802.3dj D2.3
Comment Resolution
Optical Topics

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Introduction

- This slide package was assembled by the 802.3dj editorial team to provide background and detailed resolutions to aid in comment resolution.
- Specifically, these slides are for the various optical-track comments.

180.9.6.4 TDECQ measurement method

Comments #62, 46, 158, 45, 29, 50, 4, 157, 156

TDECQ measurement method - Current D2.3 pages 482 & 483

180.9.6.4 TDECQ measurement method

The standard deviation of the noise of the reference receiver specified in 180.9.2, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

The test pattern specified for TDECQ (see Table 180–13) 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 without averaging.

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

The captured waveform is processed to find the largest noise that could be combined with the signal by an reference receiver when optimally equalized by a reference equalizer. The optimal equalizer tap coefficients are dependent on the amount of noise that can be added to the signal, so finding the noise that can be added and the optimal equalizer setting is an iterative process. One way of doing this, using estimated PAM4 symbol error ratio as the figure of merit for the equalized signal, is described below.

The reference equalizer specified in 180.9.6.3 is applied to the waveform. An eye diagram is formed from the equalized captured waveform.

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 180–11.

The TDECQ reference point where OMA_{TDECQ} is referenced to and noise is added is at the input of the reference equalizer.

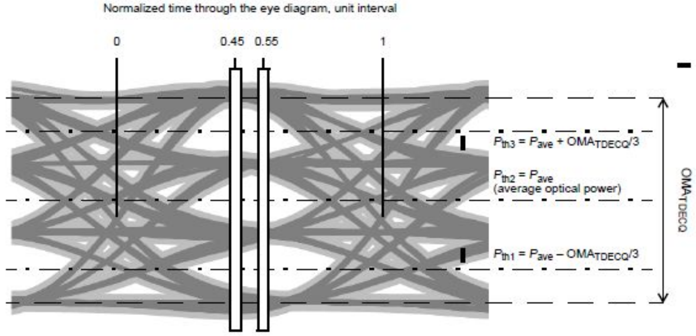


Figure 180–11—Illustration of the TDECQ measurement

Two vertical histograms are measured through the eye diagram, nominally 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 180–11. The precise time position of the pair of histograms is adjusted to minimize TDECQ while keeping the histograms spaced 0.1 UI apart.

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).

The sub-eye threshold levels P_{th1}, P_{th2}, and P_{th3}, are determined from the OMA_{TDECQ} and the average optical power of the eye diagram (P_{ave}) as defined in Equation (180–1), Equation (180–2), and Equation (180–3), and illustrated in Figure 180–11.

$$P_{th1} = P_{ave} - \frac{OMA_{TDECQ}}{3} \quad (180\text{–}1)$$

$$P_{th2} = P_{ave} \quad (180\text{–}2)$$

$$P_{th3} = P_{ave} + \frac{OMA_{TDECQ}}{3} \quad (180\text{–}3)$$

Each captured histogram is processed to, in effect, combine the PAM4 waveform with noise, in order to produce an estimate of the partial PAM4 symbol error ratio (SER) for each sub-eye. One way of doing this is described below.

The left and right histograms are each normalized, and can be represented as a series of equally spaced optical power values (y_i) with separation Δy, each with an associated fraction $F(y_i)$, equal to the number of samples captured in that power interval divided by the total number of samples in that histogram. The sum of all $F(y_i)$ for each histogram is equal to 1.

TDECQ measurement method - Current D2.3 pages 484 & 485

From the left normalized histogram $F(y_i)$, three cumulative probability functions are created, $CF_{L1}(y_i)$, $CF_{L2}(y_i)$, and $CF_{L3}(y_i)$, one around each sub-eye threshold. The right histogram is treated similarly to create three cumulative probability functions $CF_{R1}(y_i)$, $CF_{R2}(y_i)$, and $CF_{R3}(y_i)$. $CF_{L1}(y_i)$ is defined in 180–4.

