Metrology issues for different reference receiver topologies

Steve Sekel, John Calvin, Greg D. Le Cheminant **OCT 30, 2019**

Keysight CSG: Presenter John Calvin, IP Planner

KEYSIGHT TECHNOLOGIES

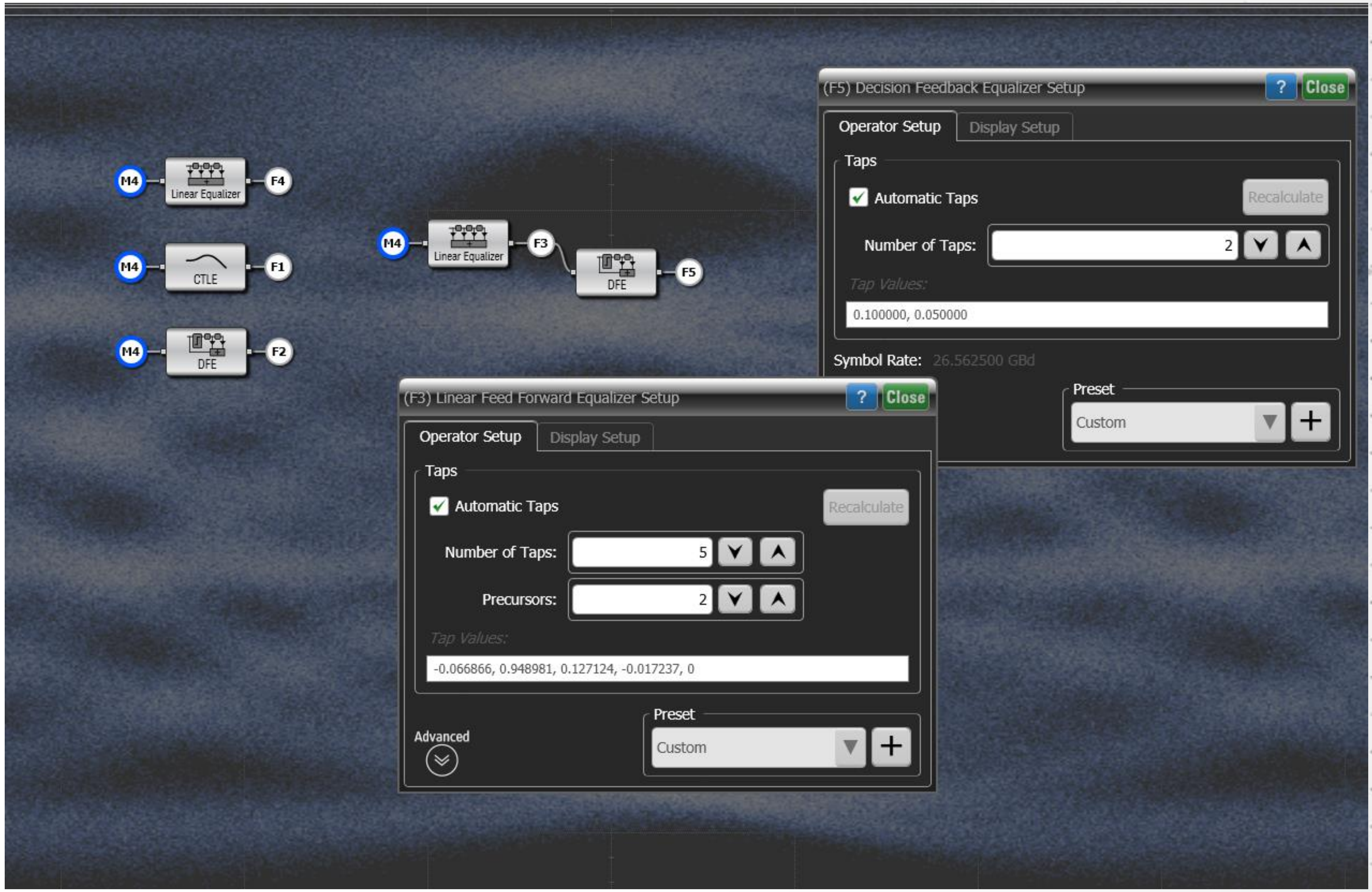
Additional technical contributors

- Ryan Chodora
- Marlin Viss
- Rob Sleigh

Using equalization when viewing transmitter waveforms

TEST INSTRUMENTATION

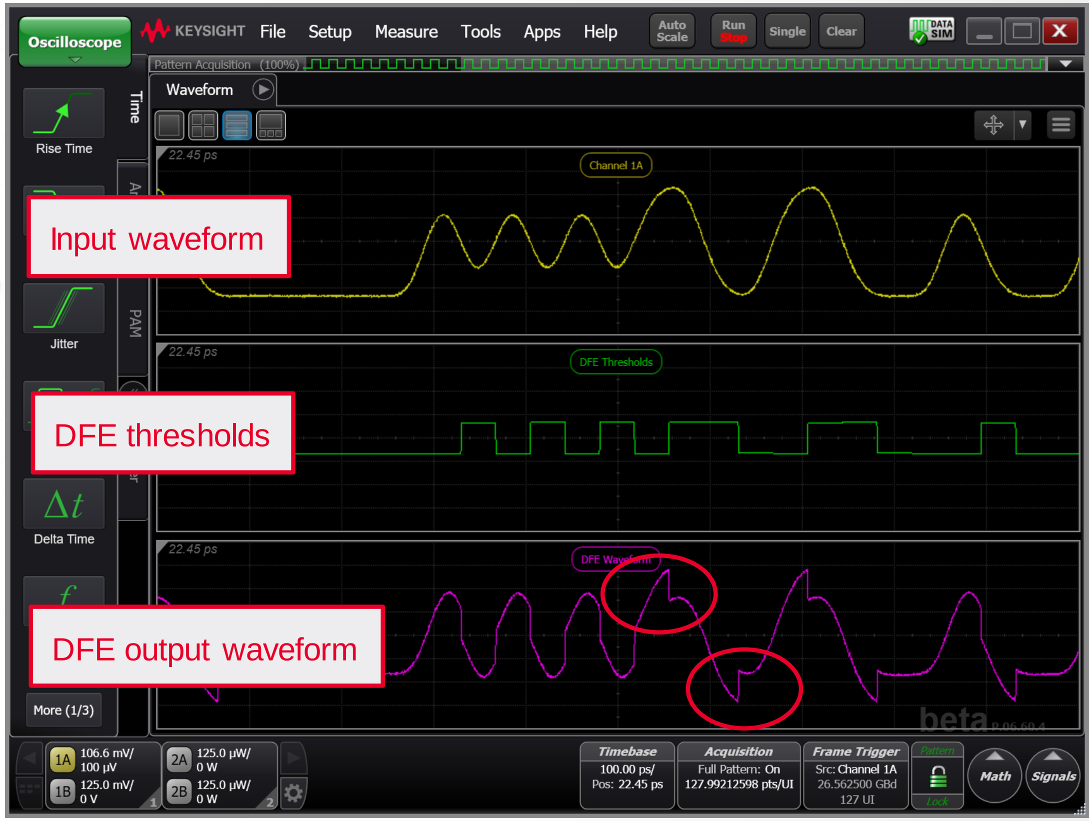
- Transmitter waveform quality is commonly assessed in the context of the system it will be used in
- When system receivers employ equalization, this should be considered when defining how transmitters are measured
- Virtual equalization, CTLE, DFE, and FFE can be achieved in most oscilloscopes. In advance of determining a specific reference receiver architecture for 802.3ck, it is important to be aware of the inherent tradeoffs and requirements for different equalizer implementations and their impact on measuring waveforms.



