TDEC for PAM4 ('TDECQ')

Changes to clause 123, to replace TDP with TDECQ

Draft 1

May 3rd 2016

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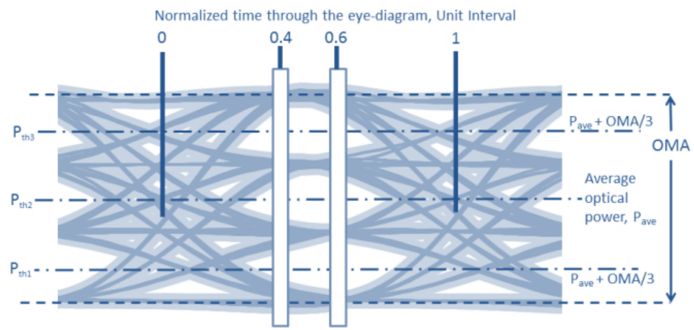
Proposal for TDEC for PAM4 signals -1



- Scope based, TDEC variant expanded for all three sub-eyes in an equalized PAM4 signal
- Reference receiver and equalizer are software based 'in the 'scope'
- Single timing position in centre of eye for all three sub-eyes, +/-0.1 UI (TBC)
- TDECQ calculated from fixed thresholds: P_{ave}, $P_{ave}+OMA/3$, $P_{ave}-OMA/3$
  - Penalizes transmitters which have unequal sub-eyes
  - Not how a 'real' PAM4 retimer is expected to work, but avoids the issue of how to measure accurately the penalty of unequal sub-eyes when received by a 'real' receiver, which may have differing sensitivities for each sub-eye.
  - Should 400GE decide that optimized thresholds should be specified for the TDECQ test, an additional (non-trivial) test will be needed to measure how transmitter and receiver sub-eye inequality/non-linearity interact.

Proposal for TDEC for PAM4 signals -2

- Conceptual basics
  - Measure scope noise without signal, σ_s
  - Measure histogram through equalized eye to be tested, normalize
    - Equalization is done in the 'scope with a ref. equalizer (e.g. 5 T/2 tap FFE)
    - This represents the vertical probability density function (PDF) through the PAM4 eye
    - Do this for left and right of eye time centre
  - From the vertical PDF through the PAM4 eye, create 3 cumulative probability functions, one around each sub-eye threshold.
  - Add normalized Gaussian noise term σ_G to the sub-eye thresholds
    - to create 3 PDFs consisting of a Gaussian PDF centred around each sub-eye thresholds
  - Multiply each threshold PDF by the appropriate cum've eye PDF to calculate a proxy for SER for that threshold; sum the results
  - Find smallest size of σ_G that makes resultant = target SER
  - TDECQ is given by:

$$TDECQ = 10.\,log_{10}\left(\frac{OMA}{6} \times \frac{1}{Q_t R}\right)$$

where Q_t is the Q function value consistent with the target symbol error ratio,

$R = (C_{eq}\sigma_G^2 + \sigma_S^2)^{½}$,

and C_{eq} is a coefficient which accounts for the reference equalizer noise enhancement factor when the equalizer has been optimized for minimum TDECQ.

Changes to 400GBASE-FR8 and -LR8 (Clause 123)

- If this proposal for TDECQ is adopted, the following slides show draft changes to clause 123 (this section is in progress….

Changes to section 123.8.5 Transmitter and dispersion eye closure

- *Paraphrased text in clause 95.8.5, with reference to appropriate tables*
  - *use a worst case fibre for longwave, use a reduced bandwidth (TBD) Rx for SR, mention reference equalizer.*

123.8.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)

TDECQ of each lane shall be within the limits given in Table 123-xxx if measured using the methods specified in 123.8.5.1, 123.8.5.2, and 123.8.5.3..

TDECQ is a measure of each optical transmitter's vertical eye closure when transmitted through a worst case optical channel (specified in 123.8.5.1), as measured through an optical to electrical converter (O/E) with a bandwidth equivalent to a reference receiver, and equalized with the reference equalizer (as described in 123.8.5.3). The reference receiver and equalizer may be implemented in software or may be part of the oscilloscope.

Table 123-11 specifies the test patterns to be used for measurement of TDECQ.

