Consensus Results: Corrections Needed in Clause 180.9.6

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Note: This presentation is being circulated to build consensus and may change before it is presented.

Addresses Comments: R2-15, R2-16, R2-17, R2-18, R2-126, R2-141, R2-144, R2-188, R2-189, R2-206

Supporters

Introduction

- With the changes introduced in 3.2, there are a few things that need cleaning up in clause 180.9.6
- The DFE is based on a:
  - Mean zero input signal
  - Balanced and scaled alphabet, {-1, -1/3, 1/3, 1}

  for the transmitted sequence
- SSPRQ is specified as a sequence from the unbalanced alphabet {0, 1, 2, 3}
- The signal out of the reference receiver is not mean zero
  - It is referred to as “optical power” in the clause, which cannot be negative

Comments: R2-141, R2-188, R2-206

The reference equalizer is a T-spaced, discrete-time equalizer with 15 feed-forward taps and a single decision feedback tap, where T is the symbol period. Equalizer coefficient constraints are given in Table 180–16. The reference equalizer may be implemented in the oscilloscope.

The equalizer is modeled as shown in Figure 180–10, where

— $r(t)$ is the output of the reference receiver defined in 180.9.2, with the mean value subtracted from the signal

— $\eta(t)$ is colored Gaussian noise, generated from additive white Gaussian noise (AWGN) filtered by a Bessel-Thomson (BT) filter as defined in 180.9.2

— $z(t)$ is the input signal given by Equation (180–1)

— z_n is the sampled response of input signal $z(t)$, given by Equation (180–2)

— y_n is the equalizer output corresponding to x_n

— X_n is the nth symbol in the test pattern sequence, $X_n \in \{0, 1, 2, 3\}$, and x_n is given by Equation (180-3)

R2-206

— $\boldsymbol{w}$ is ~~the set of feed-forward tap coefficients, given by Equation (180–3)~~ a vector of feed-forward tap coefficients, given by Equation (180-4)

— $b(1)$ is the feedback tap coefficient

R2-141

— the ~~feedback is modeled as correct, i.e., x_n is the pattern used to generate the input $r(t)$~~ decisions are modeled as being correct, i.e., the decision feedback path is fed by the sequence $\{x_n\}$ corresponding to the transmitted test pattern sequence without errors

— the received signal $r(t)$ is aligned with the test pattern such that $r(nT)$ corresponds to x_n

$$z(t) = r(t) + \eta(t) \qquad (180\text{–}1)$$

$$z_n = z(nT + \phi)\text{, where } 0 \le \phi < T \qquad (180\text{–}2)$$

$$x_n = 2/3\, X_n - 1, \qquad x_n \in \{-1, -1/3, 1/3, 1\} \qquad (180\text{-}3)$$

$$\cancel{\boldsymbol{w} = \{w(a), w(a+1), \ldots, w(a+14)\}} \qquad \cancel{(180\text{–}3)}$$

$$\boldsymbol{w} = [w(a), w(a+1), \ldots, w(a+14)] \qquad (180\text{-}4)$$

Comments: R2-144, R2-189

For a given sampling phase ϕ_0 and assumed RMS value σ_G for the colored Gaussian noise $\eta(t)$, determine the equalizer coefficients $\boldsymbol{w}$ and $b(1)$, subject to the limits in Table 180–16, that result in the minimum mean squared error (MMSE) between y_n and ~~x_n~~. Alternative optimization methods may be used to determine equalizer tap weights if they report comparable values of TDECQ.

αx_n, where α is a scaling factor chosen such that the tap weights in $\boldsymbol{w}$ sum to 1.

Explanation (not to be included in the standard):
Because we require that sum(w) = 1, we are not really minimizing MSE between y_n and x_n, we are minimizing MSE between y_n and a scaled version of x_n. One way to do this is to first minimize MSE between y_n and x_n. Let that solution be w_0 and b_0. Let $\alpha = 1/sum(w_0)$, and scale w and b such that $w_1 = \alpha w_0$ and let $b_1 = \alpha b_0$. Then w_1 and b_1 minimize MSE between y_n and αx_n.

Note that, with $x_n \in \{-1, -1/3, 1/3, 1\}$, $\alpha \approx \frac{OMA_{outer}}{2} \approx \frac{OMA_{TDECQ}}{2}$. The relation is not exact because we are not measuring OMA as steady state values. If we were, the equality would be exact.