DFE: Decision Feedback Equalizers

NRZ SHOWN FOR EASIER VISUALIZATION

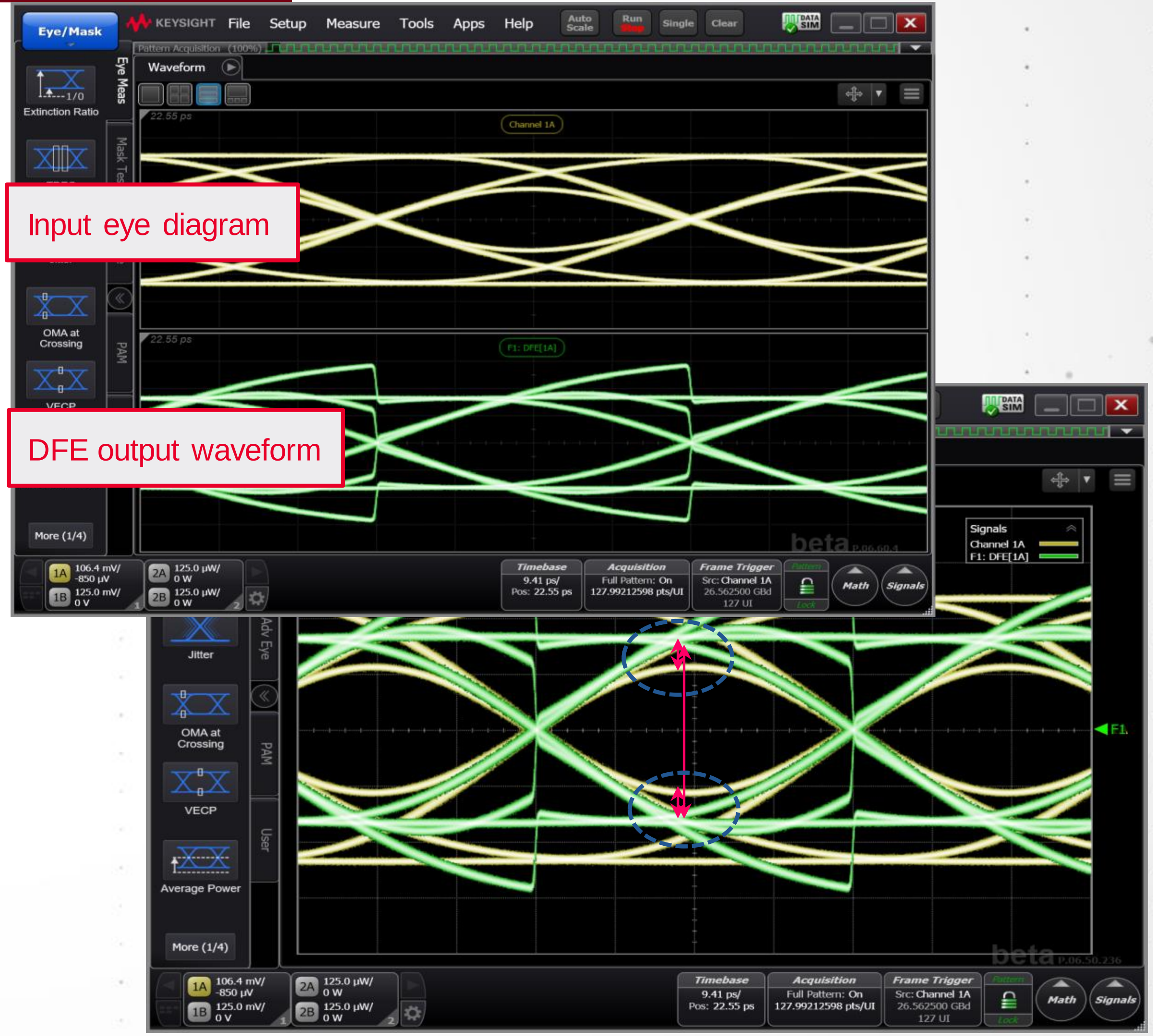
- When a signal is passed through a DFE, due to nonlinear operation, the output is no longer an ‘analog’ waveform that can be directly analyzed for communications quality
- We can create a waveform that allows us to visualize the impact of DFE and the effective margin it yields
- This DFE ‘output’ waveform is constructed by subtracting the DFE threshold adjustments from the original input waveform
- This threshold subtraction process creates abrupt discontinuities in the new waveform
- The reconstruction process is not overly complex but needs to be defined for consistent results



DFE: Decision Feedback Equalizers

WHAT CAN BE ACCURATELY MEASURED?

- An eye diagram can also be constructed from the 'created' waveform. (discontinuities remain)
- Viewing the DFE output overlaid on the input gives insight into the effective margin that the DFE has yielded
- The reconstructed DFE eye provides a reliable signal to gauge eye height, eye width and SER
- Due to how the waveform is constructed apparent edge positions do not accurately represent input waveform timing. Measurements based solely on 'edge' positions are generally not useful

