Development of an oscilloscope based TDP metric

IEEE 802.3bs November 2015

Greg LeCheminant
Jim Stimple
Marlin Viss

KEYSIGHT TECHNOLOGIES

Supporters

– Jonathan King	Finisar
– Ali Ghiasi	Ghiasi Quantum
– Pavel Zivny	Tektronix

Understanding the basic instrumentation issues

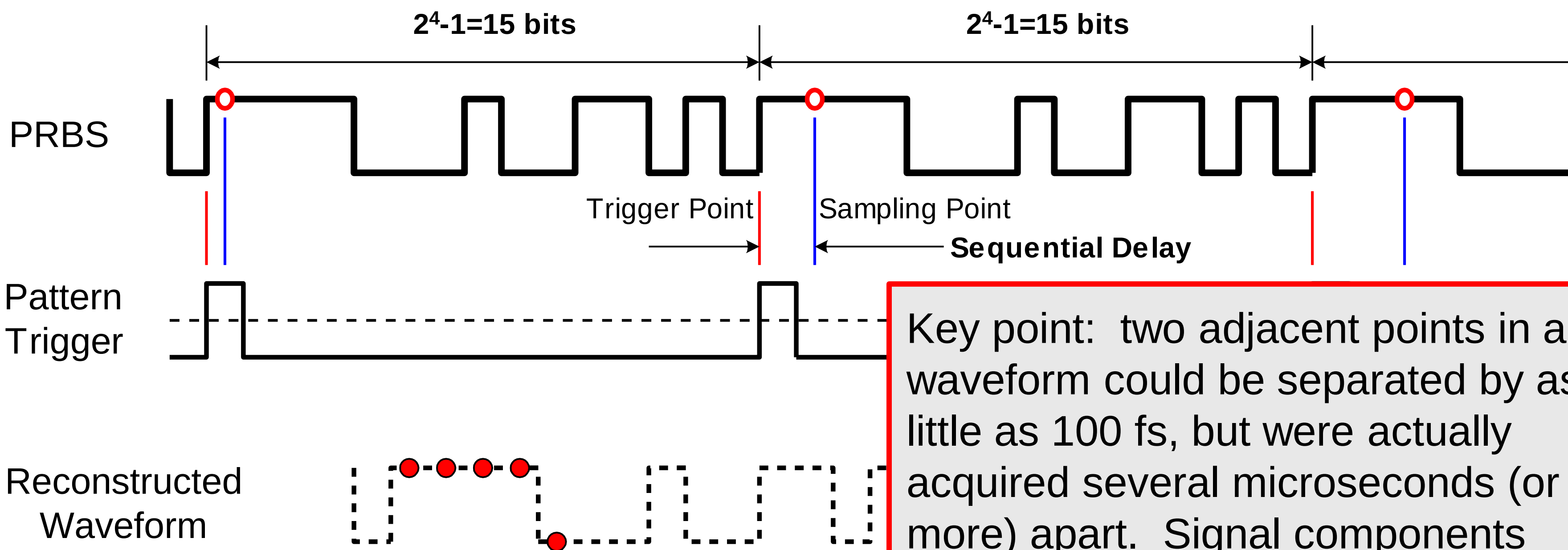
Equivalent-time ‘sampling’ scopes versus real-time scopes

– Sampling scopes
  - Very wide bandwidth (to 100 GHz)
  - Bandwidth independent of sampling rate (KSamples/s)
  - Require a trigger/timing reference
  - Random or repeating data streams
    - Significant implications on how waveform is displayed and what measurements can be made (slides to follow)

– Real-time scopes
  - Effectively a VERY fast analog to digital converter (to >200 GSa/s)
  - Bandwidth directly impacted by sampling rate (<Nyquist)
  - No pattern length restrictions, but shorter patterns yield better results
    - Record lengths to 2 Gpts

