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TDEC, OMA and TDP Evaluation for 25G EPON

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Background

In previous meeting the way of defining transmitter penalty in 802.3ca has come under discussion (Liu_3ca_1_0917)

Most common way today is to a measure transmitter dispersion penalty (TDP)

This is done by performing a BER measurement after transmission over fiber and compare agains 'ideal' transmitter to find penalty

In 802.3bm a method called Transmitter Dispersion Eye Closure (TDEC) was standardized to replace eye-mask and TDP testing

Recently the same has been proposed for PAM-4 transmission for 400 Gb/s DC (TDECQ) to reduce cost of testing (802.3cd and 802.3bs)

Purpose of this presentation is to review TDEC for 25G PON and determine if this method is suitable

Comparing TDEC to TPD :

TDP :

Measure the BER after transmission over fiber with worst case dispersion and compare against 'ideal' transmitter to find the penalty

TDEC :

Uses scope to measure eye-diagram after transmission and performs calculations on histogram to estimate sensitivity and penalty

Advantages of TDEC over TDP :

- Already implemented in DCA for 25G
- Does not require a reference transmitter
- Uses a scope instead of a BERT
- Lends itself to faster testing and automation (lower cost)

Transmitter Dispersion Penalty (TDP) Measurement

58.7.9.1 Reference transmitter requirements

The reference transmitter is a high-quality instrument-grade device, which can be implemented by a CW laser modulated by a high-performance modulator. It should meet the following basic requirements:

a) The rise/fall times should be less than 0.15 UI at 20% to 80%.
b) The output optical eye is symmetric and with good margin to the eye mask test for the transmitter (PMD) type under test.
c) In the center 20% region of the eye, the worst-case vertical eye closure penalty, as defined in 58.7.11.2, is less than 0.5 dB.
d) Jitter less than 0.20 UI peak-peak.
e) $RIN_{12}OMA$ should be minimized to less than –120 dB/Hz for 100BASE-X and –125 dB/Hz for 1000BASE-X.

58.7.9.4 Test procedure

To measure the transmitter and dispersion penalty (TDP) the following procedure is used. The sampling instant is displaced from the eye center by the amount specified for decision timing offsets in e.g., Table 58–3 or Table 58–5. The following procedure is repeated for early and late decision and the larger TDP value is used:

a) Configure the test equipment as described above and illustrated in Figure 58–7.
b) Adjust the attenuation of the optical attenuator to obtain a BER of 10^{-12}. Extrapolation techniques may be used with care.
c) Record the optical power in OMA at the input to the reference receiver, P_DUT, in dBm.
d) If P_DUT is larger than S, the transmitter and dispersion penalty (TDP) for the transmitter under test is the difference between P_DUT and S, TDP = P_DUT – S. Otherwise the transmitter and dispersion penalty is zero, TDP = 0.

It is to be ensured that the measurements are made in the linear power regime of the fiber.

IEEE STANDARD FOR ETHERNET

IEEE Std 802.3-2012
SECTION FIVE

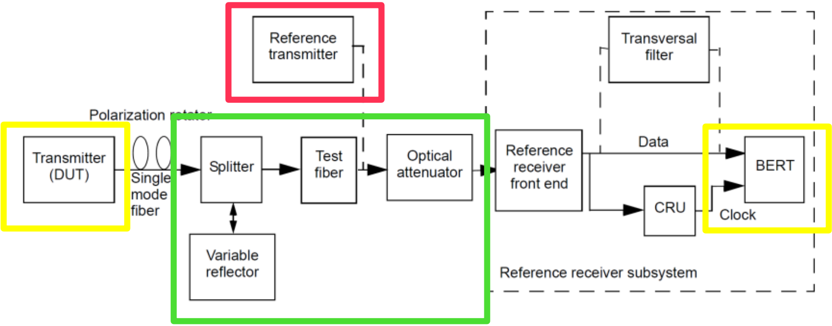

Figure 58–7—Test setup for measurement of transmitter and dispersion penalty

Table 58–12—Transmitter compliance channel specifications

PMD transmitter wavelength, fiber type	Optical channel			Electrical channel
	Dispersion[a] (ps/nm)		Optical return loss[b] (max)	Differential delay (ps)
	Minimum	Maximum		
1310 nm band for SMF	0.02325·L[c]·λ·[1–(1324/λ)^4]	0.02325·L·λ·[1–(1300/λ)^4]	See ORLT in Transmitter spec	N/A
1550 nm band for SMF	0	0.02325·L·λ·[1–(1300/λ)^4]		N/A

[a]The dispersion is specified for the actual wavelength of the device under test.
[b]The optical return loss is applied with respect to TP2.
[c]L is the upper operating range limit (reach) as defined e.g. in Table 58–1.