Comments: R2-15, R2-144, R2-188

Parameter	Symbol	Value	
		Minimum	Maximum
Number of feed-forward taps	N_w	15	
Number of pre-cursor feed-forward taps	—	0	3
Main tap coefficient limit	$w(0)$	$0.9 - b(1)$	2.5
Normalized feed-forward tap coefficient limits:	$w(i)/w(0)$		
$i = -3$		–0.15	0.1
$i = -2$		–0.1	0.25
$i = -1$		–0.5	0.1
$i = 1$		–0.6	0.2
$i = 2$		–0.2	0.3
$i = 3$		–0.15	0.15
$i = 4$		–0.15	0.15
$i = 5$		–0.15	0.15
$i = 6$		–0.15	0.15
$i \geq 7$		–0.1	0.1
Pre-post-cursor tap coefficient difference limit: $\lvert w(1)/w(0) - b(1) - w(-1)/w(0)\rvert$	—	—	0.25
Feed-forward tap DC gain[a]	—	1	
Number of feedback taps	N_b	1	
Feedback tap coefficient limit[b]	$b(1)$	0	$0.33\,\alpha$

[a] The sum of all 15 feed-forward tap coefficients, $w(i)$.

~~[b] The feedback tap coefficient $b(1)$ is referenced to $OMA_{TDECQ}/2$ (see 180.9.6.4 for definition of OMA_{TDECQ}).~~

Use of α obviates the need to define OMA_{TDECQ}

Comments: R2-188, R2-18

Use X_n instead of x_n

y_n is implicitly a function of X_n

$$P(y_{n,\mathrm{L}}, \sigma_{\mathrm{G}}) = \frac{1}{2}\begin{cases} \operatorname{erfc}\left(\dfrac{P_{\mathrm{th1}} - y_{n,\mathrm{L}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) & X_n = 0 \\ \operatorname{erfc}\left(\dfrac{y_{n,\mathrm{L}} - P_{\mathrm{th1}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) + \operatorname{erfc}\left(\dfrac{P_{\mathrm{th2}} - y_{n,\mathrm{L}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) & X_n = 1 \\ \operatorname{erfc}\left(\dfrac{y_{n,\mathrm{L}} - P_{\mathrm{th2}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) + \operatorname{erfc}\left(\dfrac{P_{\mathrm{th3}} - y_{n,\mathrm{L}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) & X_n = 2 \\ \operatorname{erfc}\left(\dfrac{y_{n,\mathrm{L}} - P_{\mathrm{th3}}}{\sqrt{2}C_{\mathrm{eq}}\sigma_{\mathrm{G}}}\right) & X_n = 3 \end{cases} \quad (180\text{–}7)$$

where

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

$P_{th1}, P_{th2}, P_{th3}$ are thresholds adjusted from $P_{0,th1}, P_{0,th2}, P_{0,th3}$ within limits described below

Addresses Hajduczenia Comment R2-18.

Comments: R2-189, R2-16, R2-17 (background)

The nominal threshold levels $P_{0,\text{th1}}$, $P_{0,\text{th2}}$, and $P_{0,\text{th3}}$, are determined from the $\text{OMA}_{\text{TDECQ}}$ and the average optical power P_{ave} as defined in Equation (180–4), Equation (180–5), and Equation (180–6), and illustrated in Figure 180–11.

$$P_{0,\,th1} = \text{P}_{\text{ave}} - \frac{\text{OMA}_{\text{TDECQ}}}{3} \qquad (180\text{–}4)$$

$$P_{0,\,\text{th2}} = \text{P}_{\text{ave}} \qquad (180\text{–}5)$$

$$P_{0,\,\text{th3}} = \text{P}_{\text{ave}} + \frac{\text{OMA}_{\text{TDECQ}}}{3} \qquad (180\text{–}6)$$

where $\text{OMA}_{\text{TDECQ}}$ is measured on the equalized captured waveform y_n using the method defined in 180.9.5.

$r(t)$ is no longer a power, as the mean has been subtracted off, and y_n is a discrete-time signal, not a continuous-time signal. The method defined in 180.9.5 is for a continuous-time signal with runs of threes and runs of zeros. If we define the thresholds in terms of α (the scaling factor applied to x_n), we do not need to define OMA_{TDECQ} at all.

Comments: R2-189, R2-16, R2-17

Original:

An eye diagram to help illustrate TDECQ is shown in Figure 180–11. The eye diagram corresponds to the optimized equalizer setting at sampling phase ϕ_0. The feedback symbol x_n changes at phase $\phi = \phi_0 - T/2$.

I suggest:

An eye diagram to help illustrate TDECQ is shown in Figure 180–11. The eye diagram corresponds to the optimized equalizer setting at sampling phase ϕ_0. The feedback symbol ~~x_n changes at phase $\phi = \phi_0 - T/2$.~~ x_{n-1} changes value to x_n at time $t = nT + \phi_0 + T/2$.

The eye diagram can be constructed, for example, by using the equalizer taps optimized at ϕ_0 and varying the phase ϕ in Eq. 180-2 to generate samples y_n at multiple phases.