Basic sampling scope operation

– A *pattern trigger* yields the pulse pattern

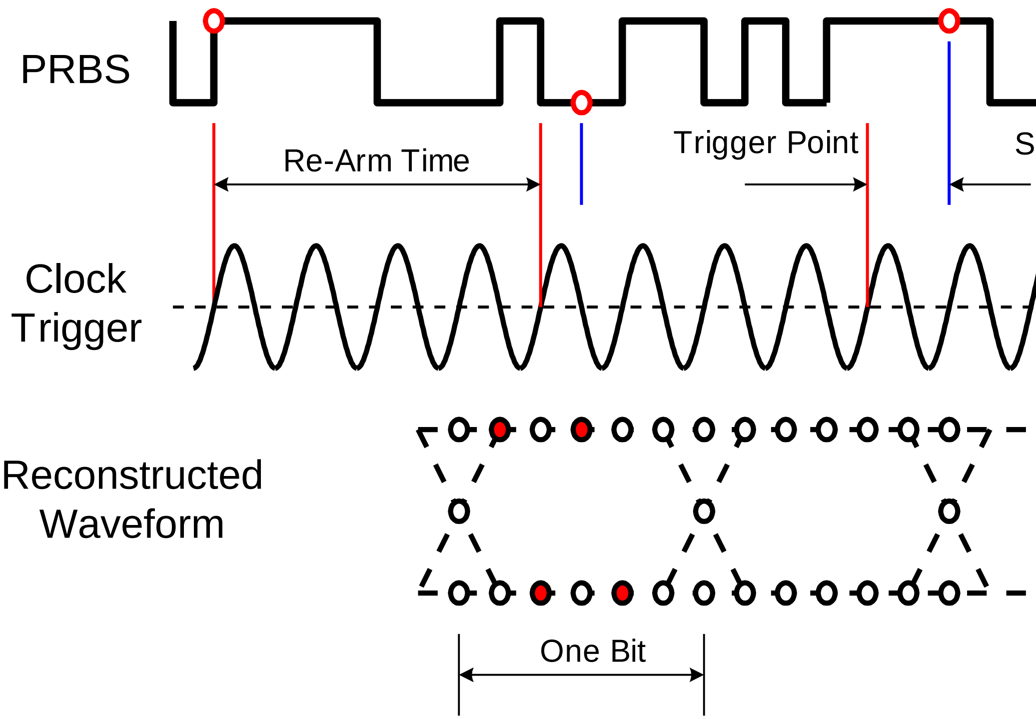


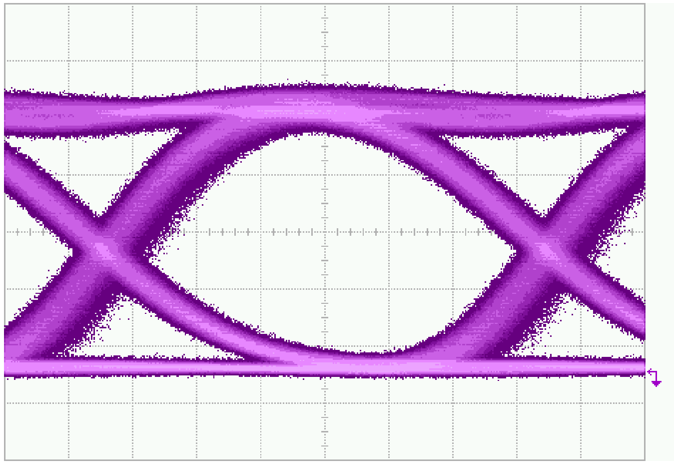
Key point: two adjacent points in a waveform could be separated by as little as 100 fs, but were actually acquired several microseconds (or more) apart. Signal components that are asynchronous to the scope trigger have valid statistical characteristics but are aliased (incorrect frequency)

$$\text{Sequential Delay} = \frac{\text{FullScreen Sweep Time}}{\text{Number of Trace Points}}$$

Sequential delay as low as 60 fs

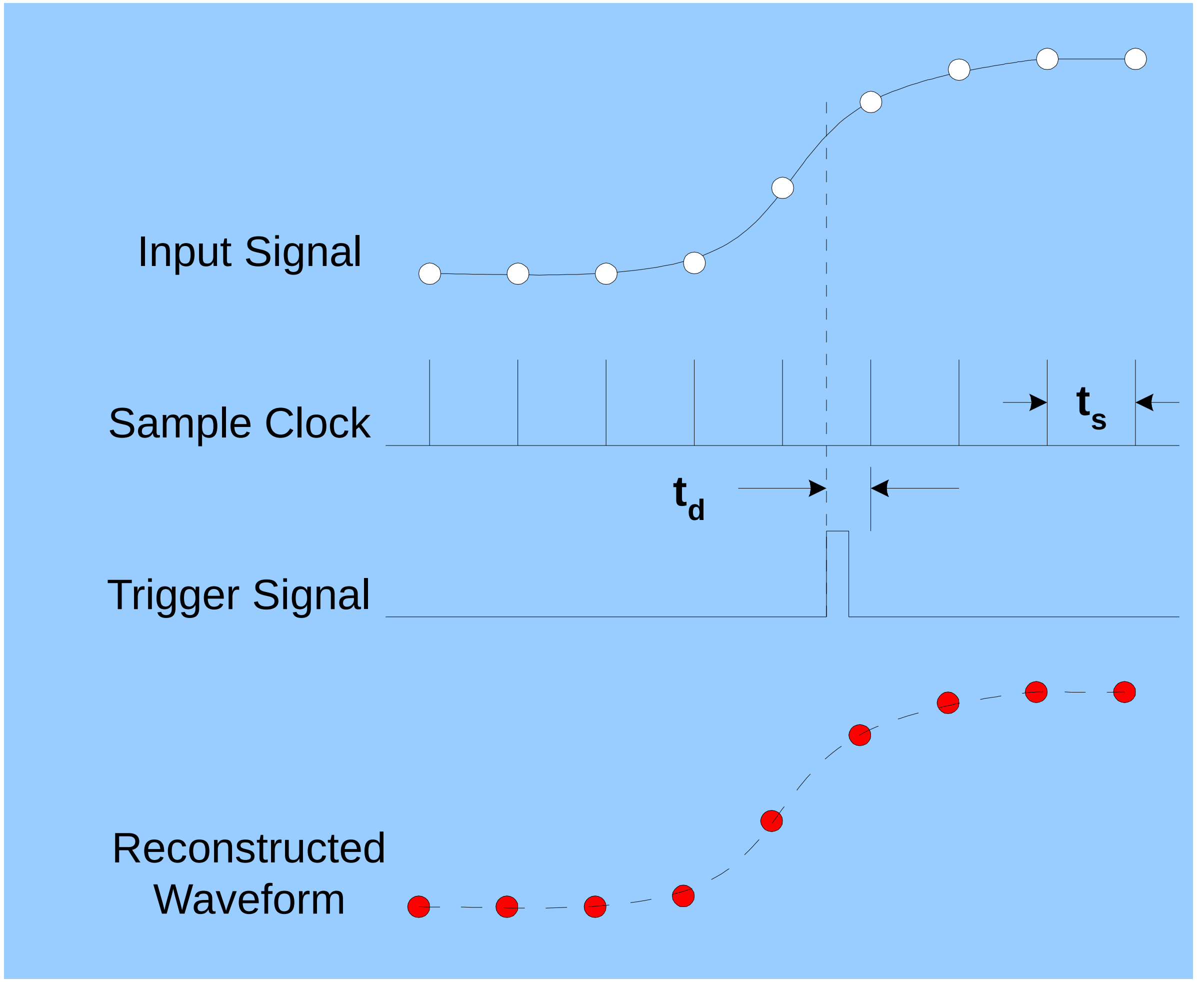
– Triggering with a clock yields an eye diagram





Real-time oscilloscope: Easy to understand

- No external trigger required (Highest flexibility with least restrictions on signal types that can be viewed)
- Sample rate determines BW (60, 70, 100 GHz achieved)
- Deep memory (2 Gpt)
- Higher noise, jitter, cost