- *2 more sub-sections need to be added after the sub-section 123.8.5.1 (which describes worst case optical channel) to describe the measurement set up and TDEC calculation method….*
- *SRS sub-sections need to be populated*

New section: 123.8.5.2 TDECQ test set up

123.8.5.2 TDEC4 conformance test setup

A block diagram for the TDECQ conformance test is shown in Figure 123-4. Other equivalent measurement implementations may be used with suitable calibration.

Each optical lane is tested individually with all other lanes in operation. The optical splitter and variable reflector are adjusted so that each transmitter is tested with the optical return loss specified in Table 123-7. Each optical lane is tested with the test fibers described in 123.8.5.1. The O/E and the oscilloscope combination has a fourth-order Bessel-Thomson filter response with a bandwidth of 19.9 GHz. Compensation may be made for any deviation from an ideal fourth-order Bessel-Thomson response.

The test pattern (specified in Table 123-11) is transmitted repetitively by the optical lane under test and the oscilloscope is set up to capture the complete pattern for TDECQ analysis as described in 123.8.5.3.

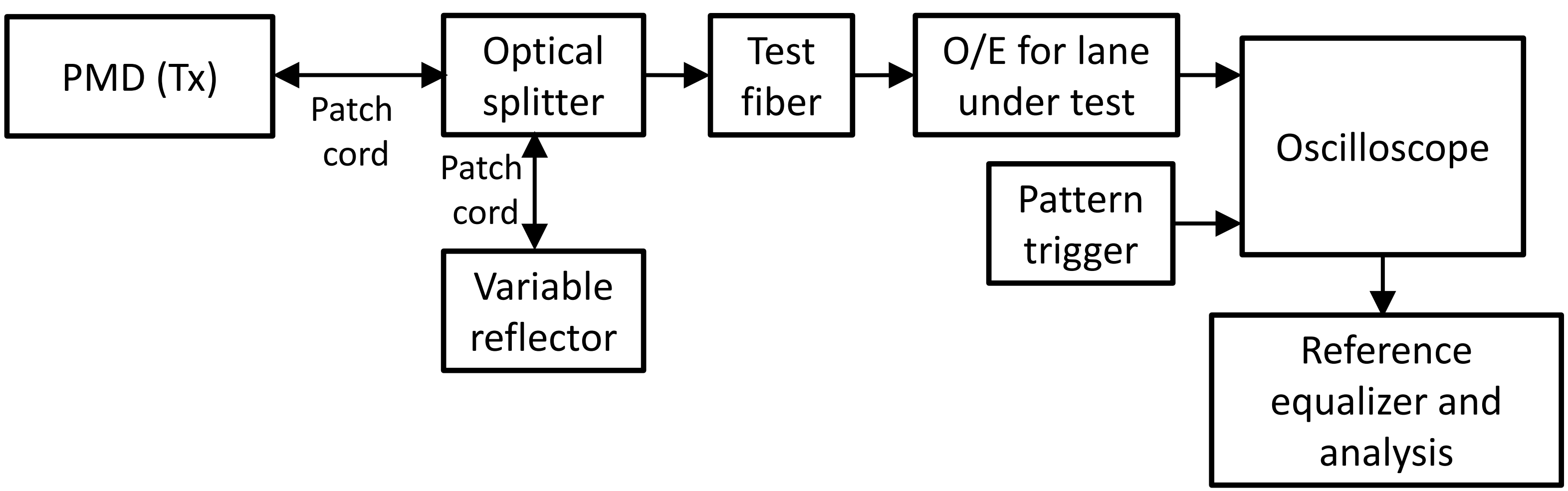


Figure 123-4 — TDECQ conformance test block diagram

New section 123.8.5.3 TDEC4 measurement method

123.8.5.3 TDEC4 measurement method

The standard deviation of the noise of the O/E and oscilloscope combination, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

OMA_{outer} is measured according to 123.8.4.

The test pattern specified for TDECQ (see Table 123-11) 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.

(Time samples/UI? Number of amplitude samples/time sample ? practical limit for number of points?)

The reference equalizer (specified in transmitter characteristics Table 123-7) is used to optimize signal to noise ratio of the captured waveform (to minimize the value of TDECQ), and the tap coefficients of the optimized reference equalizer are recorded.

If a sampling oscilloscope is used, the impact on transmitter noise of the sampling process and filtering effect of the reference equalizer must be compensated for (How?). A reconstructed eye diagram is formed from the optimally equalized captured pattern

If a real time sampling scope is used, and the reference equalizer is implemented in the oscilloscope, then the oscilloscope can be set up to capture an eye diagram directly.

