TDECQ processing
noise treatment and equalizer optimization

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P802.3bs SMF ad hoc

Jonathan King, Finisar

Preamble

- TDECQ calculates the dB ratio of how much noise can be added to a transmitter signal vs an ideal signal, while still meeting the target symbol error ratio. It's similar to TDEC, but for PAM4 and a reference receiver and equalizer.

- TDECQ is intended to be a predictor of system performance of a PAM4 transmitter.
  - It calculates partial symbol error probabilities for a measured transmitter waveform, propagated through a worst case channel, and equalized with an ideal reference receiver.

- Formally, the TDECQ signal processing should mimic what's expected for a real receiver.
  - in a real system, the equalizer would ideally optimize receiver noise and ISI for lowest error probability, with all the noise effectively before the equalizer.

TDECQ method, draft 2.1 vs draft 2.2

- 802.3bs Draft 2.1 Clause 121 said the reference EQ should be optimized to minimize resulting TDECQ.
- What is needed:
  - Optimize the EQ for the maximum amount of noise that can be added and still meet the target SER. That requires **iteration** of adding noise, then adjusting EQ to minimize SER; if the lowest achievable SER is higher than target then reduce the added noise, if SER is lower than target then increase the noise, and so on.
  - Effectively, the added noise is one more parameter that must be optimized (as well as the EQ tap weights) as part of an iterative process to just meet the target SER. It increases the complexity of computing TDECQ a bit, but ensures that the TDECQ value will be consistent across input OMA range and scope noise, and that the value calculated will be a 'global' minimum for a given Tx device.
- In Draft 2.2 Clause 121, the TDECQ reference EQ optimization method was changed to MMSE. This left the TDECQ value hostage to the input noise of the scope.
  - For high OMA input, when scope noise is relatively small, the EQ optimizes to minimize ISI, which doesn't provide the optimum equalization settings for when extra noise is added to the signal.
  - For low OMA input, scope noise is more significant, and the EQ optimizes more for noise bandwidth, giving a TDECQ value which is more representative of the penalty that would be seen in a real system (where the EQ would be expected to optimize noise bandwidth and ISI for minimum SER at whatever input SNR it sees), and generally a lower (better) TDECQ result.
  - The low input OMA signal should be closer to the 'correct' TDECQ value.
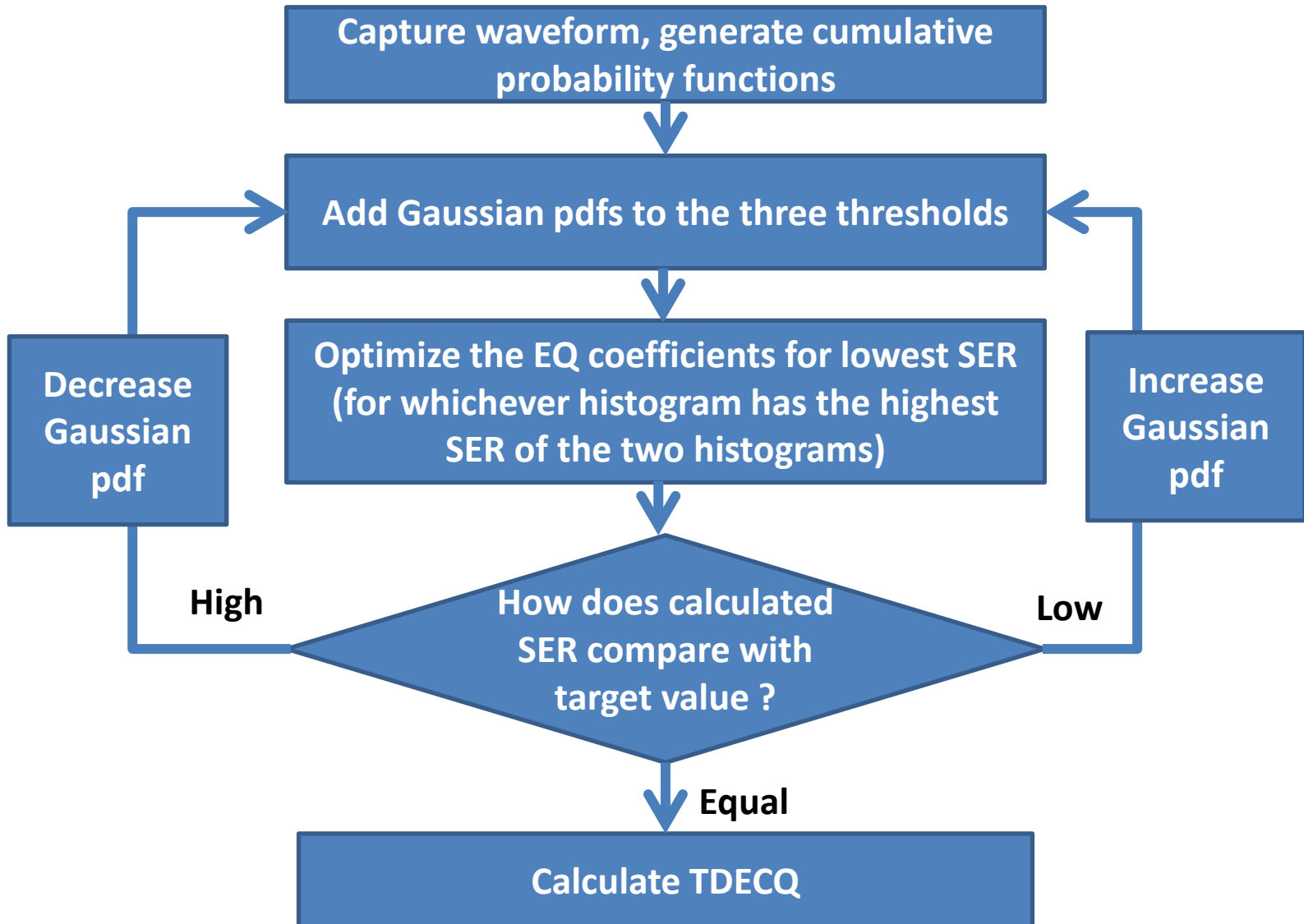
'Real' system
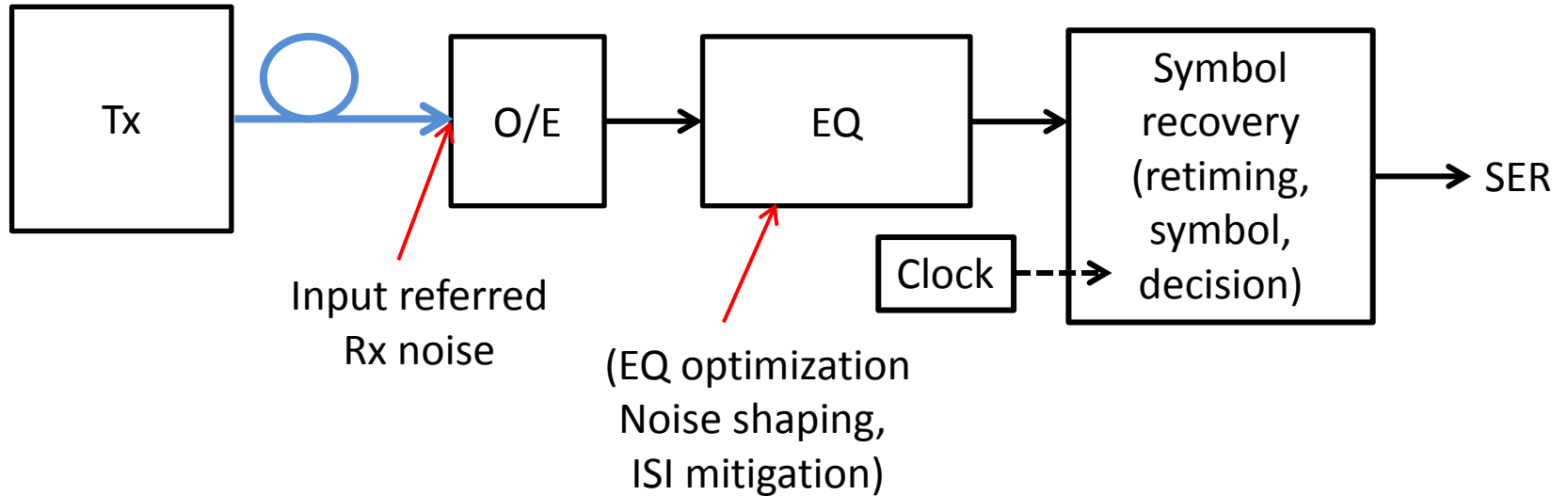
- Noise before EQ dominates, EQ optimizes noise bandwidth and ISI for lowest error ratio