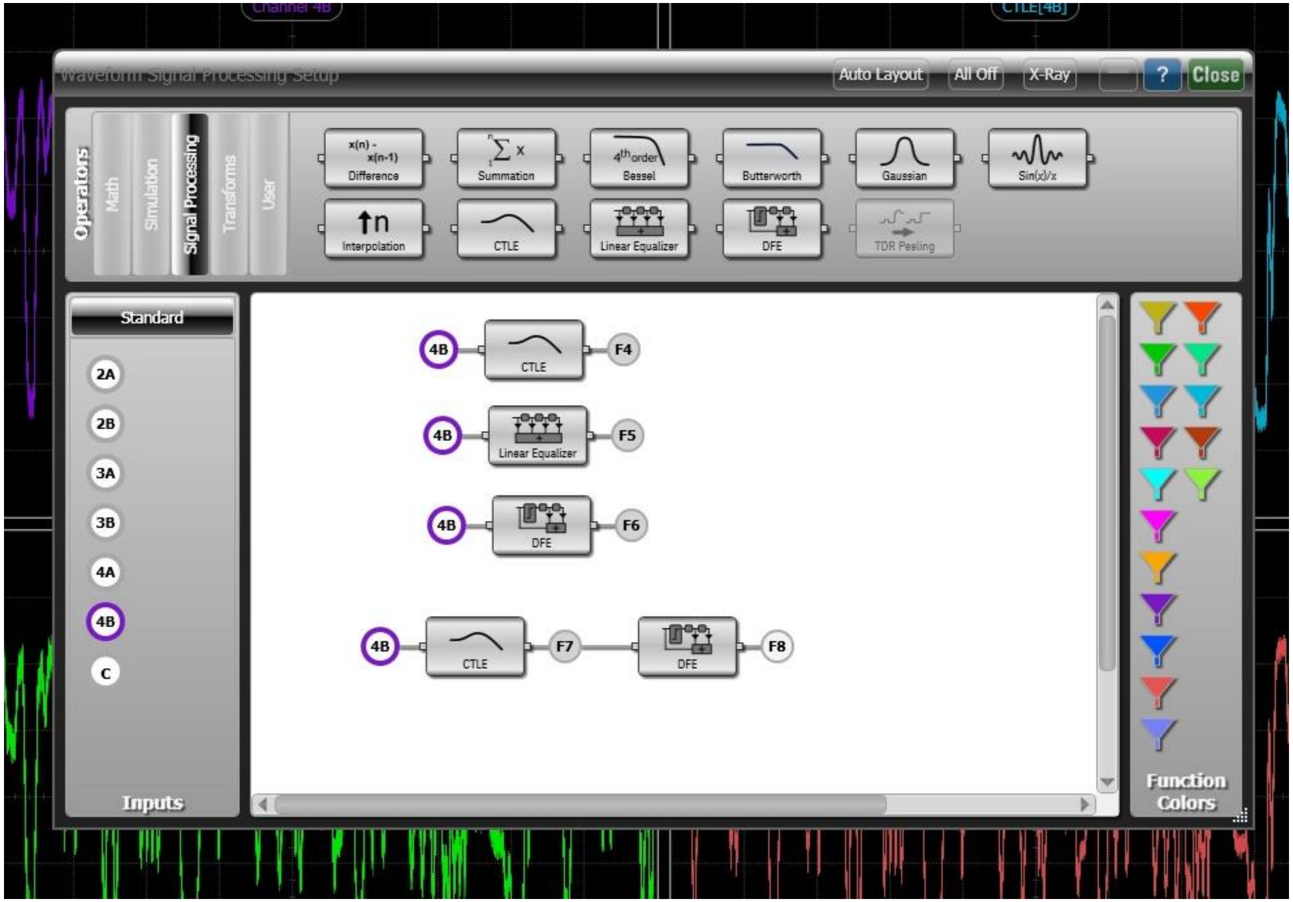
Historical perspective for optical waveform test

- Then
  - Bandwidth limitations of real-time scopes resulted in sampling scopes being the only choice for optical test
  - Test strategies developed around what could be achieved with sampling scopes
- Now
  - Real-time scopes have similar bandwidths as sampling scopes
  - Test metrics from the basic eye diagram may be insufficient in the era of heavy equalization
  - Pressure is higher than ever to produce components at lower and lower costs, even as performance improves dramatically
    - Cost of test needs to drop along with other costs

Measurements for systems employing equalization

Several ‘tools in the T&M kit

- Acquired waveform can be processed through virtual, user-defined equalizer ‘building blocks’
- Blocks can be individual or concatenated
- Real-time or sampling scopes



Sampling scopes: Software equalizers require pattern lock

Data pattern lengths should be kept under 2^16

– Mathematical transforms behind the equalizers must operate on the ‘single valued’ waveform
  - Pulse data pattern and not the eye diagram
  - After equalization, the eye is constructed and displayed
  - Overall acquisition time (and measurement time) scales with pattern length

– *I cannot overemphasize the importance of having manageable pattern lengths for best waveform analysis opportunities*