(Time samples/UI? Number of amplitude samples/time sample ? practical limits for number of points?)

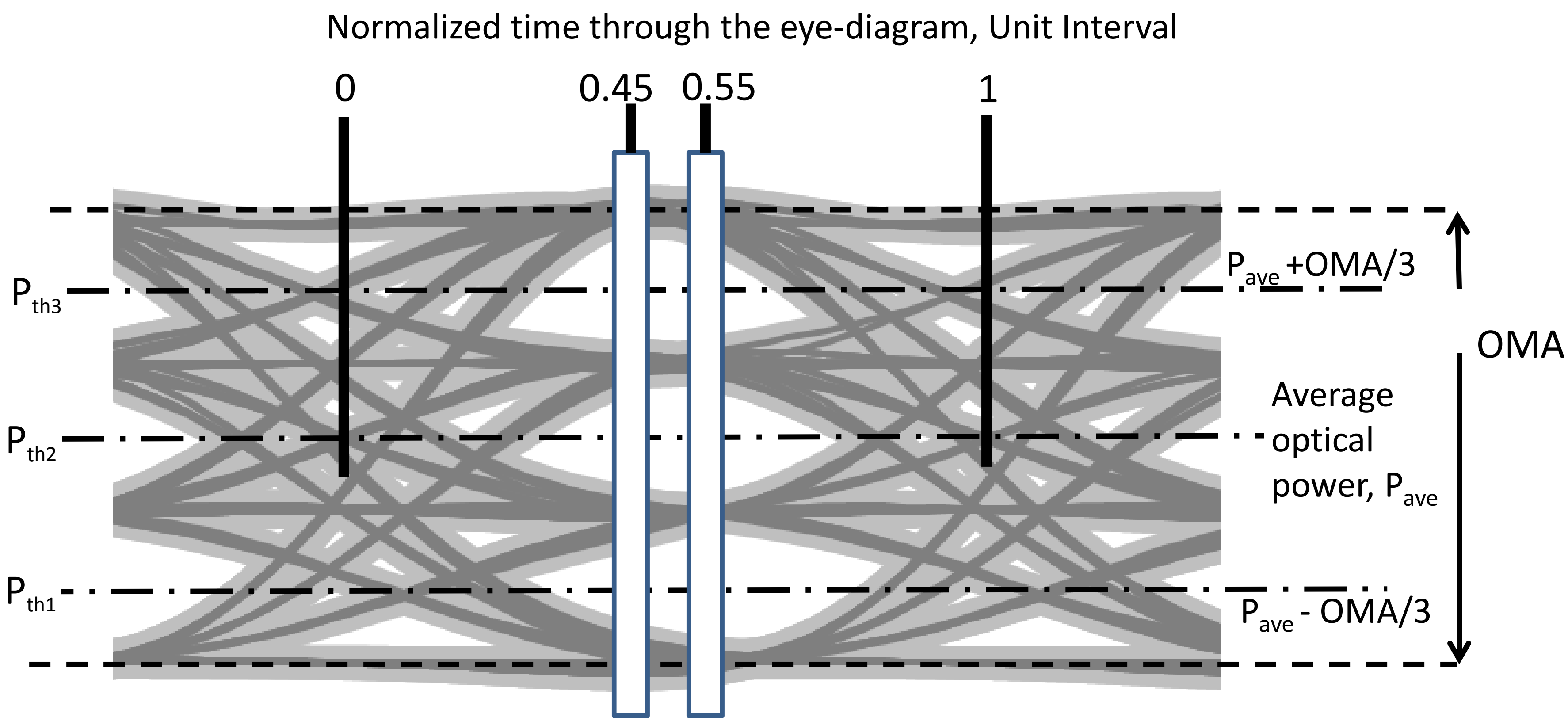
The average optical power (P_{ave}) of the eye diagram is determined, and the 0 UI and 1 UI crossing points are determined by the average of the eye diagram crossing times, as measured at P_{ave}, as illustrated in Figure 123-5.

Two vertical histograms are measured through the eye diagram, centered at 0.45 UI (TBD) and 0.55 UI (TBD), each of the histograms spans all of the modulation levels of the eye diagram, as illustrated in Figure 123-5.