$$CF_{L1}(y_i) = \begin{cases} \sum_{y = P_{th1}}^{y_i} F(y) \text{ for } y_i \ge P_{th1} \\ \sum_{y = y_i}^{P_{th1}} F(y) \text{ for } y_i < P_{th1} \end{cases} \qquad (180\text{–}4)$$

Each element of the cumulative probability function, $CF_{L1}(y_i)$, is multiplied by a value $G_{th1}(y_i)$, and then summed to calculate an approximation for SER_{L1}, the partial PAM4 SER for threshold 1. Each element of the cumulative probability function, $CF_{L2}(y_i)$, is multiplied by a value $G_{th2}(y_i)$, and then summed to calculate an approximation for SER_{L2}. Each element of the cumulative probability function, $CF_{L3}(y_i)$, is multiplied by a value $G_{th3}(y_i)$, and then summed to calculate an approximation for SER_{L3}. The sum of the three partial PAM4 SERs is the PAM4 SER associated with the left histogram, SER_L.

Each element of the cumulative probability function, $CF_{R1}(y_i)$, is multiplied by a value $G_{th1}(y_i)$, and then summed to calculate an approximation for SER_{R1}, the partial PAM4 SER for threshold 1. $CF_{R2}(y_i)$ and $CF_{R3}(y_i)$ are treated similarly to calculate SER_{R2}, and SER_{R3}, the partial PAM4 SERs for threshold 2 and threshold 3. The sum of the three partial PAM4 SERs is the PAM4 SER associated with the right histogram, SER_R.

$G_{th1}(y_i)$ is equivalent to a Gaussian probability density function with an RMS value of σ_G, centered around the sub-eye threshold P_{th1}. $G_{th1}(y_i)$ is given by Equation (180–5) and can be estimated by Equation (180–6).

$$G_{th1}(y_i) = \int_{y_i - \frac{\Delta y}{2}}^{y_i + \frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y - P_{th1}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \qquad (180\text{–}5)$$

$$G_{th1}(y_i) = \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y_i - P_{th1}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} \times \Delta y \qquad (180\text{–}6)$$

$G_{th2}(y_i)$ and $G_{th3}(y_i)$ are similar Gaussian probability density functions with the same RMS value of σ_G, centered around the sub-eye thresholds P_{th2} and P_{th3} respectively. $G_{th2}(y_i)$ and $G_{th3}(y_i)$ are given by Equation (180–7) and Equation (180–8) respectively.

$$G_{th2}(y_i) = \int_{y_i - \frac{\Delta y}{2}}^{y_i + \frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y - P_{th2}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \qquad (180\text{–}7)$$

$$G_{th3}(y_i) = \int_{y_i - \frac{\Delta y}{2}}^{y_i + \frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y - P_{th3}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \qquad (180\text{–}8)$$

where

C_{eq} is a coefficient which accounts for the reference equalizer noise enhancement

The value of C_{eq} can be calculated from the product of the normalized noise power density spectrum $N(f)$ at the input of the reference equalizer and the normalized frequency response $H_{eq}(f)$ of the reference equalizer, as shown in Equation (180–9).

$$C_{eq} = \sqrt{\int_f N(f) \times |H_{eq}(f)|^2 df} \qquad (180\text{–}9)$$

where

$N(f)$ is the normalized noise power density spectrum equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a 3 dB bandwidth of 53.125 GHz.

and

$$\int_f N(f) df = H_{eq}(f = 0) = 1 \qquad (180\text{–}10)$$

The equalizer tap coefficients are iteratively adjusted and SER_L and SER_R calculated until the largest of SER_L and SER_R is minimized. Then, if the larger of SER_L and SER_R is greater than the target PAM4 SER of 4.56×10^{-4}, the value of σ_G is decreased and the process of equalizer optimization is repeated; If the larger of SER_L and SER_R is lower than the target PAM4 SER of 4.56×10^{-4}, then the value of σ_G is increased and the process of equalizer optimization is repeated.

P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to ±1% of OMA_{TDECQ} in order to optimize TDECQ. The same three thresholds are used for both the left and the right histogram.