Virtual equalizers present some problems for the sampling oscilloscope

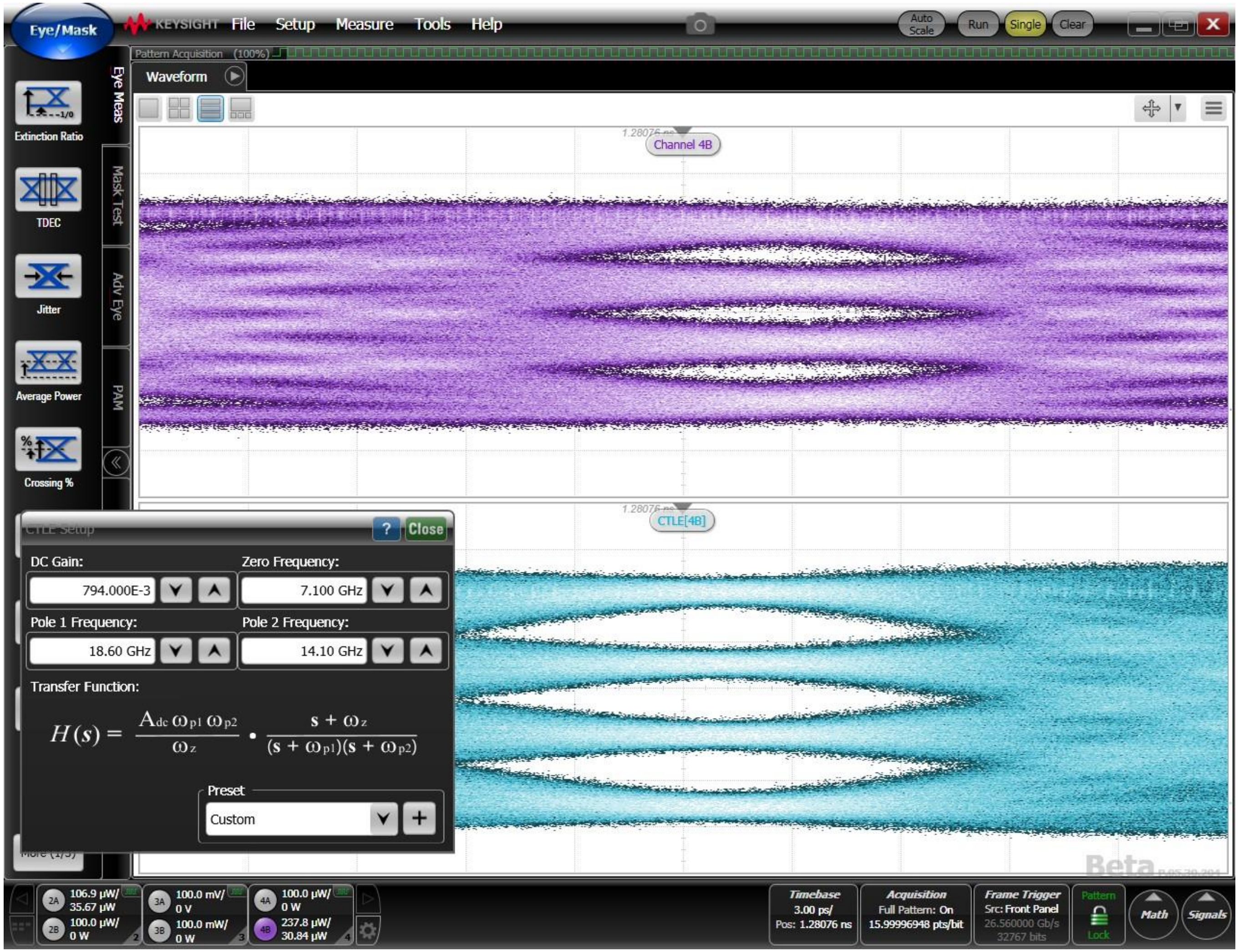
Apparent observation BW when samples are <100 fs apart

- Remember that the waveform record of the sampling scope places adjacent samples as close as 100 fs
- Signal content uncorrelated to the scope trigger appears to have a very high frequency spectrum

What happens?

CTLE

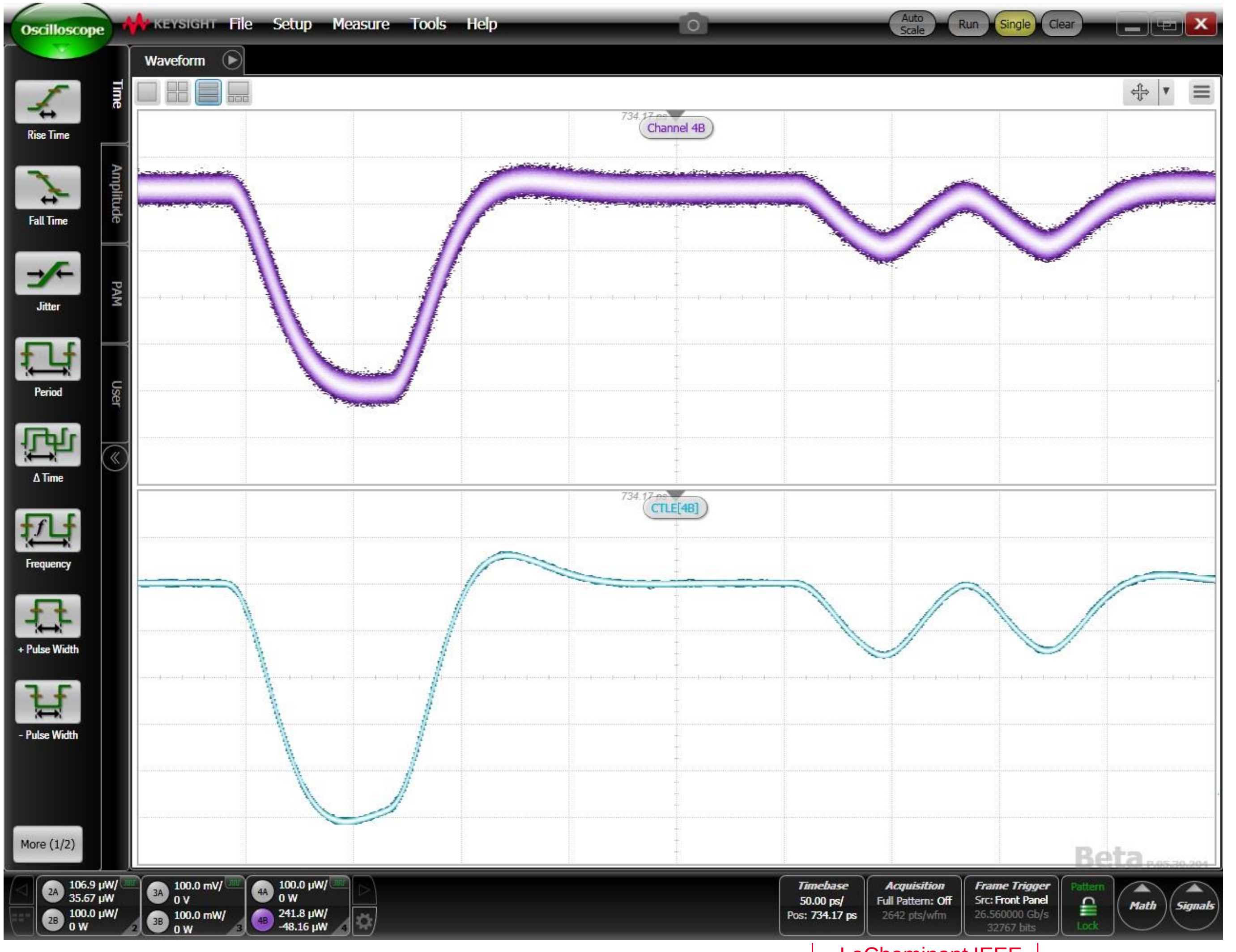
- Eye is opened
- Random signal components ‘cleaned up’