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).

cont'd….

Figure 123-5 Illustration of the TDECQ measurement



123.8.5.3 TDECQ measurement method… cont'd

The sub-eye threshold levels P_{th1}, P_{th2}, and P_{th3}, are determined from the OMA, and the average optical power of the eye diagram, P_{ave}, as illustrated in Figure 123-5.

Each captured histogram is processed as follows.

The histogram is normalized, and can be represented as a series of equally spaced optical power values (y_i) 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 the histogram). The sum of all $f(y_i)$ is equal to 1.

From the normalized histogram $f(y_i)$, three cumulative probability functions are created, $Cf_1(y_i)$, $Cf_2(y_i)$, and $Cf_3(y_i)$, one around each sub-eye threshold. For example:

$$Cf_1(y_i) = \sum_{y=P_{th1}}^{y_i} |(f(y_i) - f(P_{th1}))|$$

Each element of the cumulative probability function $Cf_1(y_i)$ is multiplied by a value $P_{th1}(y_i)$, and then summed to calculate an approximation for the partial symbol error ratio (SER) for threshold 1. $P_{th1}(y_i)$ is equivalent to a Gaussian probability density function with an rms value of σ_G , centered around the sub-eye threshold P_{th1}. $P_{th1}(y_i)$ is given by :

$$P_{th1}(y_i) = \frac{2}{3} . \frac{1}{\sqrt{2\pi}} . e^{-} \left(\frac{y_i - P_{th1}}{\sigma_{GL}}\right)^2$$

The other two cumulative probability functions $Cf_2(y_i)$ and $Cf_3(y_i)$ are treated similarly, to find the partial SER for threshold 2 and threshold 3.

123.8.5.3 TDECQ measurement method… cont'd

The smallest size of σ_G is found that makes the sum of the partial SERs equal the target SER = 3.2×10^{-4} for either left or right histogram.

TDECQ is given by:

$$TDECQ = 10.log_{10}(\frac{OMA}{6} \times \frac{1}{Q_t R})$$

where Q_t is the Q function value consistent with the target symbol error ratio,

$R = (C_{eq}\sigma_G^2 + \sigma_S^2)^{½}$,

and C_{eq} is a coefficient which accounts for the reference equalizer noise enhancement factor when the equalizer has been optimized for minimum TDECQ.

JPK note: Ideally, add paragraph(s) to describe how to derive C_{eq} (to account for noise filtering by the EQ)

Changes to Table 123-7, Table 123-8, Table 123-9, and Table 123-10 and Table 123-11

- Change "TDP" to "TDECQ" in Table 123-7 and Table 123-9
- Change "TDP" to "SECQ" in Table 123-8
- Change "TDP" to "TDECQ" in Table 123-11, add test pattern number for SSPRQ shown in Table 123-10, and
- add SSPRQ test pattern to Table 123-10

- *JPK question: Is SSPQR short enough for sampling scopes to acquire data?*

SRS test sections

- Work in progress…
  - SECQ is same metric as TDECQ but without worst case fibre
  - SECQ spec value is same as TDECQ spec value
  - SRS test description follows clause 95 SEC description with necessary changes

SRS test 123.8.10

123.8.10 Stressed receiver sensitivity

Stressed receiver sensitivity shall be within the limits given in Table 123–8 if measured using the method defined by 123.8.10.1 and 123.8.10.3, with the conformance test signal at TP3 as described in 95.8.10.2, using the test pattern specified for SRS in Table 123–11.

Stressed receiver sensitivity is defined with all transmit and receive lanes in operation. Pattern 3, Pattern 5, or a valid 400GBASE-FR8 or 400GBASE-FR8 signal is sent from the transmit section of the PMD under test. The signal being transmitted is asynchronous to the received signal. The interface BER of the PMD receiver is the average of the BER of all receive lanes while stressed and at the specified receive OMA.

SRS test: 123.8.10.1

123.8.10.1 Stressed receiver conformance test block diagram

A block diagram for the receiver conformance test is shown in Figure 95–6. The patterns used for the received conformance signal are specified in Table 123–11.

The optical test signal is conditioned (stressed) using the stressed receiver methodology defined in xxxxxxxxx and has sinusoidal jitter applied as specified in xxxxxxxx.