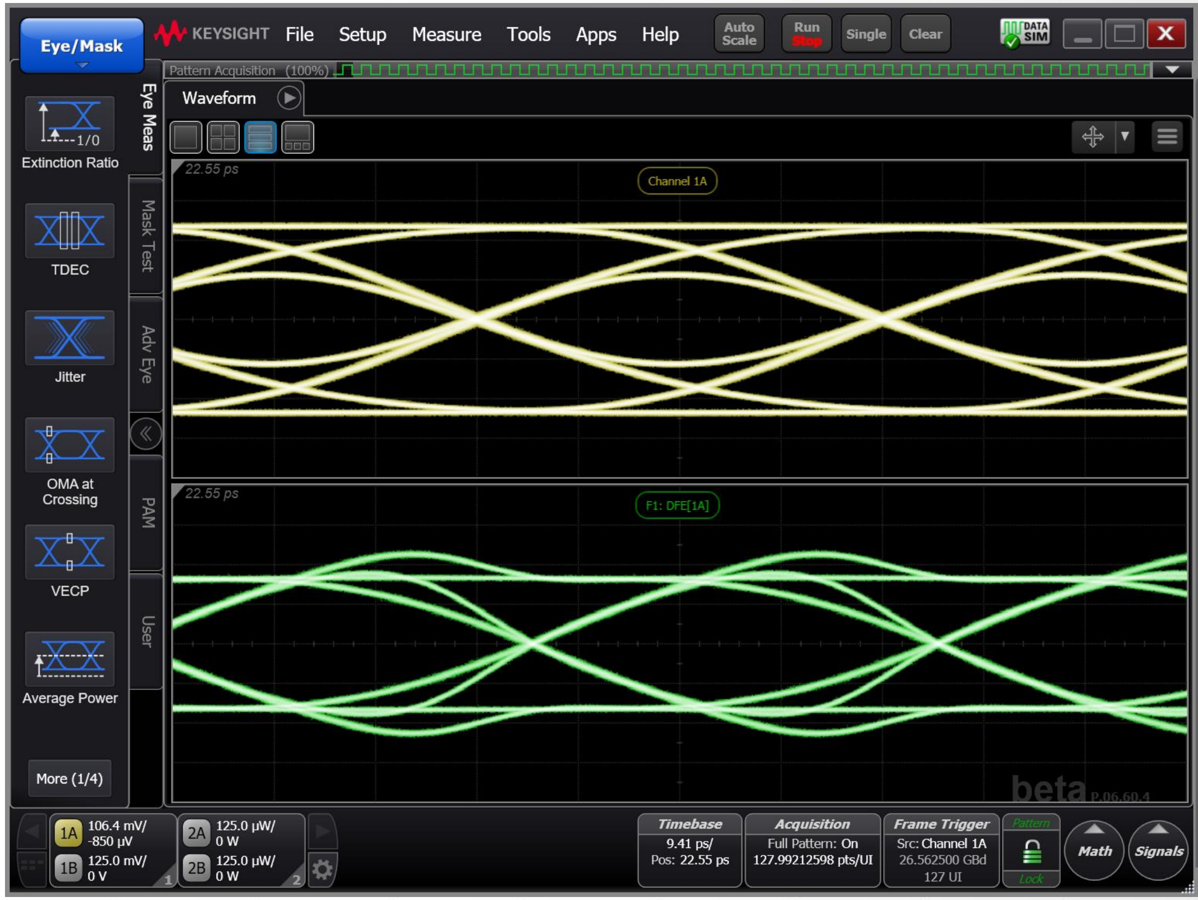


KEYSIGHT TECHNOLOGIES

DFE: Decision Feedback Equalizers

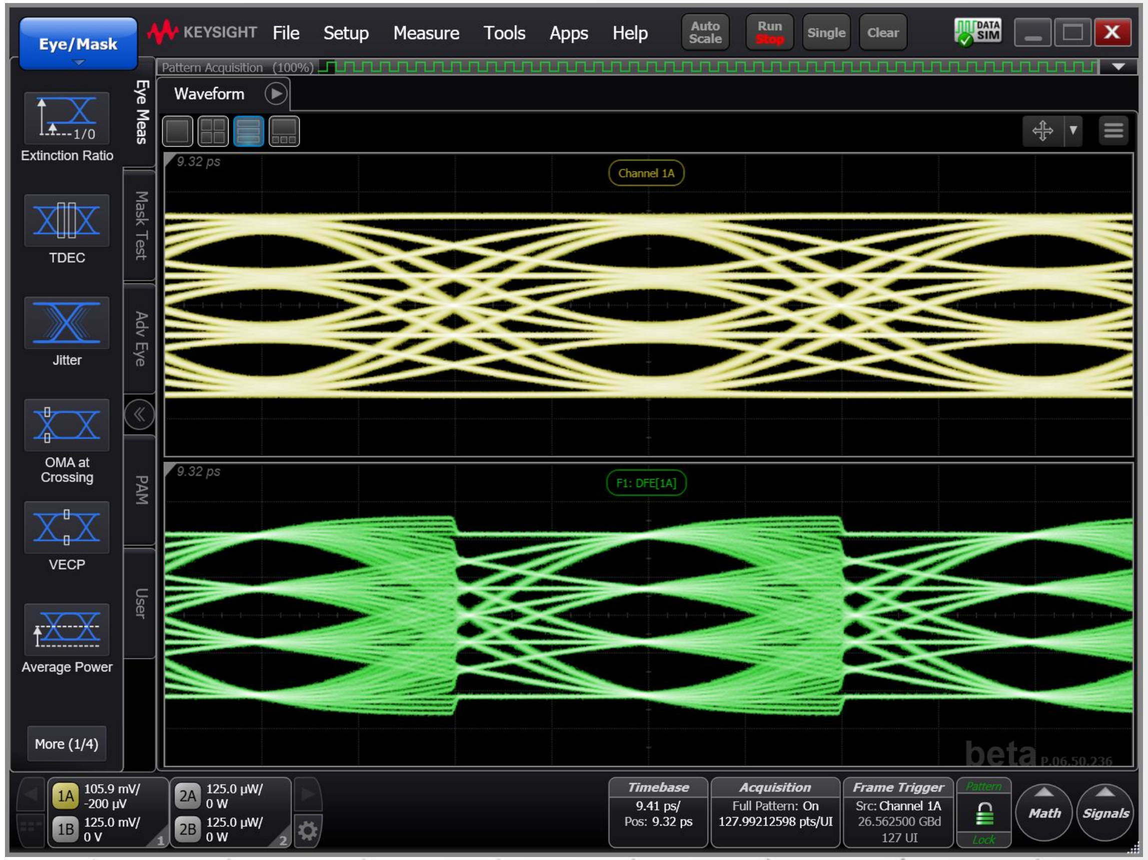
SOFTENING THE DISCONTINUITIES

- With simple software low-pass filtering we can smooth out the discontinuities and perhaps emulate the finite response of the DFE.
- Although not shown here, misalignment of the DFE decision and the input waveform crossing point can result in enhanced ISI, but this effect will generally be insignificant for PAM4 signals



PAM4 observations