CTLE: Original and equalized signal

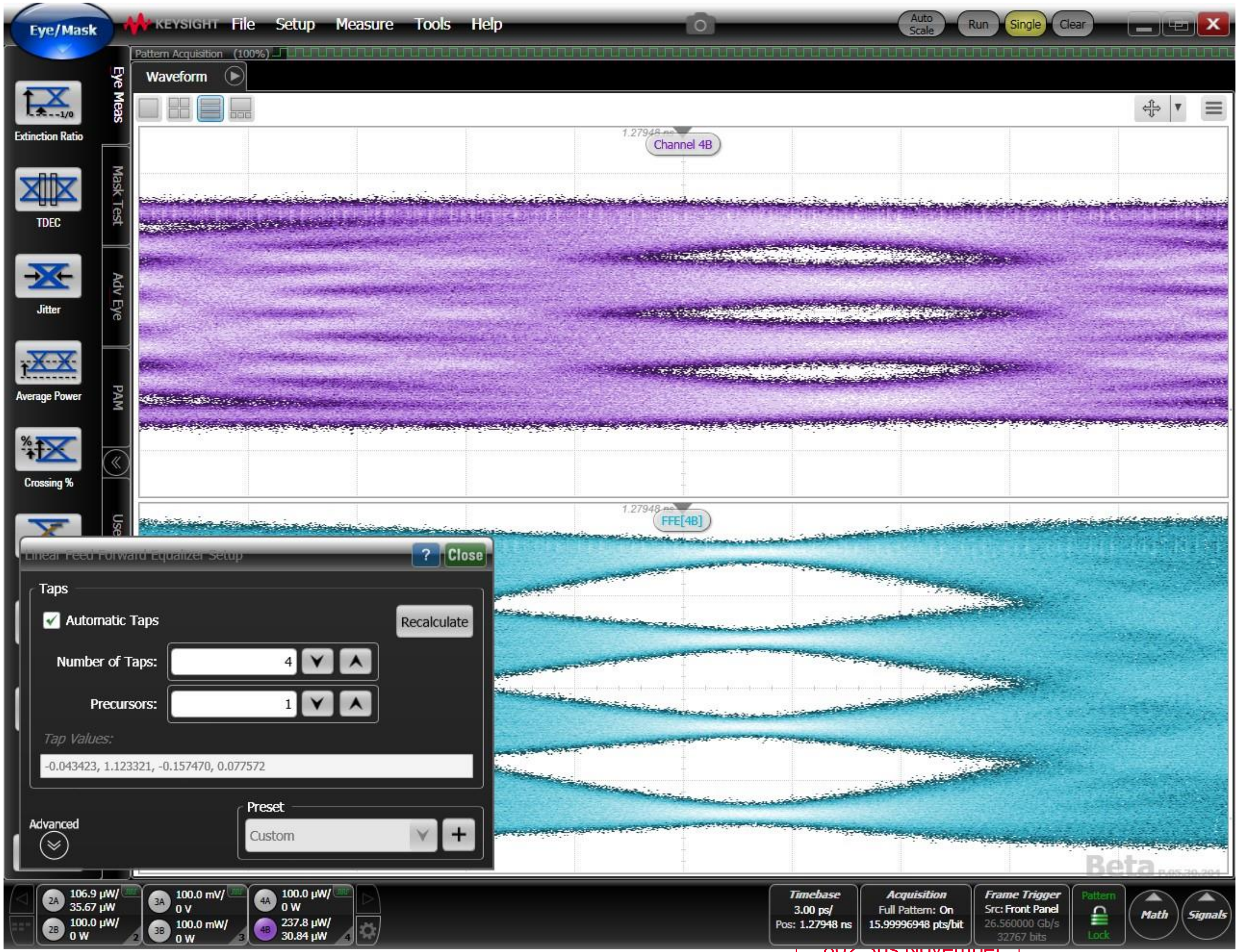
Random noise and jitter filtered

- CTLE 'filter' incorrectly treats uncorrelated signal components as being very high-frequency and reduces their magnitude
- (But there is a solution)



FFE

– FFE opens the eye, but it is more difficult to see the reduction of uncorrelated signal components