TDECQ
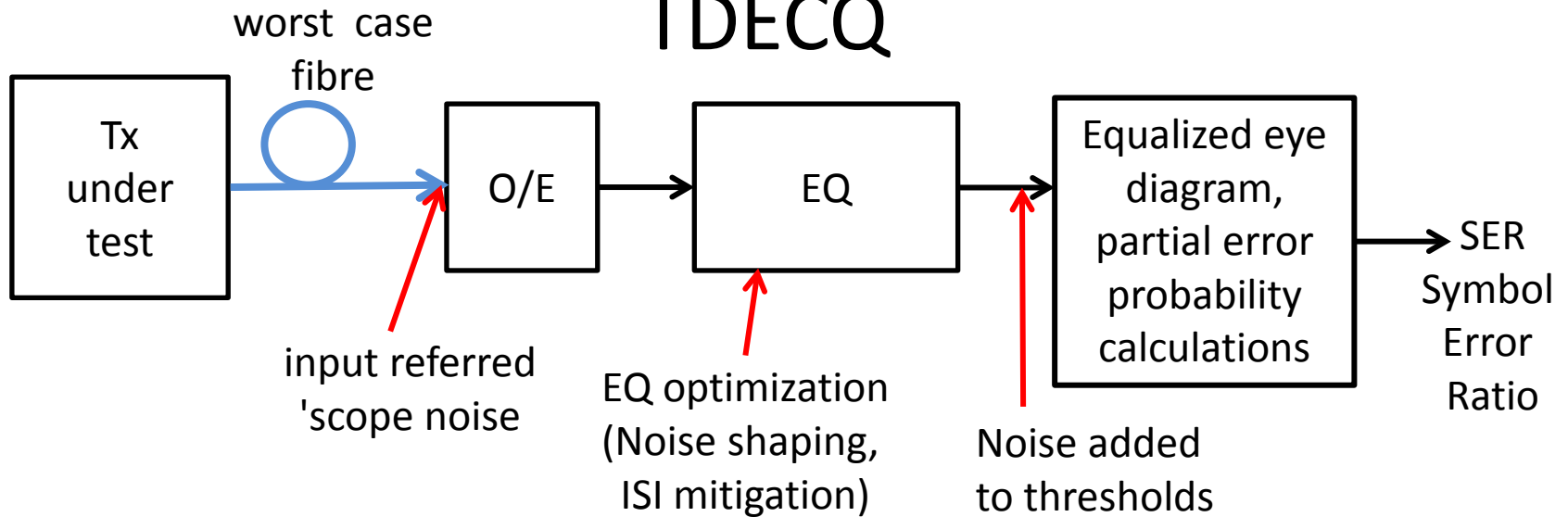
- In the TDECQ test, 'scope noise appears at the same point as receiver noise does in a real system.
- As part of TDECQ processing, a Gaussian probability density function (PDF) is added to each of the 3 thresholds to represent extra noise that a reference Rx could add while still meeting the target SER.
  - Since this noise term is effectively added after the EQ, it's amplitude needs to be scaled to account for the filtering effect of the EQ when calculating the total input referred noise that can be tolerated.
- If the EQ is optimized for MMSE with *just* the scope noise at the input, it will not minimize TDECQ when more noise is added after the EQ.
- *An iterative approach to find minimum TDECQ might be: 1) add Gaussian pdf to thresholds; 2) use the calculated SER of the worst histogram as a metric to determine EQ optimization. 3) If the minimum SER found (for the worst histogram) is greater than the target SER, reduce the noise added to the thresholds; if it's less than the target SER, increase the noise added to the thresholds; 4) repeat steps 2 & 3 until target SER is met at optimum EQ setting; 5) Calculate TDECQ from Equation 121-8, illustrated next slide.*