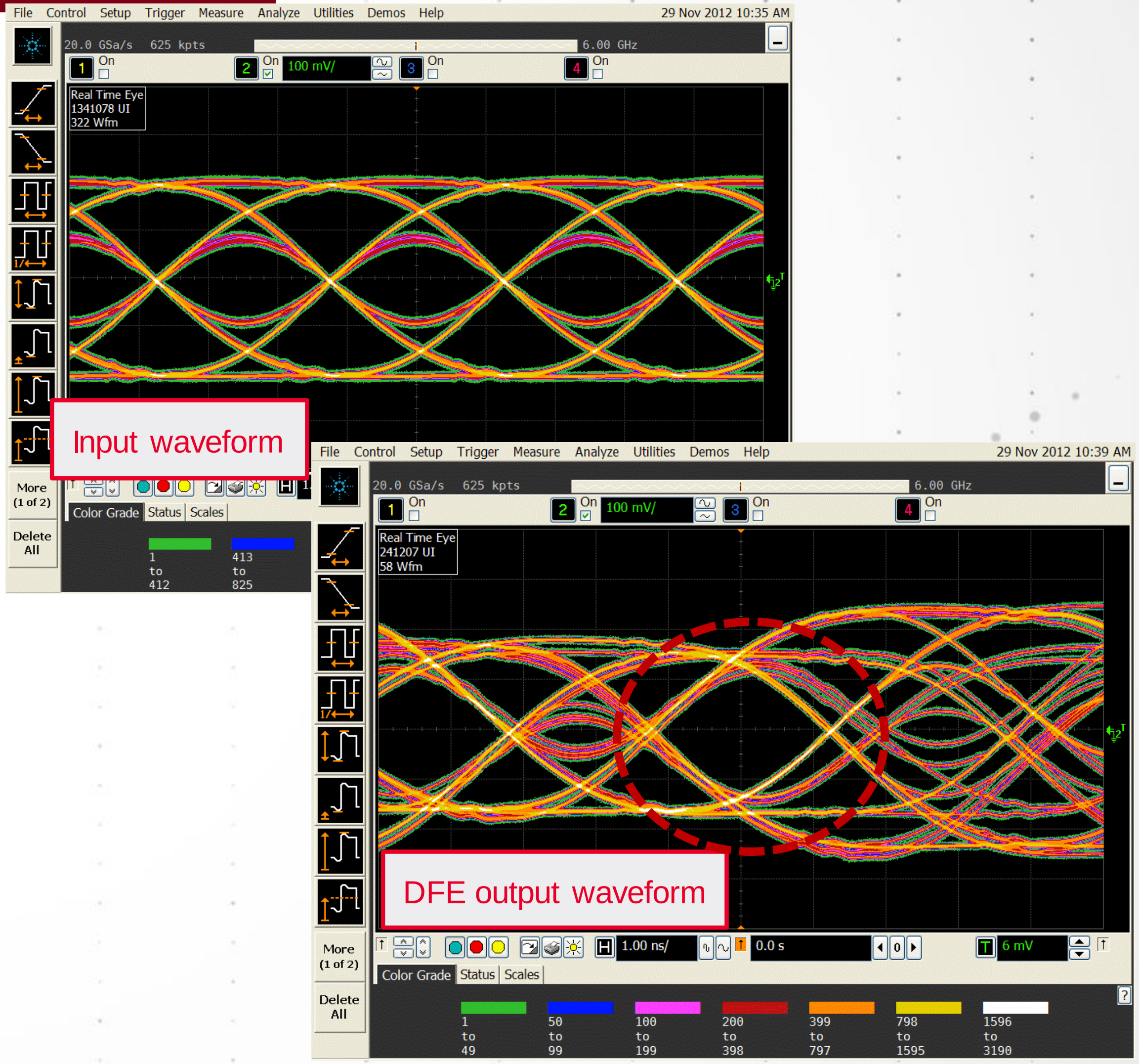
- Similar to NRZ, subtracting the DFE threshold adjustment allows construction of an ‘output’ PAM4 waveform .
- The discontinuity is observed indicating how the DFE threshold adapts for each symbol
- Eye width and height can be measured. Width measurements need to be confined to avoid the region of the discontinuity (eye width typically should fall well within this restriction)
- Key question: Do these measurements reveal what we need to know in terms of the transmitter impact on system level performance?