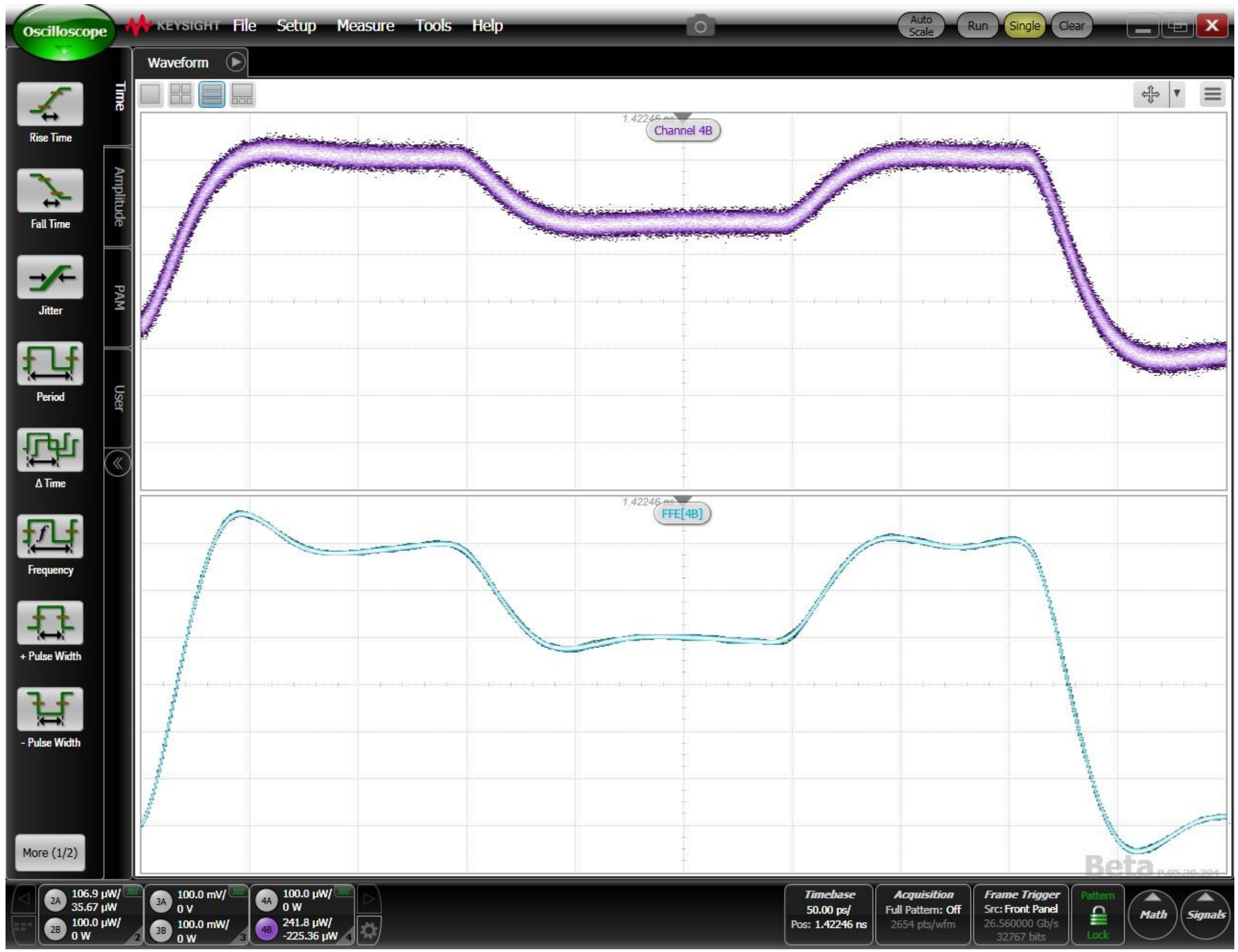


LFFE: Original and equalized signal

Random noise and jitter filtered

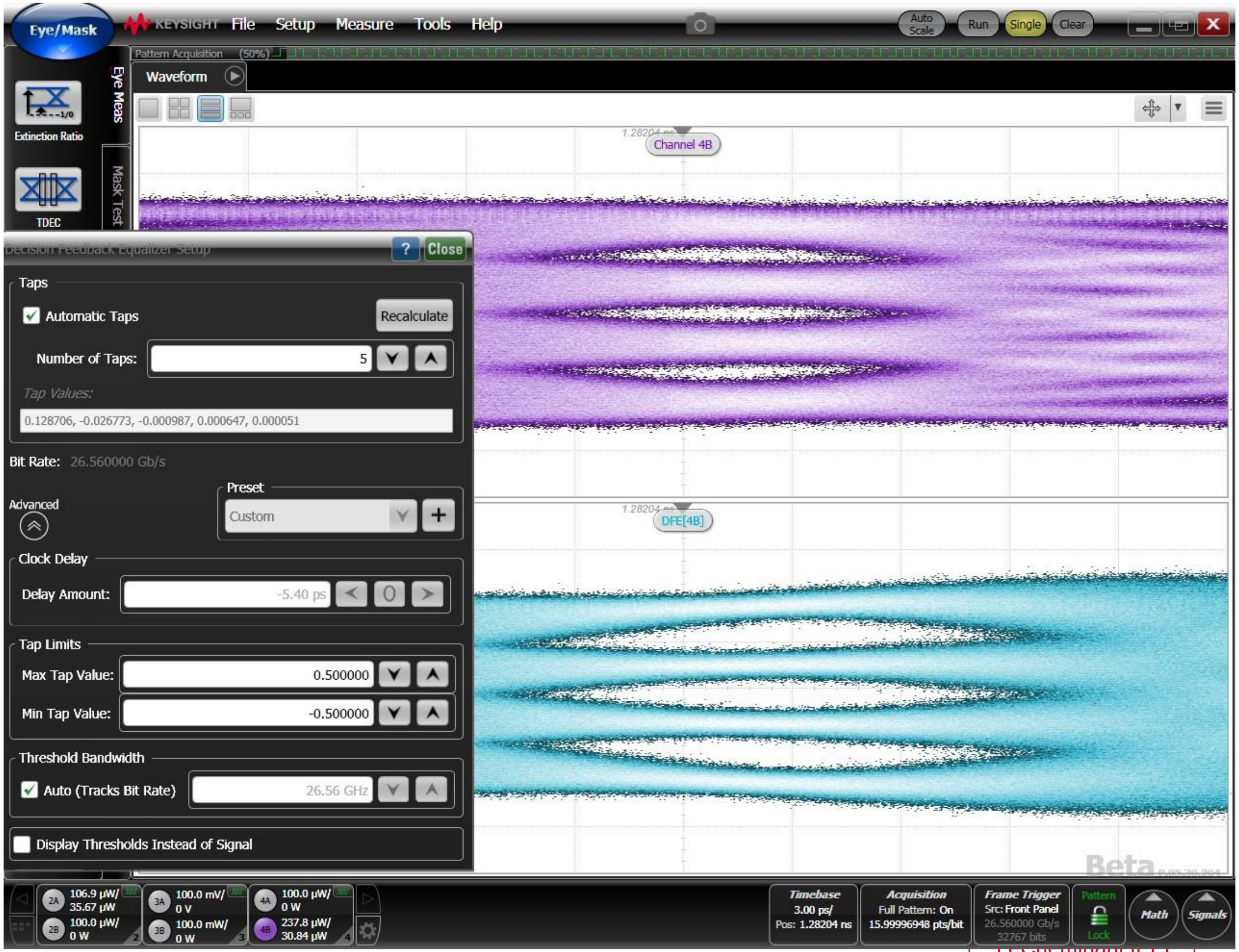
– Like CTLE, LFFE ‘filter’ incorrectly treats uncorrelated signal components as being very high-frequency and reduces their magnitude

– (But there is a solution)