When the larger of SER_L and SER_R is equal to the target PAM4 SER of 4.56×10^{-4}, and the value of σ_G cannot be increased by further optimization of the equalizer tap coefficients or the sub-eye threshold levels, then TDECQ is calculated.

The RMS noise, R, that could be added by a receiver is given by Equation (180–11).

$$R = \sqrt{\sigma_G^{\ 2} + \sigma_S^{\ 2}} \qquad (180\text{–}11)$$

TDECQ is given by Equation (180–12).

$$TDECQ = 10\log_{10}\left(\frac{OMA_{TDECQ}}{6} \times \frac{1}{Q_t R}\right) \qquad (180\text{–}12)$$

where

OMA_{TDECQ} is measured as defined in 180.9.5 except using waveforms captured at the output of the reference equalizer

Q_t is 3.428, consistent with the target symbol error ratio for Gray mapped PAM4, and can be calculated according to Equation (180–27)

Alternative optimization methods such as minimum mean squared error (MMSE) may be used to determine equalizer tap weights to reduce test time, and are expected to report equal or higher values of TDECQ. These alternative methods should not be used for receiver sensitivity and stressed receiver sensitivity calibration.

TDECQ measurement method - Proposed page 482

Cl **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 29

Huber, Thomas Nokia

Comment Type **E** *Comment Status* **D** *TDECQ and OMA (CO)*

Awkward sentence: "The TDECQ reference point where OMA(sub)TDECQ is referenced to and noise is added is at the input of the reference equalizer."

SuggestedRemedy

Rewrite as:
"The reference point for OMA(sub)TDECQ, to which noise is added, is at the input of the reference equalizer."

Cl **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 46

Brown, Matt Alphawave Semi

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (CO)*

In the sentence "The TDECQ reference point where OMATDECQ is referenced to and noise is added is at the input of the reference equalizer." it is not clear what these reference points are. Further, the measurement point for OMA_TDEQ contradicts the text on page 485 line 46 and 488 line 52. If these are intended to be the same point then one or the other locations needs to be corrected. If they are intended to be different, then a different parameter name should be used. Finally, the definition of OMA_TDECQ should be colocated where it is used, e.g., along with equation 180-1 through 180-3.

SuggestedRemedy

Reconcile the measurement points for OMA_TDECQ or use different parameter names.
Define OMA_TDECQ where it is referenced in equations, e.g., page 483 line 45.
Delete the sentence at page 482 line 53. Note that another comment deals with the mention of noise in this sentence.

Cl **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 158

Mi, Guangcan Huawei Technologies Co., Ltd.

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (O)*

OMA_TDECQ is used to calculate the threshold power, Pth_1 and Pth_2, which is set accroding to the equalized eye diagram as shown in Figure 180-11. OMA_TDECQ should not be measured at the input of the equalizer.

SuggestedRemedy

add the definition of OMA_TDECQ, "is measured as defined in 180.9.5 except using waveforms captured at the output
of the reference equalizer". Noise is added at the input of the reference equalizer.

180.9.6.4 TDECQ measurement method

The standard deviation of the noise of the reference receiver specified in 180.9.2, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

The test pattern specified for TDECQ (see Table 180–13) 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 without averaging.

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

The captured waveform is processed to find the largest noise that could be combined with the signal by an reference receiver when optimally equalized by a reference equalizer. The optimal equalizer tap coefficients are dependent on the amount of noise that can be added to the signal, so finding the noise that can be added and the optimal equalizer setting is an iterative process. One way of doing this, using estimated PAM4 symbol error ratio as the figure of merit for the equalized signal, is described below.

The reference equalizer specified in 180.9.6.3 is applied to the waveform. An eye diagram is formed from the equalized captured waveform.

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 180–11.