- ❑ TDP measurement is quite involving

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Transmitter and Dispersion Eye Closure (TDEC) measurement

IEEE Std 802.3bm-2015
AMENDMENT 3 TO IEEE Std 802.3-2012: Ethernet

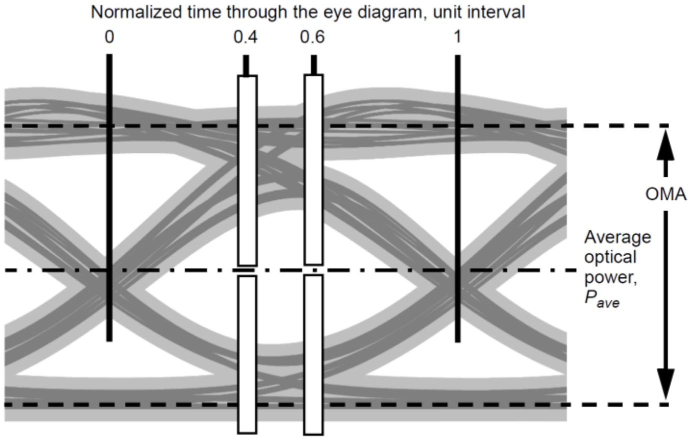


Figure 95–4—Illustration of the TDEC measurement

IEEE Std 802.3bm-2015
AMENDMENT 3 TO IEEE Std 802.3-2012: Ethernet

This procedure finds a value of σ_G such that Equation (95–2) is satisfied:

$$\frac{1}{2}\left(\frac{\int fu(y)Q\left(\frac{y-P_{ave}}{\sigma_G}\right)dy}{\int fu(y)dy}\right)+\frac{1}{2}\left(\frac{\int fl(y)Q\left(\frac{P_{ave}-y}{\sigma_G}\right)dy}{\int fl(y)dy}\right) = 5\times10^{-5}$$

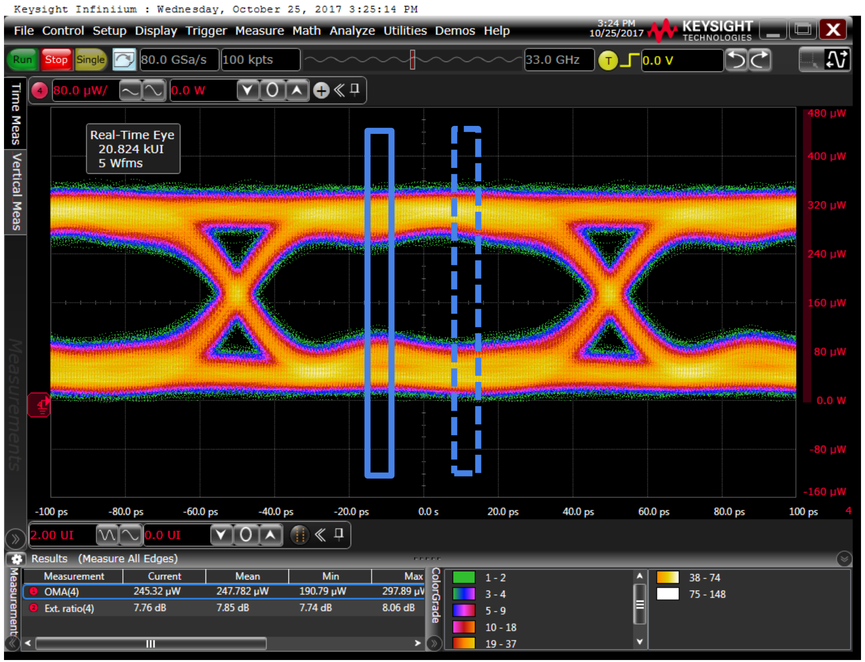
where

- *fu*(*y*), *fl*(*y*) are the upper and lower distributions
- σ_G is the left or right standard deviation, σ_L or σ_R