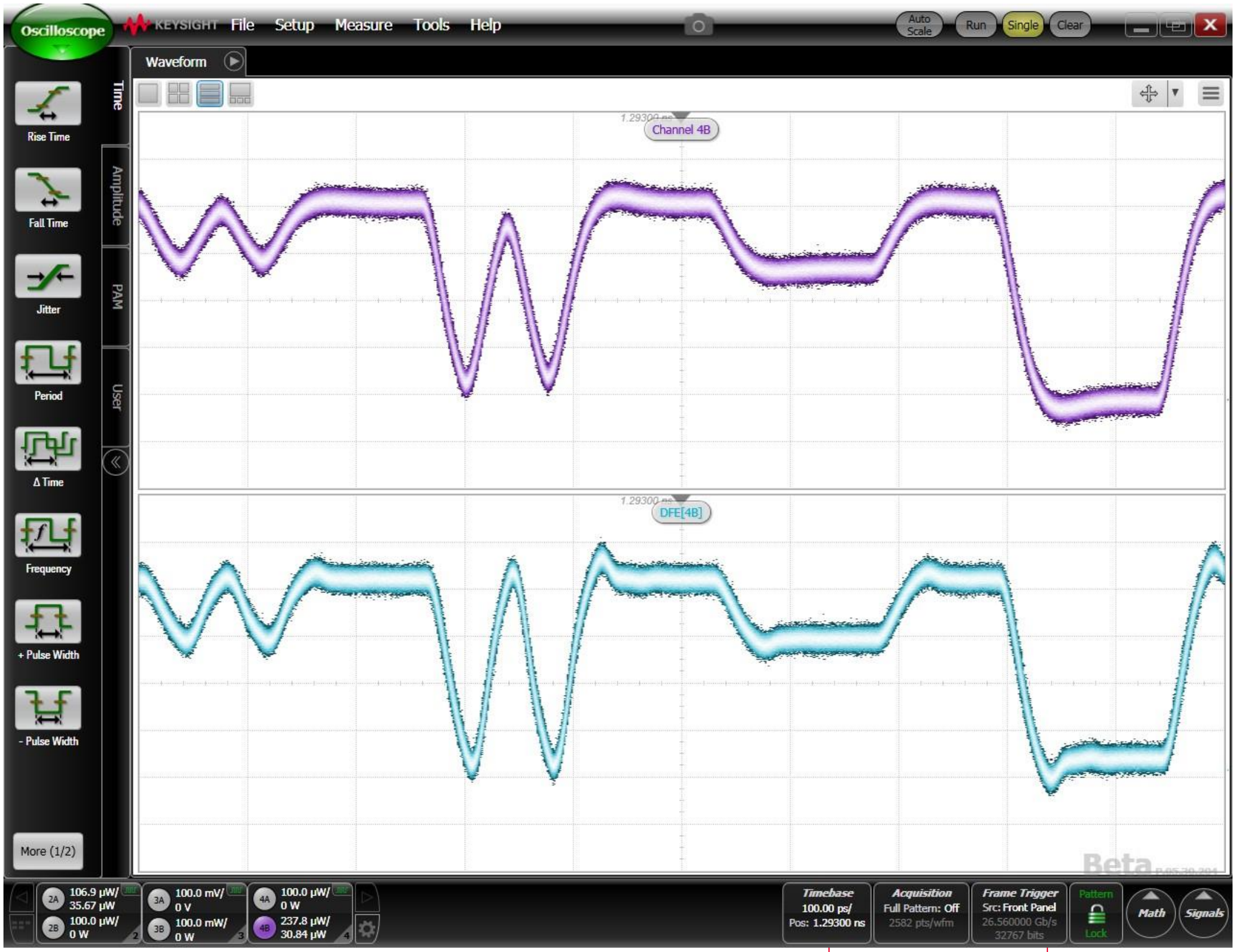
DFE

DFE does not ‘filter’ uncorrelated signal components



DFE

– Noise and jitter are preserved through the virtual DFE



Can the sampling scope provide quality results?

Yes:

- Capture uncorrelated signal components prior to equalization
- If noise/jitter spectrum is known, the noise/jitter after equalization can be managed and appropriately measured and accounted for
- One reasonable approach is to assume that the spectrum is approximately flat

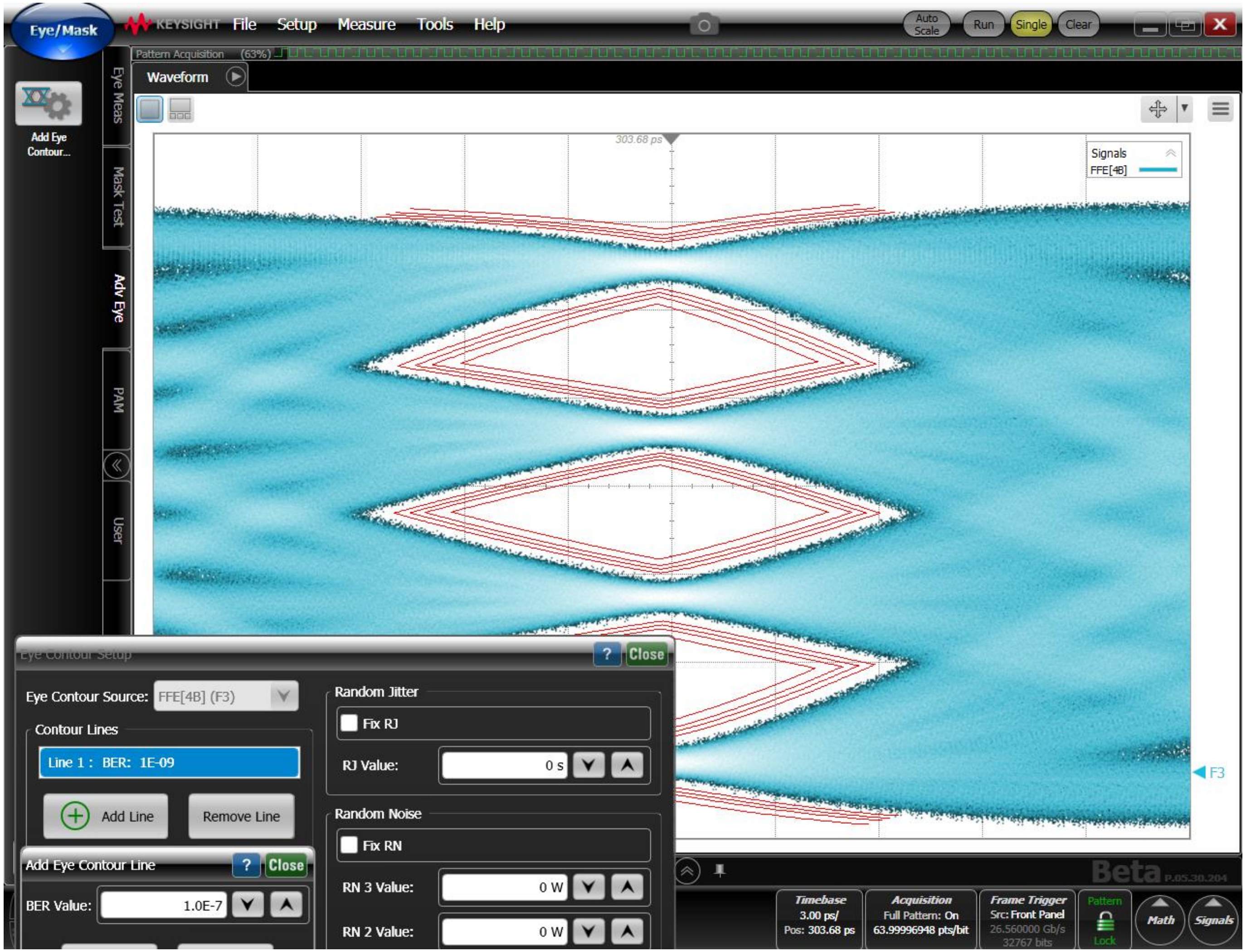
➢ Remember! Software equalization requires pattern locking and reasonable pattern lengths