Flow chart of example iteration process:

Capture waveform, generate cumulative probability functions

Add Gaussian pdfs to the three thresholds

Optimize the EQ coefficients for lowest SER (for whichever histogram has the highest SER of the two histograms)

Decrease Gaussian pdf

Increase Gaussian pdf

How does calculated SER compare with target value ?

High

Low

Equal

Calculate TDECQ

Solutions

- Keysight have demonstrated a method which adds a fixed value of noise to the signal, and optimizes the EQ (using MMSE).
  - this is an approximation to a formally correct approach where the added noise is varied and the equalizer is optimized for each noise value. Tends to emphasize optimizing for noise bandwidth.
  - but it provides a TDECQ value close to the 'correct' one – Keysight showed a difference of ~ 0.2 dB for a set of transmitters spanning a reasonable range of TDECQ values.

Options for the standard

- Option 1:
  - write in an example of iterating the addition of a Gaussian pdf to the thresholds, optimizing the EQ for lowest SER for whichever histogram has the highest SER of the two histograms; if the lowest SER achieved by optimizing the EQ is lower(higher) than the target SER (4.8e-4) then increase(decrease) the magnitude of the Gaussian pdf added to the thresholds and re-optimize the EQ setting for SER, and so on.
  - Pro's: least change to existing text and maths in D3.0.
  - Con's: iteration*.
- Option 2:
  - rewrite the maths for TDECQ to convolve Gaussian noise to the captured signal. Optimize the EQ for lowest SER for whichever histogram has the highest SER of the two histograms; if the lowest SER is lower than the target SER (4.8e-4) then increase the magnitude of the Gaussian noise convolved with the signal and re-optimize the EQ setting for SER, and so on.
  - Pro's: clarifies that the EQ has to optimize the measured noise and ISI and added noise terms.
  - Cons: iteration*; L and R histograms have to divided into four pieces each (one above and below each signal level) – substantial changes to the draft maths; the frequency response of the noise added needs to be correct.

In practice, iteration could be avoided by stepping through the allowed values of the Gaussian pdfs (or the Gaussian noise convolved with the signal), and interpolating a plot of calculated TDECQ vs SER at the target SER .