~~The TDECQ reference point where OMA_{TDECQ} is referenced to and noise is added is at the input of the reference equalizer.~~

Comment #29, 46, 158

TDECQ measurement method
Proposed page 483

Cl **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 46

Brown, Matt Alphawave Semi

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (CO)*

In the sentence "The TDECQ reference point where OMATDECQ is referenced to and noise is added is at the input of the reference equalizer." it is not clear what these reference points are. Further, the measurement point for OMA_TDEQ contradicts the text on page 485 line 46 and 488 line 52. If these are intended to be the same point then one or the other locations needs to be corrected. If they are intended to be different, then a different parameter name should be used. Finally, the definition of OMA_TDECQ should be colocated where it is used, e.g., along with equation 180-1 through 180-3.

SuggestedRemedy

Reconcile the measurement points for OMA_TDECQ or use different parameter names. Define OMA_TDECQ where it is referenced in equations, e.g., page 483 line 45. Delete the sentence at page 482 line 53. Note that another comment deals with the mention of noise in this sentence.

Insert the following text

where

OMA_{TDECQ} is measured as defined in 180.9.5 except using waveforms captured at the output of the reference equalizer

Comment #46

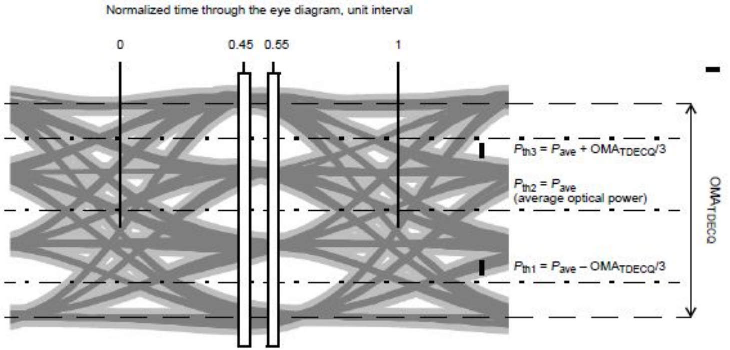


Figure 180–11—Illustration of the TDECQ measurement

Two vertical histograms are measured through the eye diagram, nominally 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 180–11. The precise time position of the pair of histograms is adjusted to minimize TDECQ while keeping the histograms spaced 0.1 UI apart.

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).

The sub-eye threshold levels P_{th1}, P_{th2}, and P_{th3}, are determined from the OMA_{TDECQ} and the average optical power of the eye diagram (P_{ave}) as defined in Equation (180–1), Equation (180–2), and Equation (180–3), and illustrated in Figure 180–11.

$$P_{th1} = P_{ave} - \frac{OMA_{TDECQ}}{3} \quad (180\text{–}1)$$

$$P_{th2} = P_{ave} \quad (180\text{–}2)$$

$$P_{th3} = P_{ave} + \frac{OMA_{TDECQ}}{3} \quad (180\text{–}3)$$

Each captured histogram is processed to, in effect, combine the PAM4 waveform with noise, in order to produce an estimate of the partial PAM4 symbol error ratio (SER) for each sub-eye. One way of doing this is described below.

The left and right histograms are each normalized, and can be represented as a series of equally spaced optical power values (y_i) with separation Δy, each with an associated fraction $F(y_i)$, equal to the number of samples captured in that power interval divided by the total number of samples in that histogram. The sum of all $F(y_i)$ for each histogram is equal to 1.

TDECQ measurement method - Proposed page 484

CI **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 45

Brown, Matt Alphawave Semi

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (CO)*

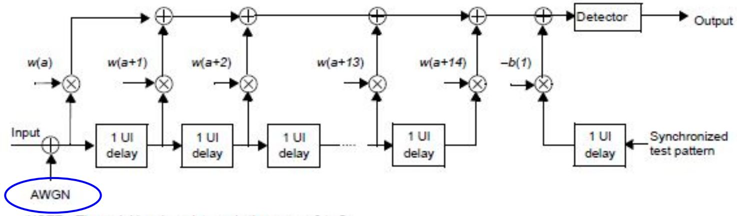
The sentence "The TDECQ reference point where OMATDECQ is referenced to and noise is added is at the input of the reference equalizer." It is not clear which noise this is referring to. It would be good to link the AWGN noise source in Figure 180-10 with sigma_g. Note that another comment deals with the OMA_TDECQ in this sentence.

