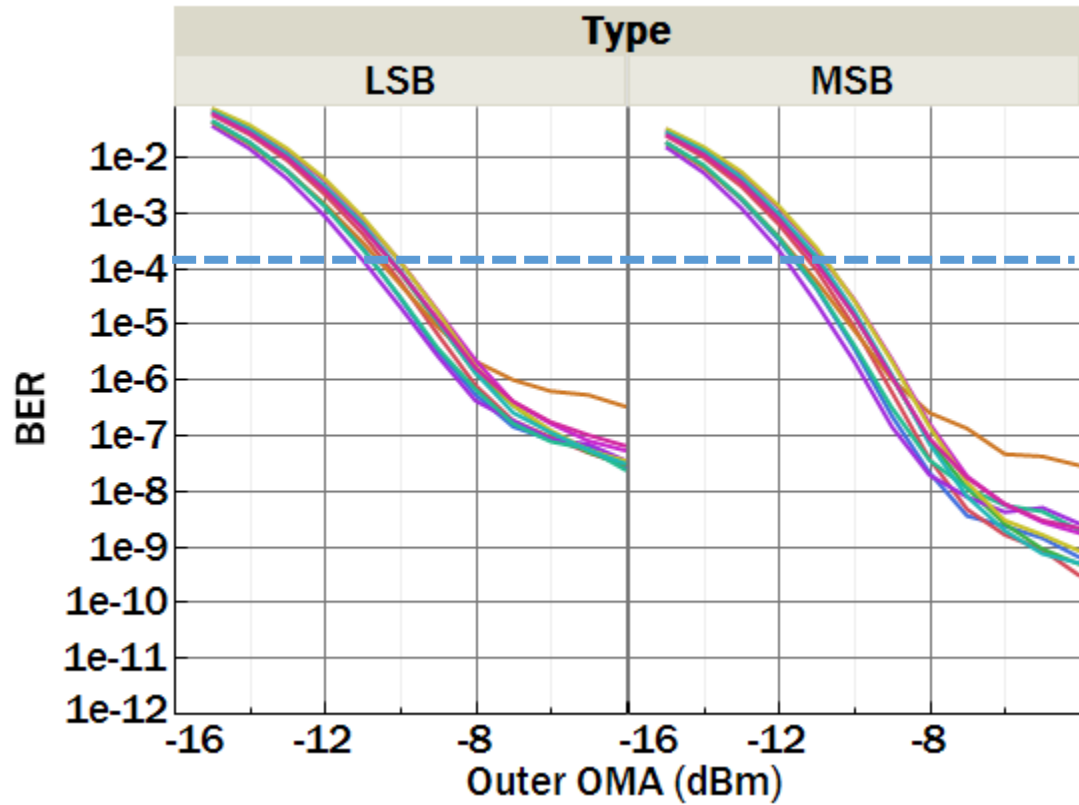
Equalized Eye



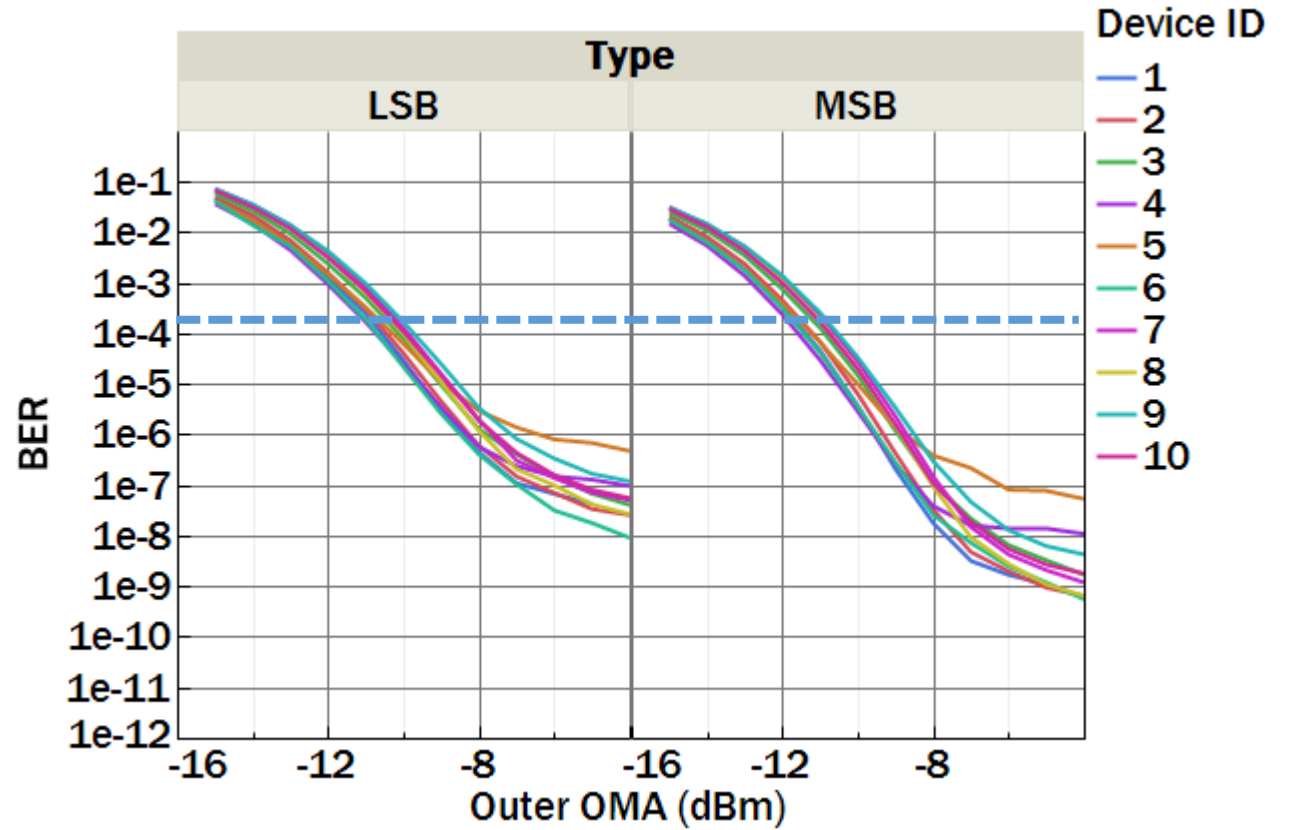
- Increasing the number of taps improves the eye equalization
- Equalized Eyes show more opening; TDECQ value improves.