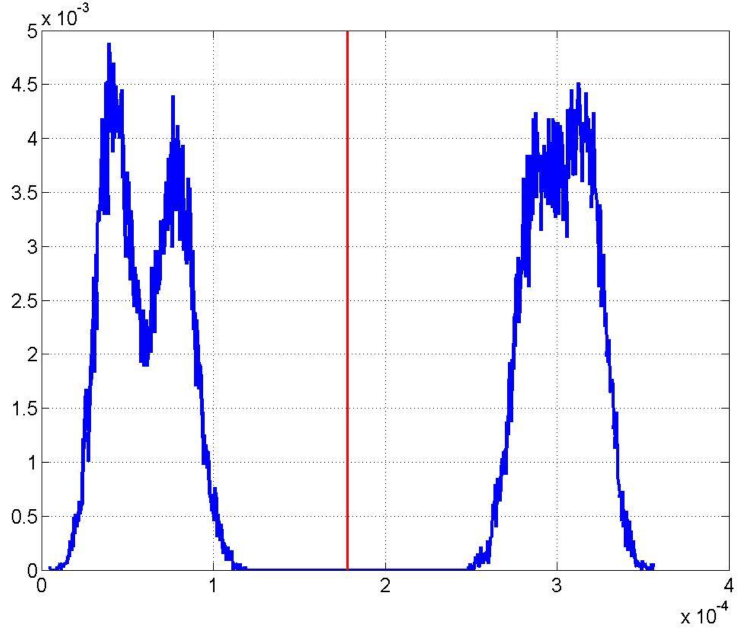
The lesser of σ_L and σ_R is *N*.

- Measure Pavg and the 4 vertical histograms fu(y) on eye at the points shown
- Multiply histograms with Q(y-Pavg) where σ is chosen so average error probability equals specified BER
- Use worst-case σ for Gaussian noise N which could be added for TDEC calculation
- Correct noise N for noise of scope to get maximum noise R which can be added
- TDEC penalty is ratio in Gaussian noise which could be added to ideal signal with the same OMA

Transmitter and Dispersion Eye Closure (TDEC) measurement example



Measured Eye diagram



Left probability distribution function

OMA = 248 µW, Pavg = 178 µW, ER = 7.85 dB

Transmitter and Dispersion Eye Closure (TDEC) measurement example

Target BER = 1e-3

OMA = 248 μW

Pavg = 178 μW

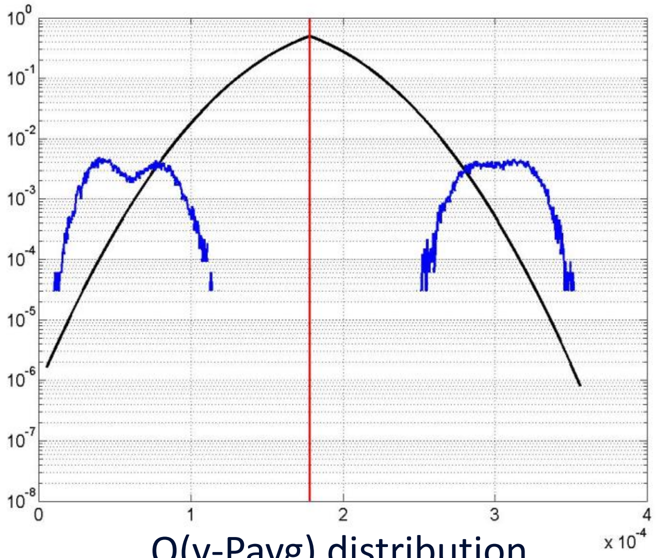
ER = 7.85 dB

R= 37.2 μW (added gaussian noise)

$$\text{TDEC} = 10 * log_{10}\left[\frac{tested\ receiver\ added\ noise}{ideal\ receiver\ added\ noise}\right]$$

$$\text{TDEC} = 10 * log_{10}\left[\frac{OMA/(2*Q_0)}{R}\right] \text{(= 0.33 dB)}$$

Q0=3.0902 at target BER = 1e-3



Q(y-Pavg) distribution

Transmitter and Dispersion Eye Closure (TDEC) measurement

TDEC seems to be a good indication of transmitter performance based on OMA

This is valid for PIN based receivers

However, transmitter penalty is determined with receiver in mind

For PON we usually rely on APD based receivers

So question is can we use TDEC to replace TDP for APD based receivers ?

To answer this question we will review OMA and its use for APDs

Optical modulation amplitude (OMA) versus Extinction Ratio (ER)

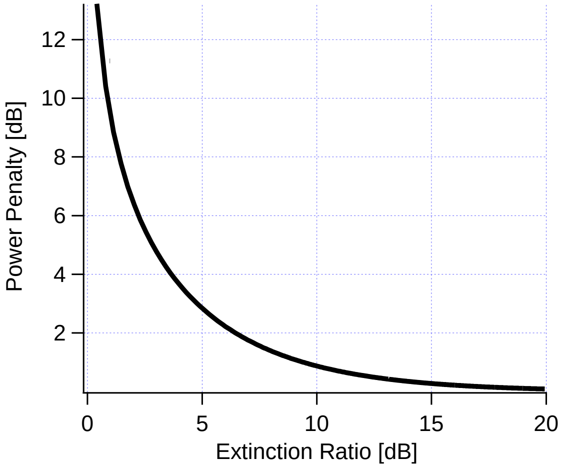
Traditionally transmitters are characterized by means of extinction ratio