SuggestedRemedy

Delete the reference sentence.
On page 484 line 26 (the first reference to σG)...
Change the sentence to: "G_th1(y_i), which represents AWGN at the input to the reference equalizer (see Figure 180-10), is equivalent to a Gaussian probability density function with an RMS value of σ_G, centered around the sub-eye threshold P_th1."

Change the start of the paragraphs to the following:

$G_{th1}(y_i)$, which represents AWGN at the input to the reference equalizer (see Figure 180-10), is equivalent …



NOTE—The variable *a* is an integer in the range −3 to 0

Figure 180–10—TDECQ reference equalizer functional model

From the left normalized histogram $F(y_i)$, three cumulative probability functions are created, $CF_{L1}(y_i)$, $CF_{L2}(y_i)$, and $CF_{L3}(y_i)$, one around each sub-eye threshold. The right histogram is treated similarly to create three cumulative probability functions $CF_{R1}(y_i)$, $CF_{R2}(y_i)$, and $CF_{R3}(y_i)$. $CF_{L1}(y_i)$ is defined in 180–4.

$$CF_{L1}(y_i) = \begin{cases} \sum_{y=P_{th1}}^{y_i} F(y) \text{ for } y_i \geq P_{th1} \\ \sum_{y=y_i}^{P_{th1}} F(y) \text{ for } y_i < P_{th1} \end{cases} \quad (180\text{–}4)$$

Each element of the cumulative probability function, $CF_{L1}(y_i)$, is multiplied by a value $G_{th1}(y_i)$, and then summed to calculate an approximation for SER_{L1}, the partial PAM4 SER for threshold 1. Each element of the cumulative probability function, $CF_{L2}(y_i)$, is multiplied by a value $G_{th2}(y_i)$, and then summed to calculate an approximation for SER_{L2}. Each element of the cumulative probability function, $CF_{L3}(y_i)$, is multiplied by a value $G_{th3}(y_i)$, and then summed to calculate an approximation for SER_{L3}. The sum of the three partial PAM4 SERs is the PAM4 SER associated with the left histogram, SER_L.

Each element of the cumulative probability function, $CF_{R1}(y_i)$, is multiplied by a value $G_{th1}(y_i)$, and then summed to calculate an approximation for SER_{R1}, the partial PAM4 SER for threshold 1. $CF_{R2}(y_i)$ and $CF_{R3}(y_i)$ are treated similarly to calculate SER_{R2}, and SER_{R3}, the partial PAM4 SERs for threshold 2 and threshold 3. The sum of the three partial PAM4 SERs is the PAM4 SER associated with the right histogram, SER_R.

$G_{th1}(y_i)$ is equivalent to a Gaussian probability density function with an RMS value of σ_G, centered around the sub-eye threshold P_{th1}. $G_{th1}(y_i)$ is given by Equation (180–5) and can be estimated by Equation (180–6).

$$G_{th1}(y_i) = \int_{y_i-\frac{\Delta y}{2}}^{y_i+\frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y-P_{th1}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \quad (180\text{–}5)$$

$$G_{th1}(y_i) = \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y_i-P_{th1}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} \times \Delta y \quad (180\text{–}6)$$

$G_{th2}(y_i)$ and $G_{th3}(y_i)$ are similar Gaussian probability density functions with the same RMS value of σ_G, centered around the sub-eye thresholds P_{th2} and P_{th3} respectively. $G_{th2}(y_i)$ and $G_{th3}(y_i)$ are given by Equation (180–7) and Equation (180–8) respectively.

$$G_{th2}(y_i) = \int_{y_i-\frac{\Delta y}{2}}^{y_i+\frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y-P_{th2}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \quad (180\text{–}7)$$

$$G_{th3}(y_i) = \int_{y_i-\frac{\Delta y}{2}}^{y_i+\frac{\Delta y}{2}} \frac{1}{C_{eq}\sigma_G\sqrt{2\pi}} \times e^{-\left(\frac{y-P_{th3}}{C_{eq}\sigma_G\sqrt{2}}\right)^2} dy \quad (180\text{–}8)$$

TDECQ measurement method
- Proposed page 485

Cl **180** *SC* **180.9.6.4** *P* **485** *L* **42** # 157

Mi, Guangcan Huawei Technologies Co., Ltd.