BER Curves @70 °C Case

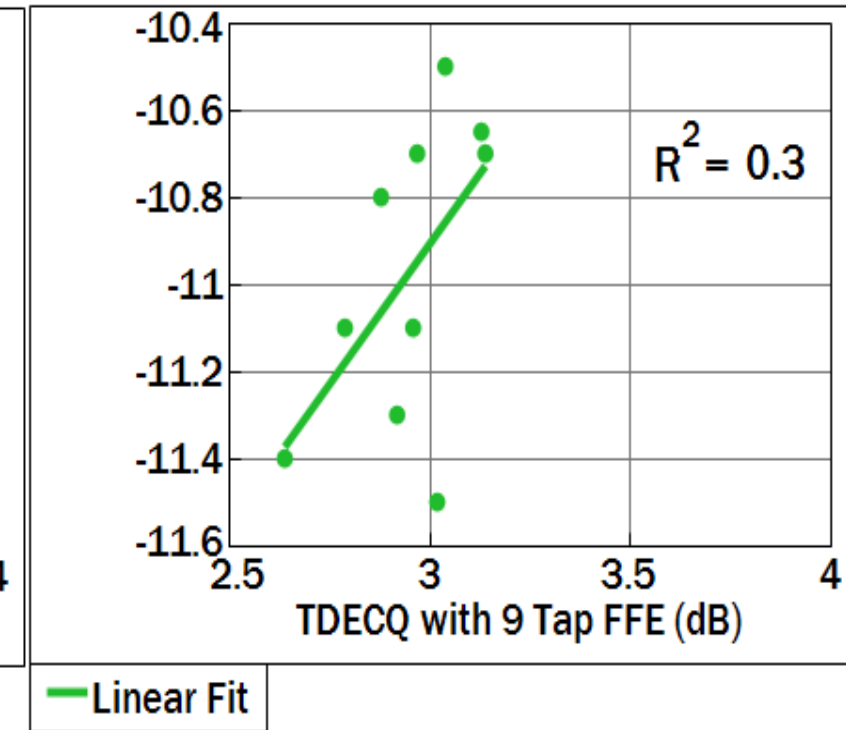
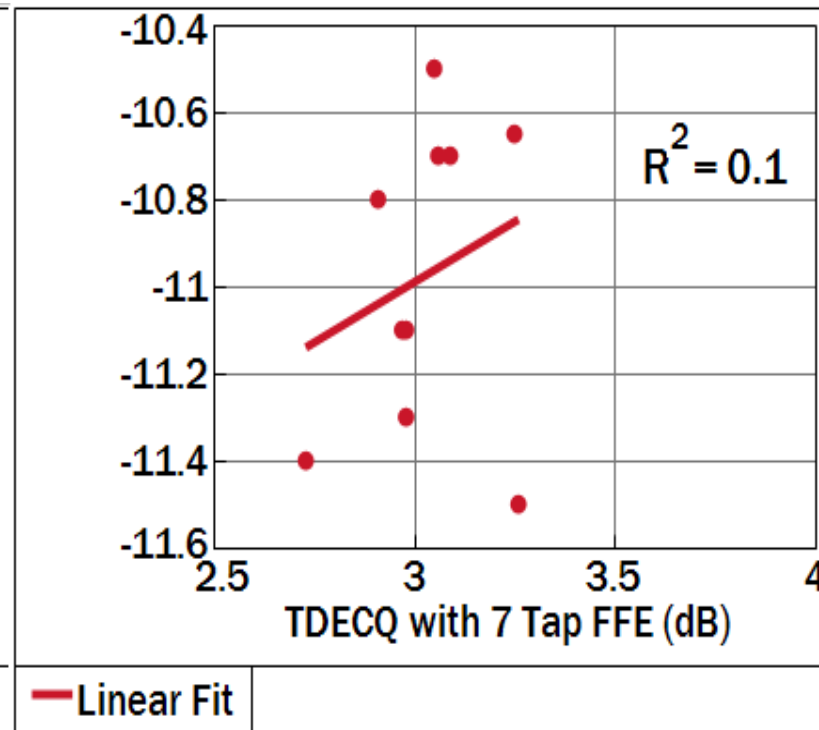
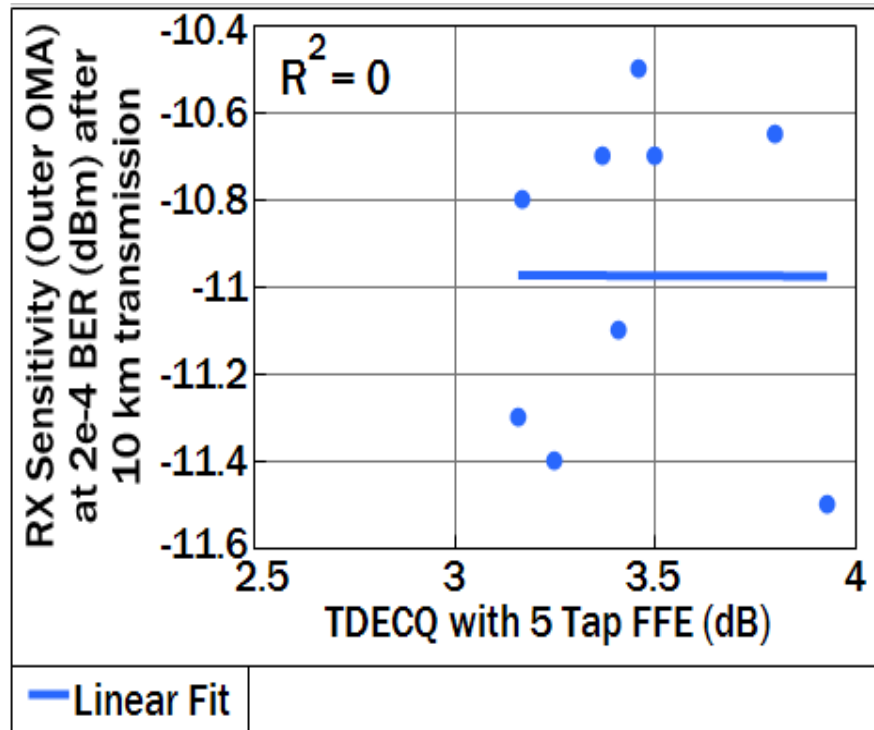
0 km



10 km



TDECQ vs. KP4 FEC Limit



- Very weak/no correlation seen between measured TDECQ and RX OMA at 2e-4 BER after 10 km transmission at 70 °C.
- Increasing no of taps sees increasing better correlation between RX OMA at 2e-4 BER and TDECQ.

Summary and Recommendation

Summary: Reference equalizer for eye quality assessment shows weak correlation to KP4 FEC limit which may cause good transmitters to fail TDECQ spec.

One Potential Recommendation: P802.3cd D2.2 Subclause 139.7.5.4

“The reference equalizer for 50GBASE-FR and 50GBASE-LR is a 5 tap, T spaced, feed-forward equalizer (FFE), where T is the symbol period. The sum of the equalizer tap coefficients is equal to 1.”

Change To

“The reference equalizer for 50GBASE-FR and 50GBASE-LR is a 7 tap, T spaced, feed-forward equalizer (FFE), where T is the symbol period. The sum of the equalizer tap coefficients is equal to 1.”



Questions