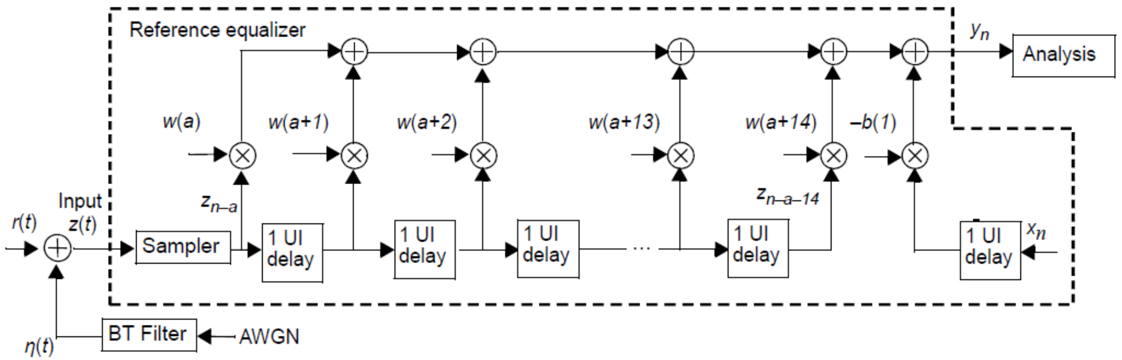

Figure 180–10—TDECQ reference equalizer functional model

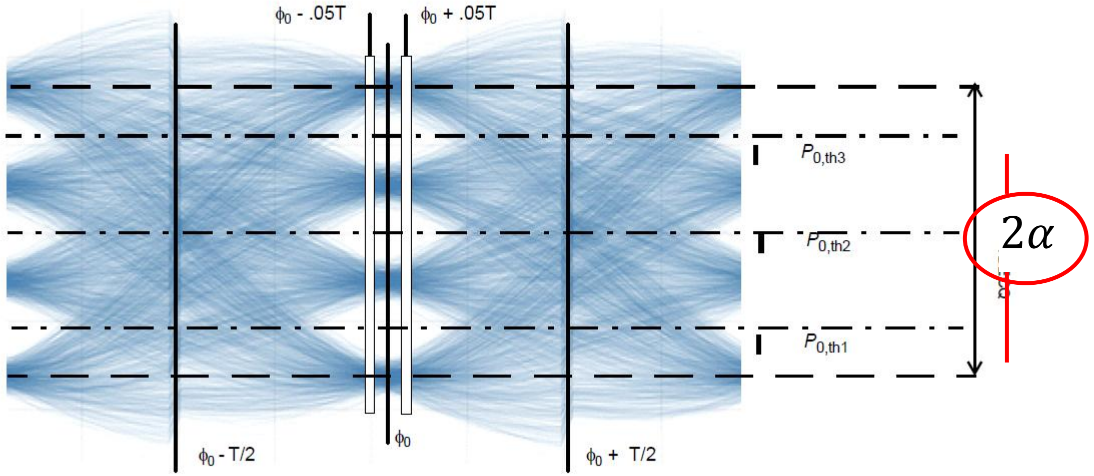

Figure 180–11—Illustration of the TDECQ measurement

Comments: R2-189, R2-16, R2-17

The nominal threshold levels $P_{0,\text{th1}}$, $P_{0,\text{th2}}$, and $P_{0,\text{th3}}$, are ~~determined from the $\text{OMA}_{\text{TDECQ}}$ and the average optical power P_{ave} as~~ defined in Equation (180–4), Equation (180–5), and Equation (180–6), and illustrated in Figure 180–11.

$$P_{0,\,th1} = \cancel{\text{P}_{\text{ave}} - \frac{\text{OMA}_{\text{TDECQ}}}{3}} - \frac{2\alpha}{3} \qquad (180\text{–}4)$$

$$P_{0,\,\text{th2}} = \cancel{\text{P}_{\text{ave}}}\; 0 \qquad (180\text{–}5)$$

$$P_{0,\,\text{th3}} = \cancel{\text{P}_{\text{ave}} + \frac{\text{OMA}_{\text{TDECQ}}}{3}} + \frac{2\alpha}{3} \qquad (180\text{–}6)$$

~~where $\text{OMA}_{\text{TDECQ}}$ is measured on the equalized captured waveform y_n using the method defined in 180.9.5.~~ ,

where α is the scaling factor applied to x_n to achieve an MMSE fit to y_n where the tap coefficients in $\boldsymbol{w}$ sum to 1.

Comment: R2-126

nominally

For a given sampling phase ϕ_0 two regions of a UI are measured, centered 0.05 UI before and after the sampling phase ϕ_0, each with a width of 0.04 UI. For the left region, all samples such that $\phi_0 - 0.07\text{T} \le \phi \le \phi_0 - 0.03\text{T}$ are included. For the right region, all samples such that $\phi_0 + 0.03\text{T} \le \phi \le \phi_0 + 0.07\text{T}$ are included. The precise time position of the pair of regions is adjusted to minimize TDECQ while keeping the regions spaced 0.1 UI apart. Let $y_{n,\text{L}}$ and $y_{n,\text{R}}$ be the equalized samples in the left region and the right region respectively.

Thank you