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (O)*

TDECQ is comparing the maximum additive noise to the optical power in OMA as measurement of the eye opening. Therefore the OMA used in equation 180-12 and noise R should be measured at the same point, which is OMA_outer

SuggestedRemedy

change the OMA_TDECQ in equation 180-12 to OMA_outer, and update its definition text accordingly.

Cl **180** *SC* **180.9.6.4** *P* **482** *L* **53** # 45

Brown, Matt Alphawave Semi

Comment Type **T** *Comment Status* **D** *TDECQ and OMA (CO)*

The sentence "The TDECQ reference point where OMATDECQ is referenced to and noise is added is at the input of the reference equalizer." It is not clear which noise this is referring to. It would be good to link the AWGN noise source in Figure 180-10 with sigma_g. Note that another comment deals with the OMA_TDECQ in this sentence.

SuggestedRemedy

Delete the reference sentence.
On page 484 line 26 (the first reference to σG)...
Change the sentence to: "G_th1(y_i), which represents AWGN at the input to the reference equalizer (see Figure 180-10), is equivalent to a Gaussian probability density function with an RMS value of σ_G, centered around the sub-eye threshold P_th1."

where,

σ_G is the standard deviation of the maximum noise that can be added at the input of the reference equalizer

σ_S is the standard deviation of the noise of the reference receiver specified in 180.9.2, determined with the same settings as the histogram measurement and no optical input signal

where

C_{eq} is a coefficient which accounts for the reference equalizer noise enhancement

The value of C_{eq} can be calculated from the product of the normalized noise power density spectrum $N(f)$ at the input of the reference equalizer and the normalized frequency response $H_{eq}(f)$ of the reference equalizer, as shown in Equation (180–9).

$$C_{eq} = \sqrt{\int_f N(f) \times |H_{eq}(f)|^2 df} \quad (180\text{–}9)$$

where

$N(f)$ is the normalized noise power density spectrum equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a 3 dB bandwidth of 53.125 GHz.

and

$$\int_f N(f) df = H_{eq}(f = 0) = 1 \quad (180\text{–}10)$$

The equalizer tap coefficients are iteratively adjusted and SER_L and SER_R calculated until the largest of SER_L and SER_R is minimized. Then, if the larger of SER_L and SER_R is greater than the target PAM4 SER of 4.56×10^{-4}, the value of σ_G is decreased and the process of equalizer optimization is repeated; If the larger of SER_L and SER_R is lower than the target PAM4 SER of 4.56×10^{-4}, then the value of σ_G is increased and the process of equalizer optimization is repeated.

P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to ±1% of OMA_{TDECQ} in order to optimize TDECQ. The same three thresholds are used for both the left and the right histogram.

When the larger of SER_L and SER_R is equal to the target PAM4 SER of 4.56×10^{-4}, and the value of σ_G cannot be increased by further optimization of the equalizer tap coefficients or the sub-eye threshold levels, then TDECQ is calculated.

The RMS noise, R, that could be added by a receiver is given by Equation (180–11).

$$R = \sqrt{\sigma_G^2 + \sigma_S^2} \quad (180\text{–}11)$$

TDECQ is given by Equation (180–12).

$$TDECQ = 10\log_{10}\left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R}\right) \quad (180\text{–}12)$$

where

OMA_{outer} is measured as defined in 180.9.5 ~~except using waveforms captured at the output of the reference equalizer~~

Q_t is 3.428, consistent with the target symbol error ratio for Gray mapped PAM4, and can be calculated according to Equation (180–27)

Alternative optimization methods such as minimum mean squared error (MMSE) may be used to determine equalizer tap weights to reduce test time, and are expected to report equal or higher values of TDECQ. These alternative methods should not be used for receiver sensitivity and stressed receiver sensitivity calibration.