Assuming the transmitter signal has been correctly captured, equalized and displayed, what can we do with it?

- Remember that the objective is an oscilloscope based TDP type measurement
- Hardware BER targets are high, and achieved with a reasonable acquisition size for a sampling scope, easy for a real-time scope

BER contour is one possibility

- Given high target BER's, good measurement uncertainty is easier to achieve
- This example shows simple constant BER contours for each PAM4 eye
- Possible extension to a mask test concept



KEYSIGHT TECHNOLOGIES

Oscilloscope bandwidth for PAM4

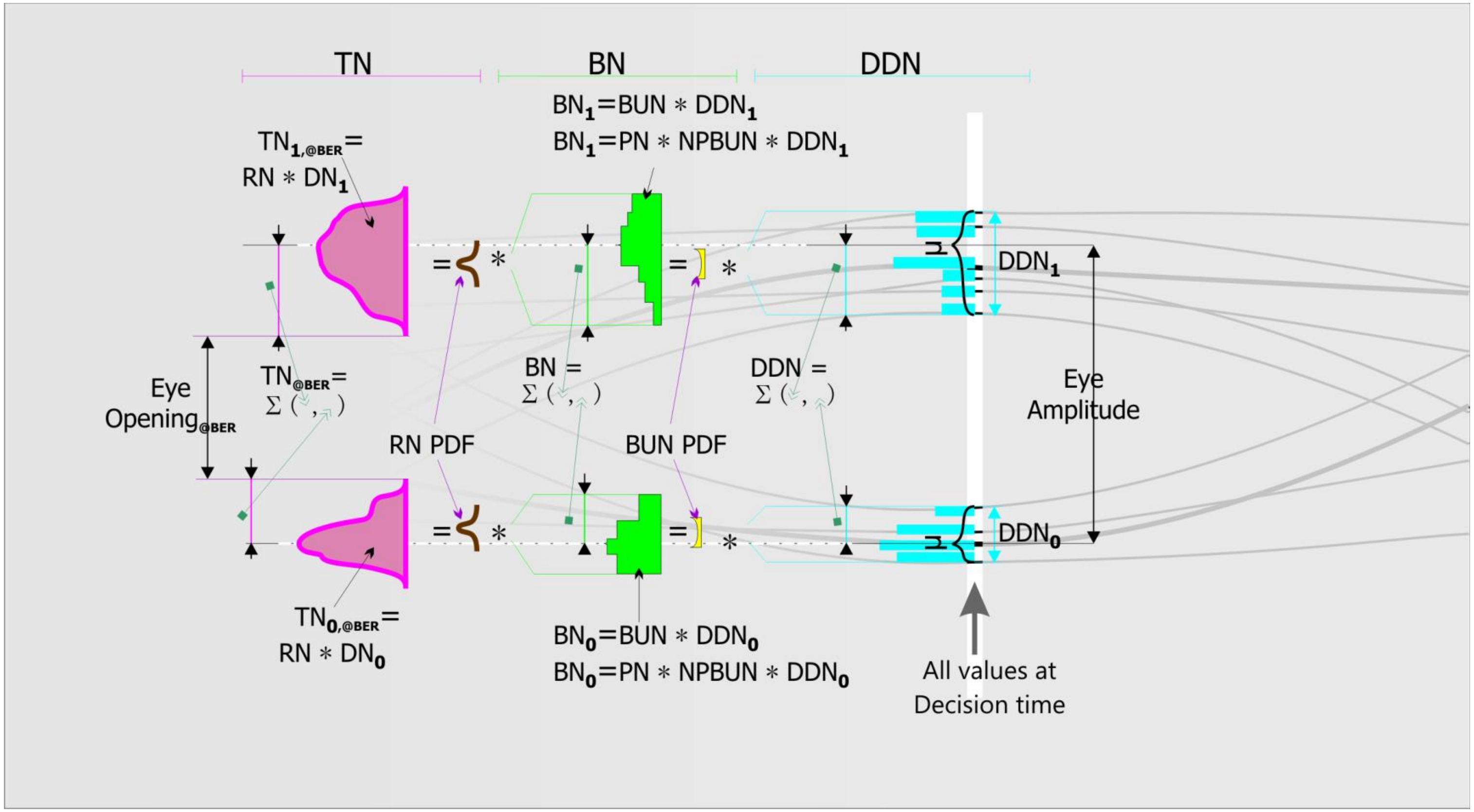
– It would be easy to just say we need to increase the bandwidth to account for the more complicated trajectories of PAM4 and likely eye closure with the classic “75% of Baud Rate bandwidth”

– We need to take a step back and:

  - Consider the philosophy behind the concept of the optical reference receiver
  - Examine how it applied to NRZ link budgets and subsequent specifications
  - Determine what is appropriate for PAM4
    - We have not even decided what is going to be measured

– Propose that the analysis and discussion take place in upcoming ad-hoc work

Backup slides



From Pavel Zivny Tektronix