Extinction ratio (ER) recognizes that power in ‘0’ bit is wasted

$$\text{ER}= \frac{P_1}{P_0}$$

Using a transmitter with a finite ER will case a receiver penalty which is given by

$$\frac{ER+1}{ER-1}$$



Optical modulation amplitude (OMA) is defined as the difference in power between the logical ‘1’ and ‘0’ levels

$$\text{OMA} = P_1 - P_0$$

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Why use OMA over ER ?

The justification for using OMA is that photoreceivers respond to signal swing not average power

$$OMA = 2 * P_{avg} * \frac{ER - 1}{ER + 1}$$

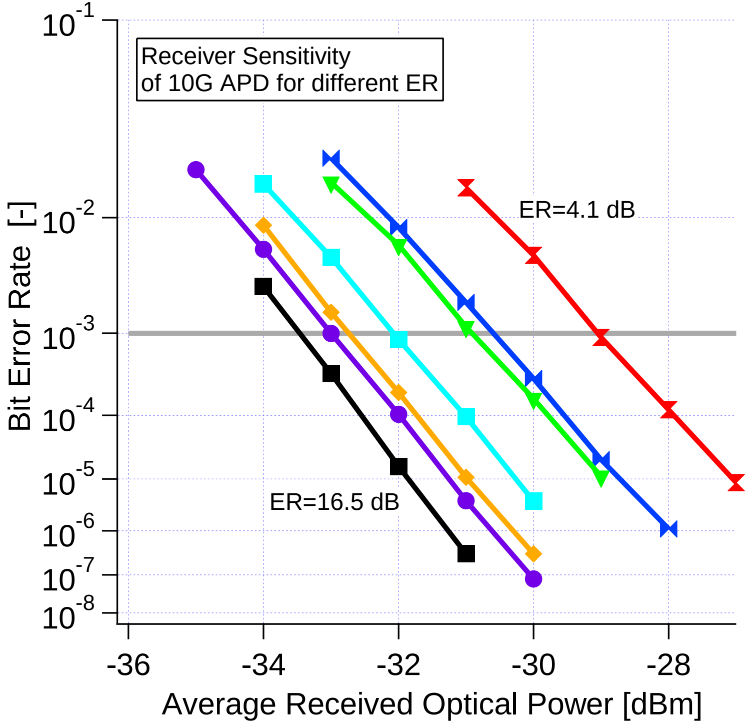
ER power penalty can be absorbed by transmitter by increasing Pavg to achieve same OMA so receiver performance is not compromised.

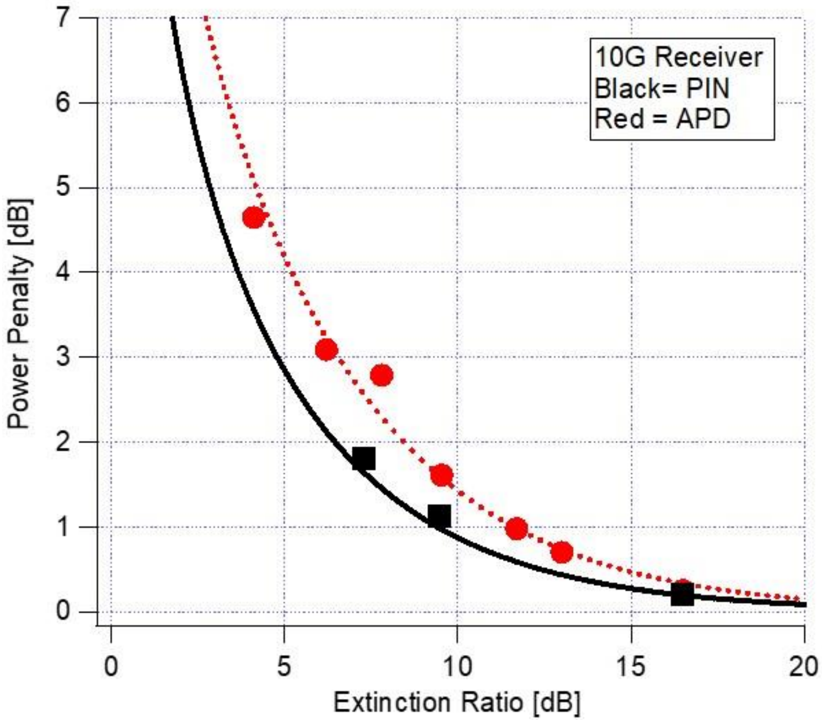
- ❑ More freedom to set bias and modulation currents in transmitter leading to lower cost
- ❑ Trade off possible between ER and average power