TDECQ measurement method
- Proposed page 485

Cl **180** *SC* **180.9.6.4** *P* **485** *L* **41** *#* **4**

Maniloff, Eric — Ciena

Comment Type **TR** *Comment Status* **D** *TDECQ and OMA (CO)*

Discrepancy in optical modulation amplitude used for OMAouter – T(D)ECQ penalty computation in link budget:
To compute the link budget the transmitter penalty (TECQ,TDECQ) per equation 180-12 is to be subtracted from the OMAouter measured per SC 180.9.5. However, in SC 180.9.6.4, equation 180-12 suggests using OMATDECQ as the reference level of the ideal PAM4 signal for computation of the transmitter penalty (TECQ,TDECQ). In case, OMAouter measured per SC 180.9.5 and OMATDECQ computed per SC 180.9.6.4 differ, the quantity OMAouter-TECQ or OMAouter-TDECQ used in the link budget will be incorrect.

SuggestedRemedy

In equation 180-12, substitute OMATDECQ with OMAouter (measured per SC 180.9.5) in the report of the TDECQ penalty.

Cl **180** *SC* **180.9.6.4** *P* **485** *L* **41** *#* **50**

Rodes, Roberto — Coherent

Comment Type **TR** *Comment Status* **D** *TDECQ and OMA (O)*

TDECQ in 180-12 is a penalty on the OMA to calculate the Link power budget. Therefore, OMA in equation 180-12 should be equivalent to OMAouter as defined in 180.9.5.

SuggestedRemedy

Replace OMAtdecq with OMAouter in equation 180-12,and use editorial license to align the rest of the text in the subclause to this change

where

C_{eq} is a coefficient which accounts for the reference equalizer noise enhancement

The value of C_{eq} can be calculated from the product of the normalized noise power density spectrum $N(f)$ at the input of the reference equalizer and the normalized frequency response $H_{eq}(f)$ of the reference equalizer, as shown in Equation (180–9).

$$C_{eq} = \sqrt{\int_f N(f) \times |H_{eq}(f)|^2 df} \quad (180\text{–}9)$$

where

$N(f)$ is the normalized noise power density spectrum equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a 3 dB bandwidth of 53.125 GHz.

and

$$\int_f N(f) df = H_{eq}(f = 0) = 1 \quad (180\text{–}10)$$

The equalizer tap coefficients are iteratively adjusted and SER_L and SER_R calculated until the largest of SER_L and SER_R is minimized. Then, if the larger of SER_L and SER_R is greater than the target PAM4 SER of 4.56×10^{-4}, the value of σ_G is decreased and the process of equalizer optimization is repeated; If the larger of SER_L and SER_R is lower than the target PAM4 SER of 4.56×10^{-4}, then the value of σ_G is increased and the process of equalizer optimization is repeated.

P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to ±1% of OMA_{TDECQ} in order to optimize TDECQ. The same three thresholds are used for both the left and the right histogram.

When the larger of SER_L and SER_R is equal to the target PAM4 SER of 4.56×10^{-4}, and the value of σ_G cannot be increased by further optimization of the equalizer tap coefficients or the sub-eye threshold levels, then TDECQ is calculated.

The RMS noise, R, that could be added by a receiver is given by Equation (180–11).

$$R = \sqrt{\sigma_G^2 + \sigma_S^2} \quad (180\text{–}11)$$

TDECQ is given by Equation (180–12).

$$TDECQ = 10\log_{10}\left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R}\right) \quad (180\text{–}12)$$

where

OMA_{outer} is measured as defined in 180.9.5 ~~except using waveforms captured at the output of the reference equalizer~~

Q_t is 3.428, consistent with the target symbol error ratio for Gray mapped PAM4, and can be calculated according to Equation (180–27)

Alternative optimization methods such as minimum mean squared error (MMSE) may be used to determine equalizer tap weights to reduce test time, and are expected to report equal or higher values of TDECQ. These alternative methods should not be used for receiver sensitivity and stressed receiver sensitivity calibration.