A suitable test set is needed to characterize the signal used to test the receiver. Stressed receiver conformance test signal verification is described in 123.8.10.2.

The fourth-order Bessel-Thomson filter has a 3 dB bandwidth of approximately 19 GHz. The low-pass filter is used to create ISI. The combination of the low-pass filter and the E/O converter should have a frequency response that results in the level of stressed eye closure (SECQ) before the sinusoidal and Gaussian noise terms are added, as described in xxxxxxx. The sinusoidal amplitude interferer 1 causes jitter that is intended to emulate instantaneous bit shrinkage that can occur with DDJ. This type of jitter cannot be created by simple phase modulation. The sinusoidal amplitude interferer 2 causes additional eye closure, but in conjunction with the finite edge rates from the limiter, also causes some jitter.

The sinusoidally jittered clock represents other forms of jitter and also verifies that the receiver under test can track low-frequency jitter. The sinusoidal amplitude interferers may be set at any frequency between 100 MHz and 2 GHz, although care should be taken to avoid harmonic relationships between the sinusoidal interferers, the sinusoidal jitter, the signaling rate, and the pattern repetition rate. The Gaussian noise generator, the amplitude of the sinusoidal interferers, and the low-pass filter are adjusted so that the SECQ specified in Table 123–8 is not exceeded, according to the methods specified in xxxxxxx.

123.8.10.1 Stressed receiver conformance test block diagram continued

For improved visibility for calibration, all elements in the signal path (cables, DC blocks, E/O converter, etc.) should have wide and smooth frequency response, and linear phase response, throughout the spectrum of interest. Baseline wander and overshoot and undershoot should be minimized.

SRS block diagram

SRS: 123.8.10.2

123.8.10.2 Stressed receiver conformance test signal characteristics and calibration

SRS test 123.8.10.3

123.8.10.3 Stressed receiver conformance test signal verification

SRS test 123.8.10.4

123.8.10.4 Sinusoidal jitter for receiver conformance test

Changes to PICS

- 123.12.4.5
  - OM5: replace TDP with TDECQ
- 123.12.4.5
  - OM10 add SECQ

back-up

123.8.5.3 TDECQ measurement method cont'd

Each histogram is normalized. to create a vertical probability density function (PDF) through the equalized PAM4 eye, $f(y)$.

The sub-eye threshold levels P_{th1}, P_{th2}, P_{th3} are determined from the OMA, and the average optical power of the eye diagram, P_{ave}, as shown in Figure 123-5.

From the vertical PDF through the PAM4 eye, 3 cumulative probability functions, $Cf_1(y)$, $Cf_2(y)$, and $Cf_3(y)$ are created, one around each sub-eye threshold:

For example $Cf_1(y) = \frac{2}{3}\int_{y=Pth1}^{y} |f_1(y)\text{-}f_1(y{=}P_{th1})|.dy$

Add a normalized Gaussian noise term σ_G to the sub-eye thresholds, to create 3 PDFs consisting of a Gaussian PDF centred around each of the sub-eye thresholds

Multiply each threshold PDF by the appropriate cumulative PDF to calculate a proxy for SER for that threshold; sum the results.

Find smallest size of σ_G that makes the resultant sum equal the target SER = $3.2\text{x}10^{-4}$.

TDECQ is given by:

$$TDECQ = 10.\log_{10}\left(\frac{OMA}{6} \times \frac{1}{Q_t R}\right)$$

where Q_t is the Q function value consistent with the target symbol error ratio,

$R = (C_{eq} s_G^{\,2} + s_S^{\,2})^{½}$,

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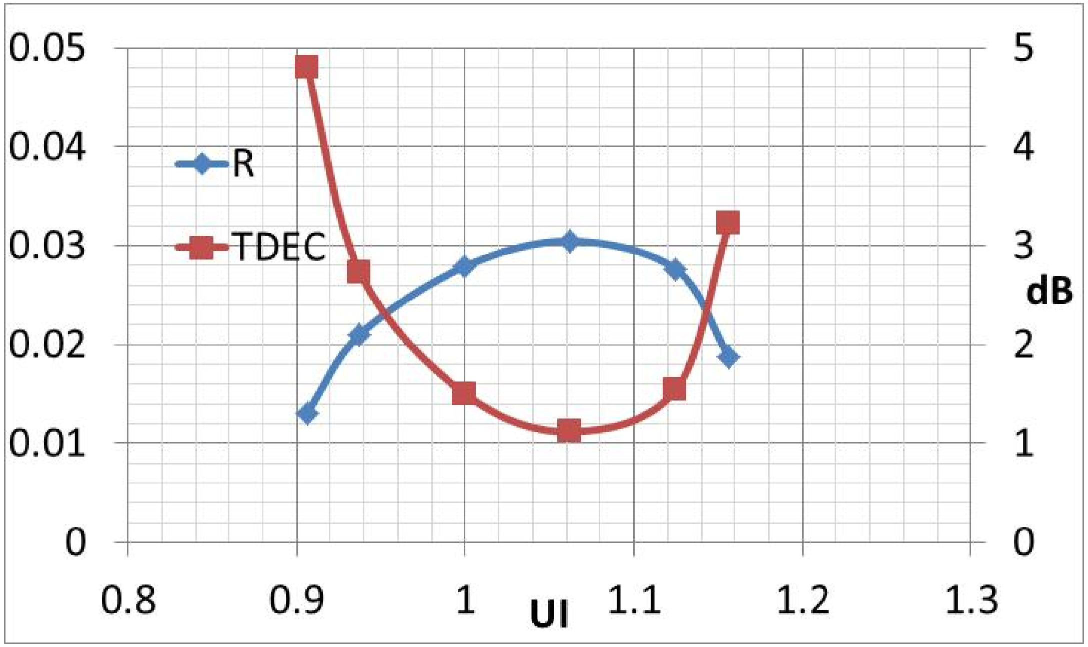
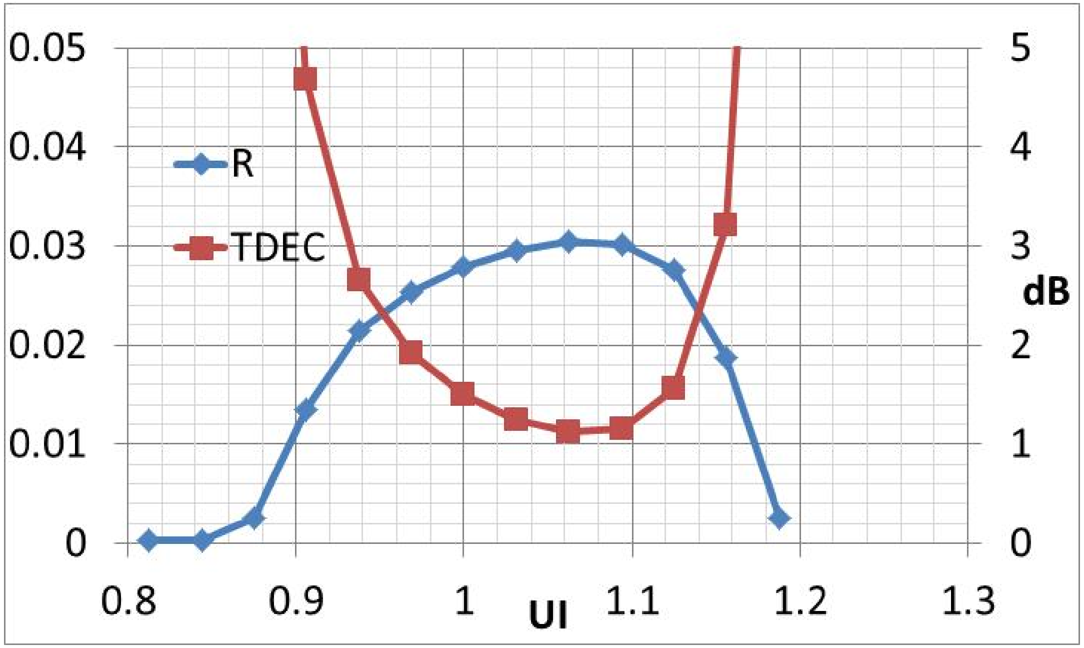
Note: need additional paragraph to describe how to derive C_{eq} (to account for noise filtering by the EQ)



- slow 142 ber count (top)
- (ber method is correct because mod levels grouped, cum distribs each go to 1 and partial error prob's are averaged (same as multiplying each by ¼)



- Eye method also checked OK: factor of 2/3 is to make sum of cumulative pdf's equal to 1 at minimum and maximum of eye heights