However this is true only if receivers are dominated by thermal noise, i.e. PIN based receivers
APD based receivers will have shot noise as well

We will therefore measured APD receiver sensitivity as function of OMA to validate

Bit-Error-Rate measurements of 10G APD with various ER





APD has larger power penalty compared to PIN receivers for same ER

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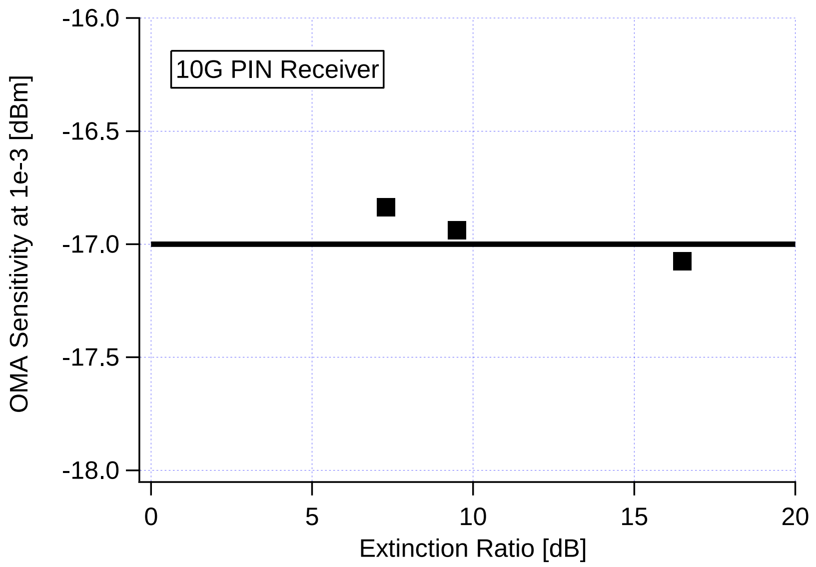
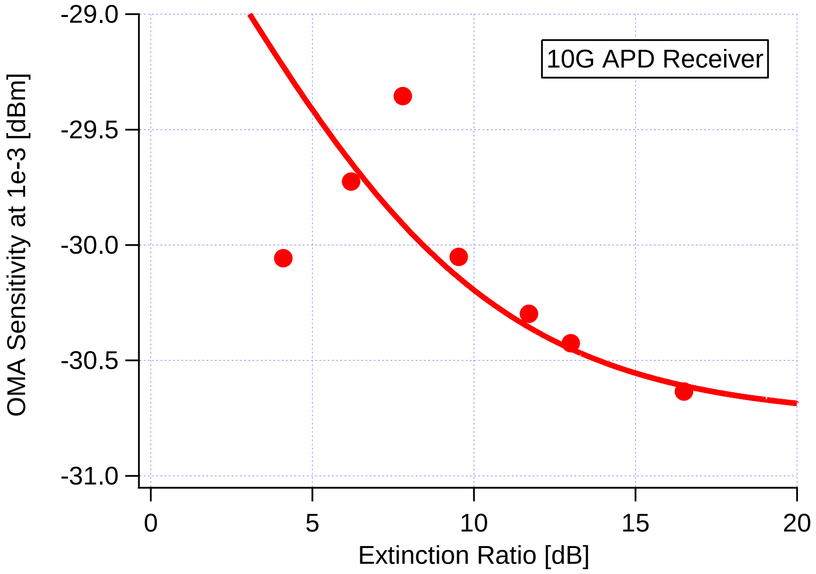
OMA Receiver sensitivity of 10G APD and 10G PIN

We can now plot the OMA sensitivity at 1e-3 for APD as well as PIN





- For PIN based receivers OMA sensitivity is (almost) independent of ER, meaning ER can be traded off with increasing Pavg at the transmitter for same OMA.
- For APD based receivers this is not the case ! (see also Sumitomo tanaka_3ca_1_1116)

Conclusions

TDEC is most likely a good measure of transmitter performance when using PIN based receivers
However since in PON we mostly rely on APD based receivers determine a transmitter penalty based on TDEC might not give accurate results

Trading off ER and Pavg while keeping OMA constant for transmitter with PIN based receivers in mind is probably valid and can be used to optimize transmitter performance for cost

However with APD based receivers in mind this is not valid, therefore specifying transmitter performance based on minimum ER and minimum Pavg is probably just as good

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