DFE using real-time oscilloscopes

NRZ EXAMPLE FOR SIMPLIFIED VIEW

- Several UI trajectories are shifted to apply the correction that the central symbol needs. This avoids discontinuities in the eye diagram
- The left eye is compressed and the right is fanned-out, but the center eye should have the same height and width observed with the sampling scope described earlier



Feed-Forward Equalization (FFE)

- The FFE is a linear system, so the output waveform can be directly measured with an oscilloscope
- Significant experience obtained with FFE in the PAM4-based optical standards through the TDECQ measurement
  - 5-tap, T-Spaced, location of amplitude ‘slice’ allowed to vary, tap weights optimized for minimum TDECQ penalty
- Several important lessons learned!

Important FFE considerations

- The FFE tap weights are adjusted to improve transmitter performance. For consistency across test solutions it is important to define the optimization process
- While the TDECQ test process adjusts tap weights to specifically minimize TDECQ, we would not recommend this type of approach
  - It can result in an equalizer optimization that real receivers likely would not do
  - It is open to more variation in actual implementation, leading to variation in results across test suppliers
- Recommend basic optimizations like mean-measurement-squared-error
- Give sufficient thought into how closely the reference receiver emulates what real receivers will do
  - Lesson learned from TDECQ: If real receivers will always perform better than the reference receiver, margin is left on the table

Summary

DFE, CTLE AND FFE ARE FINE FOR A REFERENCE RECEIVER

- DFE, CTLE and FFE approaches are acceptable and supported by test instrumentation
- DFE is a non-physical waveform, but does offer practical insights to transmitter quality
- FFE is a known process that works well. We would implement in a way for consistent results across different platforms

Recommendations:

- If a DFE is included in the reference receiver, it is recommended that some “informative” text be incorporated, to establish guidance on what can be accurately measured and how optimization should be performed. Additional “normative” text on where and how to measure EH and EW should be considered.
- Recommend 1 tap/symbol on the FFE. Multiple taps/UI allow for more funny-business on the part of transmitters along the lines of peaking the response.
- Optimize around a MMSE approach about the four levels and allow the optimization point to float left/right within the eye. This works for both DFE and FFE. While other optimization techniques can give “better” metrics. This could be dealt with by adding margin to the metrics.

Thank you!